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Research and Case Studies

The new reality of education in the face of advances in generative artificial intelligence

La nueva realidad de la educación ante los avances de la inteligencia artificial generativa

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ABSTRACT

It is increasingly common to interact with products that seem "intelligent", although the label "artificial intelligence" may have been replaced by other euphemisms. Since November 2022, with the emergence of the ChatGPT tool, there has been an exponential increase in the use of artificial intelligence in all areas. Although ChatGPT is just one of many generative artificial intelligence technologies, its impact on teaching and learning processes has been significant. This article reflects on the advantages, disadvantages, potentials, limits, and challenges of generative artificial intelligence technologies in education to avoid the biases inherent in extremist positions. To this end, we conducted a systematic review of both the tools and the scientific production that have emerged in the six months since the appearance of ChatGPT. Generative artificial intelligence is extremely powerful and improving at an accelerated pace, but it is based on large language models with a probabilistic basis, which means that they have no capacity for reasoning or comprehension and are therefore susceptible to containing errors that need to be contrasted. On the other hand, many of the problems associated with these technologies in educational contexts already existed before their appearance, but now, due to their power, we cannot ignore them, and we must assume what our speed of response will be to analyse and incorporate these tools into our teaching practice.

Keywords: artificial intelligence; generative artificial intelligence; ChatGPT; education.

RESUMEN

Cada vez es más común interactuar con productos que parecen "inteligentes", aunque quizás la etiqueta "inteligencia artificial" haya sido sustituida por otros eufemismos. Desde noviembre de 2022, con la aparición de la herramienta ChatGPT, ha habido un aumento exponencial en el uso de la inteligencia artificial en todos los ámbitos. Aunque ChatGPT es solo una de las muchas tecnologías generativas de inteligencia artificial, su impacto en los procesos de enseñanza y aprendizaje ha sido notable. Este artículo reflexiona sobre las ventajas, inconvenientes, potencialidades, límites y retos de las tecnologías generativas de inteligencia artificial en educación, con el objetivo de evitar los sesgos propios de las posiciones extremistas. Para ello, se ha llevado a cabo una revisión sistemática tanto de las herramientas como de la producción científica que ha surgido en los seis primeros meses desde la aparición de ChatGPT. La inteligencia artificial generativa es extremadamente potente y mejora a un ritmo acelerado, pero se basa en lenguajes de modelo de gran tamaño con una base probabilística, lo que significa que no tienen capacidad de razonamiento ni de comprensión y, por tanto, son susceptibles de contener fallos que necesitan ser contrastados. Por otro lado, muchos de los problemas asociados con estas tecnologías en contextos educativos ya existían antes de su aparición, pero ahora, debido a su potencia, no podemos ignorarlos solo queda asumir cuál será nuestra velocidad de respuesta para analizar e incorporar estas herramientas a nuestra práctica docente.

Palabras clave: inteligencia artificial; inteligencia artificial generativa; ChatGPT; educación.

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INTRODUCTION

Research on artificial intelligence (AI) has been steadily growing for years and shows no signs of slowing down, providing increasingly complex, larger, and faster-responding models. These models are currently trained with billions of data units, making them much more powerful than their counterparts from just a few years ago, which has led to significant advancements in linguistic models within a short span of time. This power has practically limitless applications, including ethically questionable uses, leading to legal loopholes and extreme reactions that go as far as banning their use. However, innovation based on intelligent technologies is experiencing significant growth, as the data reflects. For instance, in the past 10 years, the number of new AI companies has tripled. For example, out of the 273 companies in the latest YC (Y Combinator) batch, 57 are involved in generative AI, indicating an increase in job positions that require or are related to AI competencies (Maslej et al., 2023).

To analyse the topic of AI and education, setting aside aspects related to education policies and management and focusing on the relationship between AI and learning, Wang and Cheng (2021) identified three main research directions in AI in education. These directions are learning with AI, learning about AI, and using AI to learn how to learn. To simplify further and enhance the understanding of this article, we will differentiate between two aspects: the use of AI in teaching and learning processes and its impact on them (**AI in education**) and the role of education in fulfilling its purpose in society in the presence of AI (**education in the age of AI**).

AI in education

The Beijing Consensus on Artificial Intelligence (UNESCO, 2019) aims to address the opportunities and challenges presented by AI concerning education and provides 44 recommendations grouped into different aspects that help understand the magnitude of the task. These aspects include planning AI in educational policies; AI for the management and delivery of education; AI to support teaching and teachers; AI for learning and assessment of learning; developing values and skills for life and work in the AI era; AI for providing lifelong learning opportunities for all; promoting equitable and inclusive use of AI in education; gender-responsive AI and AI for gender equality; and ensuring ethical, transparent, and verifiable use of educational data and algorithms. These aspects are discussed in more detail in *AI and education: guidance for policy-makers* (UNESCO, 2021). As is evident, the relationship between AI and education is complex and multifaceted.

Setting aside aspects related to education policies and management and focusing on the relationship between AI and learning, the main focus is often on personalised learning when discussing AI in education (Zhang et al., 2020). Indeed, discussions about AI in education encompass various topics, such as intelligent tutors (Yilmaz et al., 2022), virtual assistants (Gubareva & Lopes, 2020), immersive and interactive learning experiences (Chng et al., 2023), and the use of data to enhance students' performance (Vázquez-Ingelmo et al., 2021), among others. Analysing this data will enable the detection of patterns and trends, assisting teachers in the early detection of failures, and identifying areas for improvement. This, in turn, facilitates the design of more effective teaching strategies (Gašević et al., 2015).

Education in the age of AI

Discussing education in the age of AI entails reflecting on the role of education in preparing individuals for a rapidly changing world where this technology will be present in all aspects of life: work, studies, leisure, personal relationships, and more. Hence, it is crucial to understand how AI works and the benefits and risks of its use. New knowledge, skills, competencies, and values are needed for life and work in the era of AI (Bozkurt et al., 2023; Ng et al., 2022).

AI as an emerging technology that can be disruptive

Universities have been concerned about emerging technologies and their application in higher education. For example, in Spain, according to the UNIVERSITIC 2022 report (Crespo Artiaga et al., 2023), 71% of universities have designed a strategy to promote innovative teaching initiatives, and 86% analyse IT trends applicable to teaching innovation; one in three universities has evolved its learning management system into a digital learning ecosystem that facilitates personalised education. However, only 17% currently utilise adaptive learning solutions to enable experiences with a higher degree of personalisation; 30% of universities have a laboratory to analyse emerging technologies and their application to their environment; 16% have a catalogue to understand better the potential of emerging technologies to promote pilot projects for digital transformation; and 25% utilise AI to prevent cybersecurity threats, thereby improving security management. AI will substantially impact society and is considered a disruptive technology (Alier-Forment & Llorens-Largo, 2023). It is as dangerous to embrace it naively as to reject it outright (Llorens-Largo, 2019).

Social implications of AI (beyond what it seems)

One should avoid falling into the naive belief that technology is neutral and that everything depends on the humans who develop and use it. Technology is not merely a means to an end but also shapes that end (Coeckelbergh, 2023).

Therefore, topics such as algorithmic decision-making, including its capacity for influence and manipulation (Flores-Vivar & García-Peñalvo, 2023a), biases, unfair discrimination, inequality (Holmes et al., 2022), surveillance, technical competencies, information bubbles, and exclusion (Nemorin et al., 2023), as well as the substitution of humans in posthumanism and transhumanism (Neubauer, 2021), and all their interrelationships, should be included in the debate.

All these aspects are highly significant in education because they impact human behaviour. Considering their double implication, they affect the educational realm regarding how AI can influence these aspects, just as it does in society. Additionally, education is crucial in preparing individuals to navigate a future world heavily influenced by technology. AI is one of the influential forces (Flores-Vivar & García-Peñalvo, 2023b).

Integral and strategic vision of AI

Therefore, a systematic vision is required, with a comprehensive global and multicultural approach. On November 23, 2021, UNESCO adopted the *Recommendation on the Ethics of Artificial Intelligence* (UNESCO, 2022). One of the areas of action addressed by the recommendation is education, recommending, among other things, "to provide adequate AI literacy education to the public on all levels in all countries in order to empower people and reduce the digital divides and digital access inequalities resulting from the wide adoption of AI systems" (p. 33). In the case of Spain, this was already reflected in strategic axis 2 (*Promoting the development of digital skills, enhancing national talent, and attracting global talent in artificial intelligence*) of the National Strategy on Artificial Intelligence (from the Spanish *Estrategia Nacional de Inteligencia Artificial*) (Gobierno de España, 2020). Therefore, it can be asserted that the concern already exists at the political level at least. So, what has transpired to prompt global discourse and analysis of the subject? The answer lies in the emergence, in November 2022, of the public release of a tool called ChatGPT by OpenAI (https://openai.com/blog/chatgpt/). This tool enables conversational interactions where individuals can ask questions or make requests, and the system provides responses within seconds that, at first glance, are indistinguishable from those that a human expert would have offered. This development has sparked global attention and analysis due to its potential implications for various domains and its ability to simulate human-like conversation and knowledge dissemination at scale. ChatGPT is based on a large-scale advanced language model (LLM) known as Generative Pre-trained Transformer 3 (GPT-3) (Brown et al., 2020).

However, ChatGPT, as an example of a tool, and GPT-3, as an LLM, are just two specific cases (albeit ones that have caused significant technological disruption) of a broader trend in AI known as generative AI (García-Peñalvo & Vázquez-Ingelmo, 2023; van der Zant et al., 2013). Generative AI refers to the ability of AI systems to generate content such as text, images, videos, audio, and more in response to a given prompt, typically expressed in natural language text. Whereas traditionally, these systems have accepted text-based inputs, some applications can now process multimodal inputs, incorporating various forms of media to generate content.

Language models and ChatGPT (and similar): Are they really intelligent?

The initial human response often underestimates any artefact that claims to be intelligent. As a result, ChatGPT has been labelled, among many other things, as a charlatan or a sophisticated parrot, as it does not truly understand what it is talking about (Alonso, 2023). Individuals may perceive themselves as more intelligent than ChatGPT if they can demonstrate ChatGPT's lack of knowledge in logic or mathematics, its tendency to fabricate information it does not know (referred to as hallucinations), and other similar weaknesses. All of this may have been true at some point. However, it may have been addressed with the continuous improvements being released or resolved in future versions or through integration with other plug-ins that enhance the versatility and capabilities of ChatGPT. Nevertheless, it should be remembered that ChatGPT is based on a language model that was not initially designed for many of the tasks it is being asked to perform.

The strongest attacks on generative AI are not new and can be traced back to John Searle's counterargument to the Turing test. In Turing's (1950) imitation game, he proposed that a machine could be considered intelligent if it could pass as a human in a blind test. However, Searle (1980) argued that if there is a room with a human who only understands Spanish, with a rule book, receives a piece of paper with indecipherable symbols (in Chinese), and follows the instructions in the book to produce another piece of paper with symbols he or she does not understand (also in

Chinese), from the outside, it may appear as a conversation. Still, no one inside the room understands Chinese. Although Dennett (2017) remarked that "nature makes extensive use of the principle of minimal knowledge and designs highly capable and expert creatures, although even cunning ones who have no idea whatsoever of what they are doing or why they are doing it" (p. 299), the reality is that our understanding of how the brain works and the relationship between the human mind and consciousness is still in its infancy.

Institutional and decision-makers' concerns

As an indication of the interest generated in university governance, in February 2023, the European University Association published its position on responsible use in university teaching, which was subsequently endorsed in Spain by Crue Universidades Españolas and the Ministry of Universities. One point stands out from its approach: the immediate consequences in the teaching and learning process, particularly in assessment, as students already use it.

EDUCAUSE has also expressed its concern and conducted a QuickPoll survey, whose main conclusion was that whereas various stakeholders in higher education are still forming opinions about generative AI, students, as well as faculty members, have already started using it in their assignments. However, most institutions do not have policies regarding its use (Muscanell & Robert, 2023).

In the same vein, the Institute for Higher Education in Latin America and the Caribbean (from the Spanish *Instituto para la Educación Superior en América Latina y el Caribe*) of UNESCO recommends using ChatGPT and AI with care and creativity, building capacity for understanding and management, and conducting AI audits (Sabzalieva & Valentini, 2023).

According to Informatics Europe (2023), this intense and rapid emergence in the academic world is both concerning and exciting. It raises concerns due to its short-term adverse effects on established conventions of trust and authenticity. At the same time, it generates enthusiasm for its potential to enhance human capabilities. Specifically, coding is a worrisome topic in informatics studies (Hazzan, 2023; Meyer, 2022).

Concern in academia

The topic has also sparked interest among the educational research community. There is a reasonably unanimous position that the way forward is not to ignore or prohibit ChatGPT or similar applications but rather to train teachers and students in their proper and ethical use. Furthermore, curriculum revisions are necessary to prioritise critical thinking and maximise the benefits of these tools (García-Peñalvo, 2023). An approach is proposed that builds trusting relationships with students, with a pedagogical design centred around people, where assessment becomes an integral part of the learning process rather than solely controlling activities (Rudolph et al., 2023).

"The emperor goes naked"

Whenever a promisingly disruptive technology emerges, it is accompanied by extreme discourses and positions, both technophilic and technophobic. Chomsky et al.

(2023) argued that generative AI "will degrade our science and debase our ethics by incorporating into our technology a fundamentally flawed conception of language and knowledge", whereas Bill Gates (2023) asserted that "the development of AI is as fundamental as the creation of the microprocessor, the personal computer, the Internet, and the mobile phone".

In this crossfire of positions and blame allocation, when the focus is placed on the consequences of applying generative AI in education, it becomes evident that ChatGPT is being held responsible for weaknesses in current educational practices that already existed but were reluctant to be acknowledged. The education system, particularly the current university system, is designed for a world with a scarcity of information, where individuals attend educational institutions during their formative years to acquire and store knowledge for future use when needed. Now, however, we live in a society with immediate and on-demand access to abundant information, including truths or tautologies, half-truths or indeterminations, and falsehoods or contradictions. Educational institutions, particularly universities, continue to uphold their commitment to society regarding knowledge creation, transmission, and preservation. However, the question remains whether they can effectively respond to the challenge posed by the arrival of "intelligent" applications that have caused a significant informational earthquake while still in their early stages.

This article aims to confront the naked emperor with the mirror of reality, a reality that has many facets and opportunities but cannot be denied or prohibited. Every effort should be made to understand its possibilities and limitations to educate all stakeholders in the educational system and incorporate these applications that use generative AI into teaching and learning processes as efficiently and effectively as possible. To achieve this, first, a mapping will be carried out, including both the initial tools that have emerged, dominating the market and with potential use in education, and the reactions within academia during the first six months since the emergence of ChatGPT, which has popularised generative AI.

IMPLICATIONS AND USES OF GENERATIVE AI IN EDUCATION

To use a specific technology in teaching and learning processes with informed decision-making, it is crucial to understand its possibilities and limitations without being swayed by extremes, which tend to be particularly biased when a potentially disruptive trend emerges, as has been the case with generative AI, which has experienced rapid penetration. Therefore, before discussing the implications of this technology in the educational context, a prospective study will be conducted focusing on the tools already available with potential educational uses and the contributions that have emerged from academia in the firsts six months since the tsunami caused by ChatGPT.

Educational tools based on generative AI technologies

Generative AI aims at content generation. The language models used for this purpose are trained to determine which elements are more likely to appear near others. To generate their responses, they evaluate large data corpora, allowing them to provide answers that fall within a certain probability range based on the training corpus. This means the responses are generated without explicit reasoning, so although they may be coherent, they are not always correct. This characteristic should be considered in any context, but especially in the educational uses of these tools.

The number of software tools incorporating some form of intelligent features increased in 2022 and, in an exponential manner, in 2023. This is primarily due to the development of LLMs (Gruetzemacher & Paradice, 2022), where the concept of "large" expands alongside advancements in AI. These models are trained on extensive knowledge bases and utilising significant computing power.

LLMs have taken the forefront due to the popularity of the Generative Pre-trained Transformer (GPT) (Brown et al., 2020; OpenAI, 2023), which, whether in version 3.5 (2022) or 4 (2023), powers ChatGPT. However, GPT is just one of the many existing LLMs based on the Transformer architecture (Vaswani et al., 2017). There are various language model proposals, ranging from earlier models that may not be considered large scale by today's standards, such as BERT (Bidirectional Encoder Representations from Transformers, 2018) (Devlin & Chang, 2018; Devlin et al., 2019) or T5 (Text-To-Text Transfer Transformer, 2019) (Raffel et al., 2020), to more recent ones, such as LaMDA (Language Model for Dialogue Applications, 2021) (Adiwardana, 2020; Collins & Ghahramani, 2021; Thoppilan et al., 2022), Chinchilla (2022) (Hoffmann et al., 2022), Bard (2023) (Pichai, 2023), LLaMA (Large Language Model Meta AI, 2023) (Touvron et al., 2023), Titan (2023) (Sivasubramanian, 2023), or Lima (Zhou et al., 2023), among many others (Yang et al., 2023; Zhao et al., 2023).

These language models enable natural language conversation by generating high-quality responses. However, closed-source code and the high costs associated with development and training pose significant barriers, even for the most influential companies in the industry.

To address these challenges, an increasing number of solutions are emerging from the open-source software community. For instance, Alpaca (2023) (Taori et al., 2023) refines LLaMA (Touvron et al., 2023), making it a more accessible and replicable model. By starting with 175 human-written instruction–output pairs, Alpaca leverages GPT-3.5 to expand the training data to 52K through self-supervision, resulting in a performance similar to that of GPT-3.5. Despite Alpaca's effectiveness, the full-scale fine-tuning of LLaMA is time consuming and computationally expensive, does not support multimodality, and is challenging to transfer to different subsequent scenarios. However, pathways have been opened for methods to design lightweight and customised models that can be trained on lower-end computing devices quickly. One example is LLaMA-Adapter (Zhang et al., 2023), which introduces 1.2 million parameters to the frozen LLaMA 7B model and can be fine-tuned in less than an hour using 8 A100 GPUs.

The intention is not to provide an exhaustive list of these tools, as there are already interesting resources that are frequently updated (Agarwal, 2023; Ebrahimi, 2023), as well as AI tool directories such as Futurepedia (https://www.futurepedia.io/) or All Things AI (https://allthingsai.com/), which aim to reflect this overwhelming evolution. The objective is instead to categorise the tools that have potential educational use and to select some representatives of this generative approach that are starting to stand out, due to either their acceptance in production environments or their potential for future advancements, even though they may still be in an early prototyping phase.

Regardless of the increasing number of multimodal tools that transform various types of inputs into different types of outputs, to understand the current landscape concerning the educational context, they can be classified into tools that primarily generate *text, images, videos, 3D objects, audio, source code*, and *tools for detecting AI-generated text*. Within each category, different functional subcategories have been established (see Table 1).

Table 1

Classification of generative AI tools with potential educational use

Tool category	Functionality	Tools
Text generation	Chatbot	ChatGPT, ChatSonic, Claude
	Content creation	Jasper, Notion
	Exam generator	Conker. Monic
	Language teaching	Twee
	Office tools	Google Workspace, Microsoft 365 Copilot
	Paraphrasing text	Quillbot
	Personal curriculum builder	Resume Builder
	Search engine	Microsoft Bing, Perplexity, You
	Research support	ChatPDF, Consensus, Elicit, Humata, Klavier, SciSpace Copilot, Scite Assistant, Trinka
Image generation	Graph generator	GraphGPT
	Image generator	Adobe Firefly, Bing Image Creator, Craiyon, DALL·E 2, Deep Dream Generator, Dream by Wombo, Leap, Midjourney, NightCafe, Stable Diffusion Online, Starryai, Stockimg, Visual ChatGPT
	Presentation generator	ChatBA, Decktopus, GPT for Slides, SlidesAI
Video generation	Video generation	Fliki, Gencraft, Imagen video, Make a video
	Video-to-text converter	YoutubeDigest
3D object generation	3D object generation	AICommand, DreamFusion, GET3D, Imagine 3D
Audio generation	Audio generator	AudioLM, Lovo, Murf.ai, Voicemaker
	Voice modulator	Voicemod
	Voice-to-text converter	Otter, Transkriptor
Source code generation	Code debugging	Adrenaline, Code GPT
	Code generator	Amazon CodeWhisper, Codeium, Ghostwriter, Github copilot, Text2SQL
AI-generated text detection	AI-generated text detection	AI Text Classifier, GPTZero
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Source: own elaboration.

After this process of reviewing and classifying some of the existing tools that make use of generative AI techniques, several reflections can be presented:

1. There is a vast array of tools that utilise generative AI. The spectrum of their use is broad, and many of them can be used for educational and/or learning purposes.

2. Many of these tools have freemium models, although the free versions often come with limited features and capabilities.
3. Text generation and writing assistants have a significant niche, and new tools in this area emerge frequently.
4. Support for automatic translation of texts is a functionality that is highly developed, which has significant implications for scientific writing as well as language teaching and learning.
5. A revolution in the concept of search engines, as we know them today, is anticipated. Syntax-based search services will be complemented by searches and report generation through the integration of generative AI techniques into search engines, as has already happened with Microsoft Bing, and it is expected that Google's response will be accessible in all geographic areas. Major tech companies are redirecting their business models towards this sector. ChatGPT itself, incorporating plug-ins, can base its responses on content obtained from the web, not just its knowledge base.
6. There are many services available for the transformation of text into images, and high-quality results are already being achieved. However, the transformation of text into other media, such as video or 3D objects, has promising proposals but is still embryonic and has not yet materialised into reliable applications accessible to end users.
7. The advancement in language models is resulting in the emergence of applications that can transform text into multimodal elements.
8. Integrating language models into everyday applications is a significant focus of office ecosystems aiming to enhance productivity in their usage. The integration of PaLM into Google Docs (Google Workspace) (Kurian, 2023) and the integration of GPT into Microsoft Office (Microsoft 365 Copilot) are notable examples of this trend.
9. Despite the increasing number of promising products, one aspect where there has yet to be as much success is detecting AI-generated texts. Text detection tools exhibit significant limitations, as acknowledged by OpenAI regarding its AI Text Classifier, which is notably unreliable for texts shorter than 1,000 characters (written in English) (Kirchner et al., 2023). Efforts have been made to address this issue by incorporating model-specific signatures into generated texts or applying watermarking techniques that imprint specific patterns on the texts. However, empirical and theoretical evidence has shown that detectors are unreliable in practical scenarios (Sadasivan et al., 2023). In other words, for a sufficiently advanced language model, even the best possible detector can only slightly outperform a random classifier. Therefore, caution must be exercised when using these tools to make decisions, such as evaluating academic works, as false positives can lead to significant reputational damage for the authors.

Rapid review: Generative AI in education

After gaining a comprehensive understanding of the tools, it is important to examine how the arrival of these technologies is being perceived within the educational community, but from an academic perspective. To achieve this, a rapid review (Grant & Booth, 2009) of the literature was conducted to assess what has been published on this particular topic, using systematic review methods to search for and critically evaluate existing research.

ChatGPT has also significantly impacted scientific production in the early stages of 2023. For example, as of April 1, 2023, there were a total of 194 articles mentioning ChatGPT on arXiv, with a primary focus on natural language processing but with research potential in other fields, including education (Liu et al., 2023). In the specific case of the conducted review, articles published and collected in Web of Science and Scopus were used as references (as of April 6, 2023). These databases are considered the most widely used and internationally accepted, as they include articles that have undergone rigorous review processes, which are not present in other databases, such as the aforementioned arXiv.

Definition of the review protocol

Concisely, the review protocol (García-Peñalvo, 2022) followed in the study is as follows:

1. Research questions:

   RQ_1. What are the characteristics of the items in the final review corpus (year of publication, type of article, sources, authors, geographical distribution)?
   RQ_2. In which disciplinary domains were the studies developed?
   RQ_3. What are the contributions of generative AI to education?
   RQ_4. What educational interventions are reflected or proposed in the studies?

2. Inclusion and exclusion criteria:

   IC_1. The article must be published or accepted for publication and accessible in early access.
   IC_2. The article should not be a note or a letter.
   IC_3. The article must be written in English.
   IC_4. The full text of the article must be accessible.
   IC_5. The article is related to the use of generative AI in education.
   IC_6. The article provides an educational experience or a reflection on the educational use of generative AI.
   IC_7. The article is not a version of an article already included in the corpus.
   EC_1. The article is not published or accepted for publication and is accessible in early access.
   EC_2. The article is a note or a letter.
   EC_3. The article is not written in English.
   EC_4. The full text of the article is not accessible.
   EC_5. The article is not related to the use of generative AI in education.
   EC_6. The article does not provide an educational experience or a reflection on the educational use of generative AI.
   EC_7. The article is a version of another article already included in the corpus and therefore does not add anything new to the article already included.

3. Data sources:

   Web of Science and Scopus.

4. Canonical search equation:

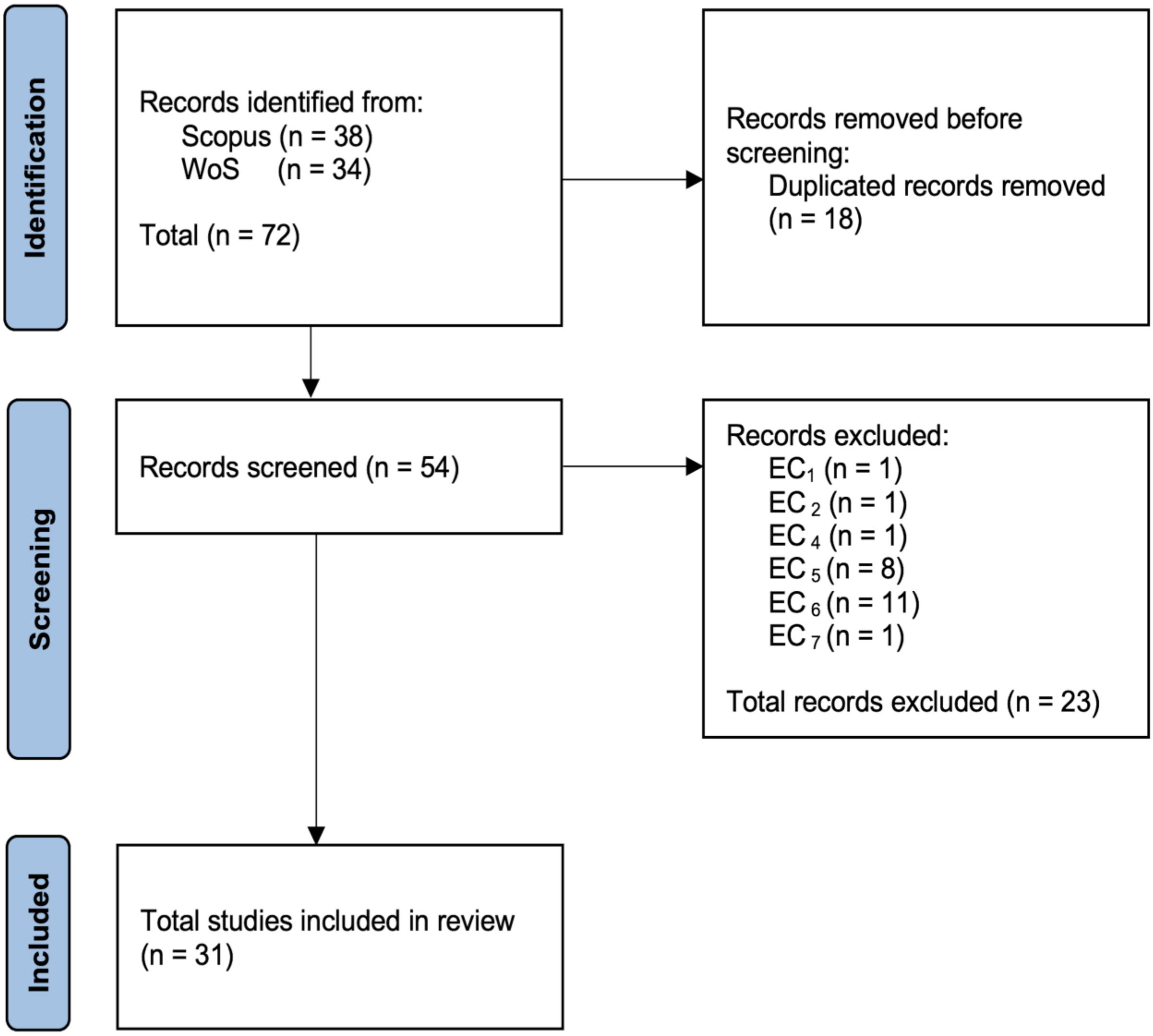
   Education AND (“generative artificial intelligence” OR “generative AI” OR “chatgpt”).

Results of the review

The PRISMA diagram (Page et al., 2021) depicted in Figure 1 summarises the search and filtering process of the obtained results, and Table 2 presents the studies included in the final corpus of the review.

Figure 1

Workflow of the rapid review. Source: Own elaboration



Source: own elaboration.

Table 2
Studies included in the final corpus of the review, sorted by the first author's surname

Code	Reference
[1]	(Ali, DiPaola, & Breazeal, 2021)
[2]	(Ali, DiPaola, Lee, et al., 2021)
[3]	(Arora & Arora, 2022)
[4]	(Choi et al., 2023)
[5]	(Cooper, 2023)
[6]	(Cotton et al., 2023)
[7]	(Crawford et al., 2023)
[8]	(Dwivedi et al., 2023)
[9]	(Finnie-Ansley et al., 2023)
[10]	(García-Peñalvo, 2023)
[11]	(Gašević et al., 2023)
[12]	(Gilson et al., 2023)
[13]	(Iskender, 2023)
[14]	(Johinke et al., 2023)
[15]	(Karaali, 2023)
[16]	(Khan et al., 2023)
[17]	(Kung et al., 2023)
[18]	(Lee, 2023)
[19]	(Lim et al., 2023)
[20]	(Lyu et al., 2022)
[21]	(Masters, 2023)
[22]	(Mbakwe et al., 2023)
[23]	(Pataranutaporn et al., 2022)
[24]	(Pavlik, 2023)
[25]	(Perkins, 2023)
[26]	(Sallam, 2023)
[27]	(Šlapeta, 2023)
[28]	(Thorp, 2023)
[29]	(Thurzo et al., 2023)
[30]	(Tlili et al., 2023)
[31]	(Vartiainen & Tedre, 2023)

Source: own elaboration.

RQ₁. What are the characteristics of the items in the final review corpus (year of publication, type of article, sources, authors, geographical distribution)?

The selected articles are predominantly concentrated in the year 2023 (approximately 84%), which clearly indicates the novelty of applying generative AI to education. Journal articles predominate, with 71% (87% if editorial papers published in journals are also considered). Editorial articles provide a reflective and critical perspective from the editorial teams of scientific journals on the emerging nature of generative AI. There is a wide dispersion in the sources where the articles were published. Among the 26 represented sources, only one has three articles (*Journal of University Teaching and Learning Practice*), followed by three sources that have published two selected articles (*AAAI Conference on Artificial Intelligence*; *Computers and Education: Artificial Intelligence*; *PLOS Digital Health*). As with the sources, there is no significant number of articles among a few authors. Among the 169 authors who contributed to the selected articles, only two female authors participated in three articles (Safinah Ali and Cynthia Breazeal), and one female author contributed to two articles (Daniella DiPaola). Regarding geographical distribution, the articles are predominantly from the United States, represented in 15 articles, followed by Australia, represented in eight articles.

RQ2. In which disciplinary domains were the studies developed?

The field of education, understood as a cross-disciplinary field, is the most represented in the corpus of the review, with nine articles (29%), followed by medicine, with eight articles (25.8%). The organisation into disciplinary fields can be seen in Table 3.

Table 3
Disciplines on which the studies included in the final review corpus focus

Discipline	Num. of papers	Papers
Crafts	1	[31]
Biology	1	[27]
Science	1	[5]
Education	9	[6] [7] [8] [10] [11] [19] [23] [28] [30]
Nursing	1	[4]
Writing	2	[14] [25]
Informatics	1	[9]
Mathematics	1	[15]
Medicine	8	[3] [12] [16] [17] [18] [21] [22] [26]
Dentistry	1	[29]
Journalism	1	[24]
Pre-university	3	[1] [2] [20]
Tourism	1	[13]

Source: own elaboration.

RQ3. What are the contributions of generative AI to education?

The most widespread perception about generative AI-based technologies in education is a mix of enthusiasm and apprehension. This stance is well reflected in the four paradoxes expressed by Lim et al. (2023) regarding generative AI:

1. Generative AI is a “friend” yet a “foe”.
2. Generative AI is “capable” yet “dependent”.
3. Generative AI is “accessible” yet “restrictive”.
4. Generative AI gets even more “popular” when “banned”.

The benefits, risks, and challenges in the papers that comprise the review corpus are presented on the following basis.

Benefits and potential uses of generative AI in education:

B1. Access to a large amount of relevant information in real time to later process, summarise, and present as if it were a human [4] [6] [16] [24].

B2. Generation of extensive sets of educational content (cases, units, rubrics, questionnaires, etc.) that can preserve privacy in critical cases, such as in the domain of medical education [3] [5] [16] [17] [24] [26].

- B_3. Supportive tools for learning new concepts compared to traditional media, including the ability to summarise or explain complex concepts [5] [16].
- B_4. Understanding context, enabling interaction (dialogue) with these tools, which can help obtain self-directed answers to questions and learn more effectively about various topics [4] [12].
- B_5. Enhancing critical thinking and creativity by allowing students to receive feedback on their assignments and question their beliefs [7] [26] [31].
- B_6. Supporting students in repetitive tasks, allowing them to focus on the essence of the tasks and be more critical in their learning [7] [13].
- B_7. Facilitating the initial development of ideas and reflection upon them [7] [13].
- B_8. Providing an asynchronous communication platform, which increases engagement and facilitates student collaboration [6].
- B_9. Allowing for personalised learning [6] [12] [16] [18] [26].
- B_{10}. Helping students with writing difficulties and, in general, anyone to have more control over their writing skills [5] [7].
- B_{11}. Becoming virtual learning assistants [7] [10] [18].
- B_{12}. Serving as tools for continuous and informal learning [4].
- B_{13}. Facilitating the development of language skills [6] [16].
- B_{14}. Improving teachers' productivity by reducing the time spent answering the same student questions, grading written assignments, etc., allowing them to focus on higher-level tasks, such as providing feedback and support to students [4] [6] [8] [13] [16] [18].
- B_{15}. Supporting automated assessment and other innovations in evaluation [6] [16].

Risks of generative AI in education:

- R_1. Rapid and superficial learning [8].
- R_2. Hindering students from developing critical and independent thinking skills, which could have long-term repercussions [4] [8] [9] [13] [18].
- R_3. Potential hindrance to the development of creativity [8] [13].
- R_4. Providing incomplete information, leading to the misinterpretation of a concept [4] [7] [10] [24] [26].
- R_5. Offering seemingly plausible but incoherent answers, often producing "fabricated" results known as hallucinations [14] [16] [18] [26] [27] [31].
- R_6. Limitations for interpreting quantitative information embedded in a text [15].
- R_7. In many cases, no information being provided about the authorship or the source of evidence supporting the obtained results, which also constitutes a violation of copyright [5] [6] [10] [11] [14] [26] [31].
- R_8. Possible adverse effects on developing interpersonal skills, such as communication and interaction between students and teachers and among peers being compromised [4] [18].
- R_9. Dishonest use of these tools, which occurs when the output generated is used without proper attribution, which can be considered plagiarism [4] [6] [8] [10] [11] [13] [16] [18] [25] [26] [29].

- R_{10}. The differential access and usage of these tools, particularly premium paid versions, between individuals who can afford them and those who cannot, which is a potential cause of equity issues [4] [6] [13] [19].
- R_{11}. The invasion of data privacy and confidentiality [13] [18].
- R_{12}. An increase in racial and socio-economic prejudices due to data biases in the training of these applications [13] [18] [29] [31].
- R_{13}. Potential negative environmental impact due to the high processing power required to obtain the results [5].
- R_{14}. Cybersecurity problems [26].

Challenges that generative AI opens up for education systems:

- C_1. Adaptation of all actors involved to the digital ecosystem derived from generative AI, which is continuously evolving [8] [19].
- C_2. Teacher training in generative AI competencies [4] [5] [6] [10] [11] [30].
- C_3. Communities of practice generation to share experiences on the educational use of AI [4].
- C_4. Development of students' competencies in generative AI, with an emphasis on fostering critical thinking skills to understand its potential and limitations and to make ethical use of these technologies [4] [10] [18] [30].
- C_5. Reviewing, updating, and innovating curriculum content and teaching methods that may have become outdated, along with addressing the resistance to change, opening up more opportunities for students' reflection [10] [11] [13] [14] [18] [22] [24] [26] [28] [29] [30].
- C_6. Exploration of alternatives and/or complementarities in assessment methods, such as incorporating oral assessments as a complement to written assignments, utilising open-ended evaluations to encourage originality and creativity, providing visual diagrams or graphics, and emphasising the importance of the learning process rather than solely focusing on the final product [4] [6] [7] [8] [10] [18].
- C_7. Development of ethical codes and the establishment of general guidelines regarding generative AI, ensuring responsible and ethical practices in its implementation [8] [19] [21] [26].

RQ_4. What educational interventions are reflected or proposed in the studies?

The selected works encompass various educational interventions implemented or proposed as measures to address the widespread adoption of generative AI technologies. These interventions are distinguished in the classroom setting and in formulating educational strategies and policies.

Work in the classroom

The initial works (from a temporal perspective) that apply generative AI techniques in the classroom refer to the design of activities to bring generative adversarial networks (GANs) (Goodfellow et al., 2020; Karras et al., 2021) into pre-university studies. Ali, DiPaola, and Breazeal (2021) designed educational activities to help students understand the concepts of generators and discriminators concerning

GANs. The generator aims to create something new, and the discriminator must classify it as real or fake. These activities aimed to provide students with a better understanding of how GANs function and their role in generative AI. Ali, DiPaola, Lee, et al. (2021) employed educational activities with high school students to raise awareness about the ethical aspects of AI using tools for deepfake generation. The purpose was to engage students in critical discussions and reflection regarding the ethical implications of using AI technology, specifically in the context of deepfakes. These activities aimed to foster a deeper understanding of AI generative tools' potential risks and ethical considerations. Pataranutaporn et al. (2022) investigated the effects of artificially generated virtual instructors on learning. In their study, they explored the correlation between students' affinity for the virtual instructor and their motivation levels, although no significant impact on test scores was observed. Lyu et al. (2022) introduced AI at the pre-university level through interactive tools, Plato's allegory of the cave, and artistic explorations. However, instead of GANs, the authors utilised variational autoencoders (Kingma & Welling, 2022) as the underlying technique.

GANs also have practical applications in training future medical professionals by quickly generating training materials and simulations that can be used as educational resources (Arora & Arora, 2022). These synthetic cases would increase the number of extreme cases with which to create learning scenarios while protecting patient identities. An additional benefit is facilitating resource sharing (cases) between institutions.

Dwivedi et al. (2023) proposed that educators and students explore together the applications and limits of generative AI, both ethical and capacity-wise, thus enabling this technology in unimaginable ways. To do so, they suggested using the IT Mindfulness framework (Thatcher et al., 2018), which includes four elements: 1) alertness to distinction, 2) awareness of multiple perspectives, 3) openness to novelty, and 4) orientation in the present.

Šlapeta (2023) reflected on how to start using generative AI tools in the classroom. It begins by establishing their limits, with the idea that they are models, not sources of wisdom or absolute truth. Any assistant helps to organise thoughts and tasks into meaningful chunks. However, suppose one wants to incorporate this technology into a daily routine. In that case, they must learn to use it so that the user becomes the expert and, as such, is responsible for verifying the results provided by the assistant.

Defining education strategies and policies

The use of generative AI tools in educational institutions should not be prohibited (Choi et al., 2023; García-Peñalvo, 2023; Iskender, 2023; Lim et al., 2023; Perkins, 2023; Tlili et al., 2023). Prohibition is the best indication that educational institutions are not yet prepared for the natural incorporation of these technologies. Moreover, these tools are already available to students outside educational institutions and will be commonplace in their workplaces after they have completed their studies (Masters, 2023). Therefore, teachers need to feel supported by their institutions' administrations and clearly understand the expectations associated with these tools throughout the teaching and learning process, with particular attention to assessment practices (Cooper, 2023).

To curb fraudulent or unethical use, which is not a new issue but has become more prevalent with the advent of these technologies, teachers must enhance their role in raising student awareness about the importance of academic honesty, the value of critical thinking, and the consequences of dishonest practices (Choi et al., 2023; Dwivedi et al., 2023). They should assume a more significant leadership role (Crawford et al., 2023) and shift the narrative towards distributed responsibility when addressing academic misconduct. In other words, the government, teachers, and students must share responsibility (Lim et al., 2023). However, promoting good practices should not mean relinquishing the need for academic fraud detection, as undetected cheating represents a form of inequality in the present and a lack of preparedness for the future. Additionally, given the global nature of these tools, international coordination is necessary to maximise their benefits (Dwivedi et al., 2023).

REFLECTION

AI is a set of information processing tools representing a further step in the advancements made in this field over the past century. AI enables the processing of information in a helpful way for humans due to its speed and alignment with objectives. What is most remarkable about recent developments, and likely has the most significant impact on education, is a subset of AI known as generative models. The commercial and collaborative strategies surrounding these models have allowed millions worldwide to interact with them, making people globally aware of the possibilities they offer and the potential risks involved.

Although AI systems have been dedicated to various tasks, such as image or video creation and manipulation, those offering natural language processing capabilities have had the greatest impact. This is our first time witnessing such dimension and quality in this area. We are no longer impressed by machines' ability to handle numbers, which was controversial in the past. We have become accustomed to robots or drones that many now have in their homes. However, when it comes to language processing, something considered part of human beings' essence, it raises concerns. It is important to note that the fact that a machine can handle language like a human can only makes it human if we perceive it as such.

A similar line of thought has emerged regarding the suffering and feelings of love in other living beings. Qualities exclusively attributed to human beings for centuries are now acknowledged to exist in other living beings as well. In a further display of human inconsistency, we may wonder whether language-processing machines have feelings, as has been suggested in some cases, while we continue to doubt whether other living beings possess them. The difference between these two cases is that machines handle the same language as humans, allowing people to ask them questions directly and receive responses. In contrast, other living beings use different forms of communication with which most humans cannot interact. It does not seem this should be the criterion that makes the difference.

Not everything imaginable with AI is currently a reality. Each emerging option must be carefully analysed and placed within the appropriate utility framework. There is not a single AI; many different models are trained in different ways to perform specific tasks. Furthermore, the outputs are used by other types of software that generate functions no longer exclusive to AI. If resistance can jeopardise the use of such powerful tools we are discussing, the questions must align with the facts so that the answers can provide real options.

There is no relevant example of access to a technology being successfully prohibited. Access to the Internet or smart mobile devices has also sparked numerous debates, with clear proposals to limit access by specific individuals based on age or condition. However, none of these initiatives has been successful. This is mainly because the focus is more on limiting access than on users' ability to filter information and utilise the available tools. This is a phenomenon that is not new either, as unrestricted access to information has always generated debates.

In this article, we do not intend to answer the question of whether tools such as ChatGPT are intelligent. What seems to be beyond doubt is that they perform functions that, when performed by a human being, reflect the intelligence of the subject using them. We have no problem saying that similar models designed to play chess are extremely intelligent (to the point that humans do not compete against them in tournaments). Why do we now have these reservations? Perhaps it is only because the other tasks are ones that not all humans perform (playing chess) or ones that are of little interest. However, language use concerns everyone; we all believe we understand what we discuss (never better said).

While organisations and institutions debate the stance they should take or recommend regarding using these AI technologies in education, technology will advance enough to render those resolutions meaningless once approved. It is crucial to remember this to avoid dedicating time to rules or recommendations that are impossible to enforce.

The problem for the academic world is that machines can easily and quite accurately (perhaps totally correctly in a few months) perform tasks that have been assigned to students as a mechanism to determine if they have achieved the objectives of a subject (i.e., for their assessment). The initial reaction to this situation is to prevent them from using these tools. However, the question now becomes more interesting: If a machine can already perform a task, what other things could humans begin to do with the assistance of these machines? We faced similar questions during the 18^{th} and 19^{th} centuries with the Industrial Revolution, when machines replaced manual labour in numerous factories. Now, we can do the same things much faster, and even better, which enables us to consider doing different things. Whether this leads to the betterment of our societies or not will be our responsibility.

The problems we have presented here are not unique to the field of education. They also affect other sectors, such as law, medicine, engineering, and programming. They will impact any task that requires the rapid handling of large amounts of information in databases or, as a great novelty, in texts. Education should not be exempt from these debates, and we must pay attention to the options these tools give us to maximise the learning possibilities for both teachers and students. Perhaps we need to make certain changes in the curricula of our degree programs by incorporating the learning of these tools' usage in each field. However, what is certain is that we will have to make substantial changes in how we teach and what we expect our students to do.

Finally, in writing this article, we have realised our main challenge: the speed at which we will have to analyse and incorporate these innovations. In the time it took us to write this and address the reviewers' suggestions, more and more options have emerged. This will be the true challenge from now on.

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Education in 2030. Prospects of the Future by Trainee Teachers

La educación en 2030. Prospectiva del futuro por profesorado en formación

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ABSTRACT

This study analyses 389 science-fiction stories about the future of education, written by students of the Teacher Training and Research in Education Master's Degrees at the University of Alicante between the academic years 2009-2010 and 2019-2020. These stories were written as part of an assignment called "Education in 2030", and they are available on our open-access course blogs. Our project employs a mixed-research approach and the analyses include both quantitative and qualitative aspects through descriptive statistics in a longitudinal study. According to the results, the stories are classified into two main categories: Positive Predictions and Negative Predictions, the latter being more prominent (52.94% of total), closely connected to dystopian science-fiction models. Within these two macro-categories, three main codes are established about Negative Predictions on one hand, namely Teacher-Learner, Learning process and System, and about Positive Predictions on the other hand: Teaching, Contents and Model. These codes structure the analysis branching into more sub-codes which also mark frequencies of occurrence of ideas and notions. We would like to highlight those codes that characterize the teacher figure as a "mediator" or "clandestine" as two recurrent educational models for the future. Excerpts from the analysed stories are included to illustrate the codes employed. The creation of educational stories within the science-fiction genre offers a rich, critical and comprehensive vision of the future. The stories analysed in this project portend significant changes in teaching practices and a new use of technology, but also show concern about potential dehumanisation in education and a growing distance between ideals and reality concerning work improvement, inclusion and sustainability.

Keywords: education trends; future (of society); science fiction; creative writing; master's degree; educational technology.

RESUMEN

Este estudio analiza 389 relatos de ciencia ficción sobre la educación del futuro escritos por alumnado de los másteres de formación del profesorado y de investigación educativa de la Universidad de Alicante entre los cursos 2009-2010 y 2019-2020. Durante la práctica "La Educación en 2030" se escribieron estos relatos, disponibles en abierto en los blogs de las distintas asignaturas. Se realiza una investigación mixta con un análisis cualitativo de los relatos y la expresión cuantitativa mediante estadísticos descriptivos en el estudio longitudinal. En los resultados se clasifican los relatos en dos grandes categorías: Predicciones Positivas y Predicciones Negativas, teniendo mayor relevancia estas últimas (52.94 % total), relacionadas con los modelos distópicos de la ciencia ficción. Sobre estas dos macrocategorías se establecen tres códigos principales, que son Predicciones Negativas: Docente-discente, Aprendizaje y Sistema; y Predicciones Positivas: Docencia, Contenidos y Modelo; que articulan el análisis con más subcódigos y frecuencias de aparición de las distintas ideas. Destacamos los códigos sobre la figura del docente como "mediador" o "clandestino", como dos modelos educativos que se repiten como profesorado del futuro. Se incluyen fragmentos de los relatos analizados para ejemplificar los códigos utilizados. La creación de relatos educativos desde la ciencia ficción ofrece una visión rica, crítica y diversa del futuro. Los relatos estudiados revelan cambios significativos en la praxis docente y en la incorporación de tecnologías, pero también preocupaciones sobre aspectos deshumanizados y la distancia entre ideales y la realidad en temas como las mejoras laborales, la inclusión y la sostenibilidad.

Palabras clave: tendencias en educación; futuros (de la sociedad); ciencia ficción; escritura creativa; máster/maestrías; tecnología educativa.

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INTRODUCTION

The origin of the term *science fiction* is commonly attributed to William Wilson, who first used the expression in his work *A Little Earnest Book upon a Great Old Subject,* published in the mid-19th century (Stableford, 2006). The way the author used the term suggested the possibility of revealing the truths of science by means of a narrative that could be, at the same time, poetic and truthful. The expression was not intended then to encompass the consequences that new scientific and technological developments could have on our future, but rather to draw attention to a genre that could combine fictional –or poetic– elements with scientific discoveries. There are no signs, however, of questioning nor advocating new scientific advancements that may challenge our society or imply the creation of a new social order. These futuristic considerations directly influence the way we conceive the education of the future (Burbules et al., 2020).

These particular ideas have been present in science fiction for some time now, especially since the mid-20th century, as the genre has been offering us different versions of the consequences of technological development. Science fiction is closely related to utopian or dystopian literature due to its capacity to include the potential materialization of the current technological conditions and also offer a critical view of what our society could be like in the future (Rovira-Collado et al., 2022).

There are two positions regarding future societies: the optimistic and the pessimistic points of view, and it goes without saying that the latter has been unquestionably predominant in fiction. The decline of utopian thinking is a clear sign of how current societies envision the future world, and we could very well be facing an unmistakable sign of despair, where the predominance of dystopic representations may reveal the political and social consequences of the relentless development of technology.

There are two main perspectives regarding these depictions of the future, as certain authors have singled out, and they correspond to two states of mind that are predominant in contemporary societies. Martínez Mesa (2016) perceives on one hand a pragmatic spirit that resignedly accepts the progressive technology deployment, and on the other hand, a disposition that alternates between enthusiasm and suspicion but always in a general mood of despondency, accepting defeat in the face of the inexorable rise and ubiquity of technology.

If we assume that these states of mind are preponderant, it is not surprising that the scenario we picture for the future is filled with ominous predictions. The outline of that scenario and its circumstances derives from the need to use those stories and narratives to alleviate our anxiety in the face of a certainly negative prospect, in the same manner that mythological stories were, in another time, intended to help people alleviate their concerns and worries. It is not our intention to overlook the existence of optimistic expectations, or the fact that many sombre predictions of the past did never come true (Pogue, 2014), but what characterizes our society today is the critical stance regarding technology. Those hopeful visions about the excellence and magnificence of a post-human future (Kurzweil, 2015) are criticised for their pettiness and lack of consideration regarding the consequences that such a rupture would entail.

Our project focuses on the educational analysis of the perceptions of trainee teachers about the future of their profession (Barnes, 2008). The concepts of utopia and dystopia are presented within this theoretical frame not as whimsical musings or naïve fantasies, but as appropriate tools to examine the conditions under which we currently live, characteristics that are inevitably associated to a specific historical situation. This understanding also unfolds on a comparative level which enables the integration of different disciplines and knowledge. It is not our aim to dismiss those procedures involved in the imaginative creation of both utopias and dystopias, but to emphasise the aesthetic and ethical consequences of their narrative development.

There is a long research tradition about the potential dilemmas that the future holds for us, especially about certain circumstances that are assumed as a challenge to the current order, and related to different fields of knowledge. Some of those circumstances concern learning processes, human values and knowledge transfer. The study of those fictional expectations and those imagined futures, unquestionably related to linguistic aspects and creative writing, is still object of research, as evidenced by recent publications (Kozel et al., 2019).

Looking into what potential positive or negative consequences may derive from changes in our societies, especially in our field of study –Education–, is a sign of our present worries and insecurities and also proof of the already existing issues that have yet to be solved. The answers are necessarily found in experience, whether it be present or past, and that is why when we tend to these questions and concerns we are not only contemplating what is to come but also, and perhaps more importantly, we are testing the firmness of the ground we are stepping on, or maybe the bumps along the way.

All the elements that result from the analysis of future conditions will therefore be compelling tools for those researchers who intend to interpret the social, cultural and political disposition of our societies, and we could interpret them as questions regarding our research: what hypotheses are formulated about technological advancements, what is their function in the educational debate, what is their role in the exploration of our identity and, lastly, how are the rights and responsibilities of future educators addressed? All these questions fall within a theoretical framework which will enable us to reflect on the development of our trainee teachers' digital competence (García-Ruiz et al., 2023; Marimon-Martí et al., 2022).

There is a considerable amount of research about depictions of the future in science fiction (Pogue, 2014; Gidley, 2017), and whether or not the predictions eventually come true, that are useful to define our approach. Westfahl and Yuen (2014) offer a comprehensive selection of essays on predictions about the future. Bowler (2017) traces the work of the so-called "prophets of progress", such as Wells or Asimov. By the end of the last century, Thomson (1996) was already considering whether Asimov was a visionary or if he was simply describing reality. More recent studies (Briggs, 2013) focus on other science fiction sub-genres such as "cyberpunk", for instance William Gibson's *Neuromante* (1984), or on significant audio-visual products such as the *Star Trek* series (Gene Roddenberry, 1966), which is still offering different visions of the future as of 2021 (Pogue, 2017). Prosser (2019) highlights the interest that large companies or national defence institutions have in futuristic stories as inspiration for their strategy building.

Some of the ongoing educational debates, for instance, revolve around questions and issues that were considered unalterable until recently, namely face-to-face teaching (Suárez Ramírez et al., 2016). Undoubtedly, the need for and the increase in virtual learning environments has brought about significant changes in the teaching-learning process.

METHOD

Participants

This research project is based on the study of a narrative corpus of 389 science-fiction stories written by university students within the "Education in 2030" project assignment. Mixed research has been conducted using qualitative and quantitative analysis and the results have been shown through descriptive statistics in a longitudinal study. Our analysis demonstrates the process through an emerging design (Flick, 2015) in which we first identify the categories that structure the data, and then we analyse the codes used to label and identify the ideas underlying in the narratives. The research team established two distinctions by consensus regarding the interpretation of the students' stories, namely *positive* and *negative* visions of the future. Two of the stories were not taken into account because they did not meet the necessary requirements for the analysis, hence the total number of stories in the corpus came down to 387. In order to harmonize the data, since the size of the non-probabilistic sample varied each year, they are displayed in terms of absolute frequencies (AF) and their percentage contribution to the general meta-code (%AF).

Instrument

The elements analysed are science-fiction stories written by trainee teachers. Building upon Connelly and Clandinin's (1990) classic narrative for schools model, these visions of the future are regarded as biographical narratives or accounts of schoolwork practices (Branda & Porta, 2019), where personal experiences are combined with the hopes and aspirations for what future education should be like. To enhance the futuristic atmosphere of the assignment, all the stories were delivered in digital format (Londoño, 2012) and they are available on our open-access course blogs as individual digital stories (Molas-Castells et al., 2022). These digital spaces can be considered as collaborative settings that foster communicative interaction (Mesa Rave et al., 2023).

We must emphasize that the main purpose of this assignment was to create science fiction. The basis for our research lies in the stories created for the *Education in 2030* assignment, a project that has been gradually evolving over eleven academic years and whose main objective is to have students create stories about what they consider their teaching practice will be like in twenty years' time. The students (trainee teachers) are encouraged to reflect upon potential changes in teaching and learning practices and the evolution of the profession in a feasible and verisimilar future, following the directions received in the creative writing workshop they attended as part of the course. Therefore, the purpose of this literary assignment is twofold: on one hand, students are given tools that promote and foster their literary creativity and on the other hand, they are encouraged to reflect upon possible solutions for the educational challenges of our society regarding the relentless rise of technology. This research has paved the way for other studies about how science fiction can be representative of education and the development of reading habits in the future (Rovira-Collado, 2020a).

The qualitative data analysis has been conducted using *ATLAS.ti* (v.7). The final rubric consists of a total of 25 codes grouped under 6 categories, which are in turn divided into two macro-categories depending on the nature of what we call the students' *predictions*: negative and positive educational predictions. These networks of codes (including their codes and sub-codes) are linked to the research objectives according to three different levels of specification, as determined by school curricula, aiming to provide a systemic view of actual classroom work in relation to content, also considering socio-cultural determinants. In this way, a Hermeneutic Unit (HU) containing the students' writings has been developed for each course and subject. Every one of these units has been assigned the same network of codes developed through an inductive coding process, in order to synthesise the expressions and concepts employed by the students. *Excel* has been used for frequency quantification and distribution, in order to hyperlink the stories with the identified codes for subsequent statistical analysis.

Procedure for data collection and analysis

Firstly, we collected narratives from the course "Research, Innovation, and the Use of ICTs in Language and Literature Teaching", offered by the Teacher Training Master's Degree at the University of Alicante since the academic year 2009-2010. The provided dataset is composed of 311 narratives written along a total of 11 courses, and labelled *INVTIC10* to *INVTIC20*. Secondly, we collected 78 stories from the Master's Degree in Educational Research, particularly from the courses named "'Research on the Development of Reading and Literary Competence, Children's Literature" (4 courses labelled *INVLIJ16* to *INVLIJ19),* and "Research in Language and Literature Teaching" (1 course labelled *INVDLL19*), both from the University of Alicante. In the following table, we provide links to the course blogs and the total number of stories collected.

Table 1

Distribution and location of the narratives

Label	Course blog	N
INVTIC10	http://didacticalenguayliteraturaua.blogspot.com/	20
INVTIC11	http://didacticalenguayliteraturaua2011.blogspot.com/	17
INVTIC12	http://didacticalenguayliteraturaua2012.blogspot.com/	25
INVTIC13	http://didacticalenguayliteraturaua2013.blogspot.com/	15
INVTIC14	http://didacticalenguayliteraturaua2014.blogspot.com/	26
INVTIC15	http://didacticalenguayliteraturaua2015.blogspot.com/	51
INVTIC16	http://didacticalenguayliteraturaua2016.blogspot.com/	42
INVTIC17	http://didacticalenguayliteraturaua2017.blogspot.com/	23
INVTIC18	http://didacticalenguayliteraturaua2018.blogspot.com/	34
INVTIC19	https://didacticalenguayliteraturaua2019.blogspot.com/	30
INVTIC20	https://didacticalenguayliteraturaua2020.blogspot.com/	27
INVLIJ16	http://theintertextawakens.blogspot.com/	13
INVLIJ17	http://thelastreader2017.blogspot.com/	14
INVLIJ18	http://lijmilenaria.blogspot.com/	15
INVLIJ19	http://siempresevuelvealaprimeralectura.blogspot.com/	18
INVDLL19	https://mientrasdurelaliteratura.blogspot.com/	18

Source: own work.

Textual analysis in qualitative research allows for the reflection of the students' views on the evolution of socio-cultural contexts through time, and a better understanding of how these historical-cultural determinants are interpreted by the participants in their narratives (Fernández et al., 2022) in a cross-sectional study.

These stories written by our students demonstrate the possible ways in which a feasible future can be depicted; for their implementation, they followed the directions offered in our literary workshop aimed to help them develop their creativity and imagination. The project is thus conceived as a didactic tool to promote the creation of literary narrative while, at the same time, creating tools that enable us to better address the current educational challenges.

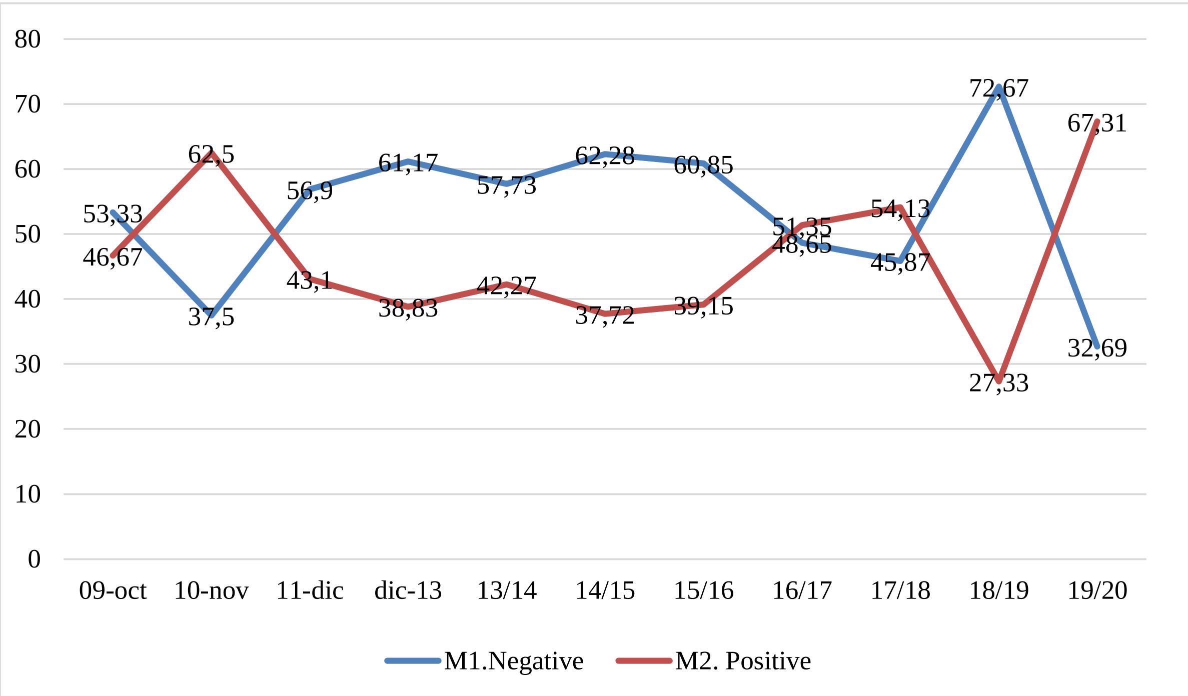
RESULTS AND DISCUSSION

Overview of Students' Educational Prospects

In this initial approach to the cross-sectional study of the students' predictions (P) we can observe a progression in the contributions for each course in the meta-codes used: *negative educational predictions* are labelled with the meta-code 1 (M1) and *positive predictions* are labelled M2, all expressed as percentages. When expressed as percentages, differences and variations are more clearly seen: there is a higher percentage of negative predictions (in 6 out of 10 courses) in the Master's Degree in Secondary Education, as opposed to a greater contribution of positive predictions in the Master's in Educational Research (except for the 2019/2020 academic year with %M2=31.94%). As we can see, this assignment was offered in different courses, and the percentages are inversely proportional between the two degrees every academic year since 2015/2016, when we began this project with the students of the Master's in Educational Research, except for the 2017/2018 course. This evolution can be seen in Figures 1 and 2.

Figure 1

Evolution of predictions in Master's in Secondary Education

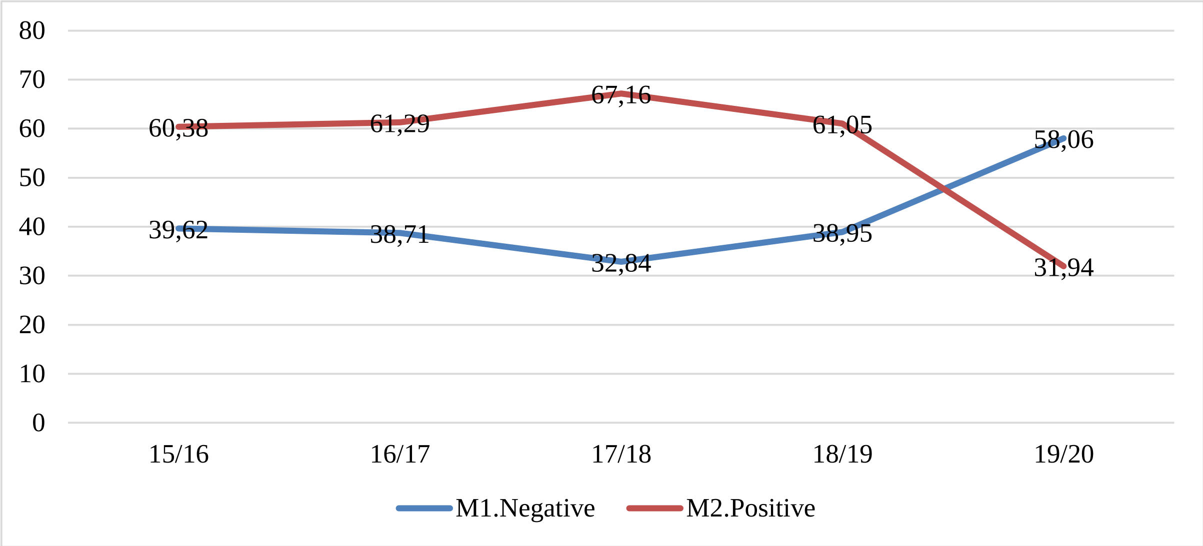


Source: own work.

This chart illustrates the progression of the assignment over more than ten academic years. We could resort to historical data to interpret these results, although it is worth noting that the bleakest year was 2018/2019, just before Lockdown, whereas the Lockdown year actually yielded a positive result.

Figure 2

Evolution of predictions Master's in Research



Source: own work.

In the second figure we can observe a contrasting trend, which may be due to the students' different and personal traits depending on the Master's Degree they belong to.

Qualitative analysis results

In this section the different descriptive results that arose from the analysis of the corpus of stories are presented, along with the codes employed. To identify distinct fragments of the stories the labels for the corresponding course are used (see Table 1) followed by a number which indicates the position the story occupies in that course (examples: "INVTICXX-RYY" or "INVLIJXX-RXX").

Negative educational predictions by students

This main meta-code is structured into three basic codes. In Table 2 the results are broken down into four columns, after the analysis of the whole set of stories belonging to both Degrees, and subsequent sub-codes are shown.

Table 2
Total of negative educational predictions

		M.S.E.		M.E.R.	
Code	**Sub-codes**	**AF**	**AF (%)**	**AF**	**AF (%)**
1.1. Teaching role	1.1.1. Substitute	61	7.39	11	6.67
	1.1.2. Testimonial	45	5.45	2	1.21
	1.1.3. Traditional	36	4.36	7	4.24
	1.1.4. Clandestine	64	7.75	18	10.91
1.2. Learning	1.2.1. Virtuality	75	9.08	15	9.09
	1.2.2. Technology	99	11.99	19	11.52
	1.2.3. Digitalization	78	9.44	20	12.12
	1.2.4. Utilitarianism	67	8.11	12	7.27
1.3. System	1.3.1. Non-inclusive	62	7.50	7	4.24
	1.3.2. Dehumanised	138	16.71	32	19.40
	1.3.3. Catastrophism	41	4.96	15	9.09
	1.3.4. Legislative instability	60	7.26	7	4.24

Note. MSE: Master's in Secondary Education / MER: Master's in Educational Research
N1(MSE): Total 826; N2(MER.): Total 165; AF: Absolute Frequency.
Source: own work.

We observed that negative predictions are the most common for both Degrees (991, representing 52.74%), with a higher percentage in the MSE (55.18%) compared to the lower incidence of these negative predictions in the narratives from the MER (165, representing 43.20%). Code *1.1. Teaching role* focuses on the relationship between teacher and student and the role it plays in these narratives. To make this clearer, we established four sub-codes to illustrate the different teaching roles that appear in the stories. The most occurrent elements in the whole dataset are *1.1.4. Clandestine* and *1.1.1. Substitute*, and they reflect different throwbacks or issues perceived by the students. Code *1.1.4. Clandestine* refers to a teaching figure that opposes to the general conditions surrounding the teaching process, and wants to change them through individual action or as part of a collective with a divergent mindset:

> "Confronted with this situation, some of us regrouped under the name 'Alexandrians' in honour of the mythical Library of Alexandria, and we travelled the world rescuing our own and preparing to unleash our revenge." (INVTIC16-R36)

Code *1.1.1. Substitute* appears in those stories that portray the disappearance of the teacher figure in the classroom, due mainly to technological advances such as robots, mental devices, or artificial intelligence systems. Here are some examples:

> "Teachers, in addition to having to contend with all that is to come, will have very strong enemies on top of all that: the robots that the Ministry of Education will place in every school." (INVTIC10-R19)

> "Once upon a time there will be, in a not-too-distant future, a child named Cyberlearner who will not attend school. He will use contact lenses instead, that will connect him to his everyday lessons and there will be no need for teachers." (INVTIC14-R13)

The least occurring sub-codes are those assigned to models in which there actually is -a teaching input but it is seen as ineffective. Code *1.1.2. Testimonial* (which is less common in the Master's in Educational Research with 1.27% of the total occurrence and 5.26% of the code) refers to a physical figure in the classroom that is often inconsequential and whose role is merely to be an adult among the students. Lastly, *1.1.3. Traditional* shows a negative side of the teaching input, which is incapable of progress and unable to motivate the students or innovate in methodology.

For the second category of codes, *1.2. Learning* encompasses a set of elements that interfere negatively in the teaching process. Students from both Master's Degrees agree in their negative views of these elements, mainly regarding the way the contents are taught, the methodology used and the technological devices available at school. The code with the maximum number of occurrences is *1.2.2. Technology*, which refers to situations in the classroom in which the use of technology is inefficient, whether it might be due to obsolescence, system failures or excessive dependence on devices and/or applications. For example:

> "All the students were looking at the screens they had in their hands, and they didn't even talk to each other. I can't yet understand how they could dodge one another when walking like that." (INVTICUA14-R11)

The next most frequent code is *1.2.3. Digitalization*, and it concerns the stories that show non-conformity and nostalgia for long-lost physical books, or for old reading and writing activities. For instance:

> "The boy shrugs, unfazed. Piles of books lie amongst the rubble. A true treasure. Heating material that will last for days." (INVTIC13-R09)

> "Now everything is digital. Boys and girls have interactive desks at school, where everything is displayed: the activities, the videos… What a pity! I can still remember that smell of a freshly-opened book." (INVDLL19-R07)

With a lower occurrence but still well represented, sub-code *1.2.1. Virtuality* refers to the difficulties that arise when using online teaching platforms, tools or applications that concentrate the teaching performance in spaces that are regarded as impersonal. Here is an example:

> "In 2030 everything will be computerized, and students' attendance to class will be irrelevant because we will have ICTs, with video-classes." (INVTICUA10-R19)

Furthermore, code *1.2.4. Utilitarianism* refers to narratives that contemplate the disappearance and rejection of all matters related to humanities and social sciences, to the benefit of other subject matters related exclusively to professional development, and also a decrease in creativity or the ability to make personal choices. Code *1.3. System* takes a broader perspective regarding curricular design and specificity and shows the intrusion of socio-cultural factors in education. To a greater extent, the biggest danger identified by the students is concentrated in sub-code *1.3.2. Dehumanised*, and it is one of the most frequent elements. These stories show the students' concern about the rise of extremist positioning that may affect the education system by the settling of an oppressive stance (either political or related to technological dominance), typical of dystopian narratives. For instance:

> "Six years ago, the 'non-opinione', a worldwide group against citizens that show critical thinking abilities, destroyed all the schools, computers, books, communication, life." (INVTIC13-R12)

Code *1.3.1. Non-inclusive* is assigned to those stories that portray a society in which good-quality schooling systems are not accessible for all people, and *1.3.4. Legislative Instability* describes issues that arise due to changes in educational legislation, and also problems caused by a wrong use of the law.

> "Of course, I don't want to scare you, but this is what is going on in public education. Private schools receive funding from the largest companies in the country, also at an international level, and they are financially supported regarding projects, studies and exchanges." (INVTIC18-R03)

> "Some things will surely remain unchanged, but perhaps they will not, like the laws. These past 20 years we have witnessed several changes in laws, we've had the LOE, the LOCE, the LODE, etc., I wouldn't be surprised if it all starts happening again." (INVTIC10-R20)

Code *1.3.3. Catastrophism* is reserved for a less occurrent element: extreme situations that directly affect education, such as climatic conditions or determinants that make coexistence impossible in the futuristic society portrayed. These ideas can be related to sustainability and climate emergency, issues which are currently hot topics in society. Covid-19 is only mentioned by the students in the last course, but other catastrophes are present in stories from previous years.

Positive educational predictions by the students

The second category used to classify the students' stories focuses on the positive educational predictions for the not-so-distant future. Once again, as we can see on Table 3, the data is structured within three levels of specificity: the educational relationship between teacher and student, elements concerning content learning and, finally, socio-cultural factors that have a positive influence in education.

Table 3
Total of positive educational predictions

		M.S.E.		**M.E.R.**	
Code	**Sub-codes**	**AF**	**AF (%)**	**AF**	**AF (%)**
2.1. Teaching	2.1.1. Virtual teaching	23	3.43	3	1.38
	2.1.2. Hybrid learning	23	3.43	3	1.38
	2.1.3. Mediator	106	15.79	34	15.67
	2.1.4. Self-teaching	5	.75	1	.46
2.2. Content	2.2.1. ICT support	129	19.22	46	21.20
	2.2.2. Tech-classrooms	102	15.20	19	8.76
	2.2.3. Multiculturality	24	3.58	11	5.07
	2.2.4. Interdisciplinary	24	3.58	8	3.69
	2.2.5. Preservation	62	9.24	22	10.14

2.3. Model	2.3.1. Inclusive	69	10.28	25	11.52
	2.3.2. Legislative stability	23	3.43	5	2.30
	2.3.3. Environmentalism	11	1.64	14	6.45
	2.3.4. Work improvements	70	10.43	26	11.98

Note. N1(MSE): Total 671; N2(MER): Total 217; AF: Absolute Frequency.
Source: own work.

In contrast to the previous section, positive educational predictions represent a lower percentage in the whole dataset of narratives (coded elements amounting to 47.26%), and it is in the Master's Degree in Educational Research where these types of predictions have the highest frequency (56.80% of total absolute frequencies). Within *2.1. Teaching*, the most recurrent sub-code is *2.1.3. Mediator*, which focuses on the teacher's role as motivator, as a figure who uses a meaningful learning-based methodology and acts as a guide that fosters the students' personal development. For example:

> "The students work in groups quite frequently, and the teacher's methodology is focused on discovery learning, with the purpose of stimulating students' interest, curiosity and creativity." (INVTIC17-R16)

Sub-codes related to the way in which the teaching process unfolds have a lower occurrence. Sub-code *2.1.1. Virtual teaching* appears in those narratives where all the teaching takes place in virtual environments, something which is regarded as an improvement, described as a more beneficial system than in-person teaching. Here are two examples, one from 2013 and another from 2020:

> "Whether she ever preferred to be face-to-face with the students was of little consequence. She was very happy since she didn't have to physically face the students anymore." (INVTIC13-R01)

> "I could have never imagined I would be teaching in this way, virtually. But after what happened with Covid-19, it was only logical to expect world changes, and education could not be an exception." (INVTIC20-R06)

Sub-code *2.1.2. Hybrid learning* refers to the combination of both in-person and online instruction (associated to *flipped classroom* or *blended learning* methodologies). Sub-code *2.1.4. Self-teaching* has a very low frequency, but it has been included in order to demonstrate that positive predictions always include the teacher figure as an essential element of the learning process.

Code *2.2. Content* encompasses the greatest number of elements concerning determinant features in the educational process. Sub-code *2.2.1. ICT support* is particularly relevant and is employed to classify all those narratives that highlight the benefits of using technology for teaching purposes. For instance:

> "Teenagers nowadays do not use books at school, but virtual reality glasses. Conventional lessons don't exist anymore. We teachers put our own glasses on and guide our students." (INVTICUA18-R30)

The second more predominant element is found in sub-code *2.2.2. Tech-classrooms*, regarding the use of technological resources and devices that facilitate students' learning and raise their motivation. Here is an example:

> "The classroom was large and bright. Another thing that caught his attention was that the desks popped out of the ground and arranged themselves depending on the number of students present at that moment." (INVTICUA12-R10)

As a counterpart to sub-code *1.2.3.* which expressed nostalgia for physical paper and writing activities, sub-code *2.2.5. Preservation* is assigned to those narratives that highlight either the recovery of such practices or their combination with digital resources. With a lower frequency, *2.2.3. Multiculturality* shows up when there is reference to the benefits of plurilingual education, contact with other cultures, or globalization in education made possible thanks to technological tools. Furthermore, *2.2.4. Interdisciplinary* encompasses the students' accounts of the benefits of interdisciplinary projects that combine different subject matters and promote teachers' teamwork, breaking down boundaries between subject areas.

Code *2.3. Model* covers all those narratives that focus on socio-cultural improvements that benefit the education system. With a similar number of occurrences, sub-codes *2.3.4. Work improvements* and *2.3.1. Inclusive* (together they make 78.49% of the code) are the most significant. Sub-code *2.3.4.* is concerned with improvement in the education system regarding work conditions, namely working hours, student-teacher ratio, or the availability of training courses for teachers:

> "Classrooms are less crowded so that we can devote time to all of our students. And we have one less teaching hour so that we can attend training courses." (INVTIC17-R05)

Sub-code *2.3.1.* is assigned to the stories in which students advocate for a true educational inclusion, a public system able to overcome social differences and respectful of diversity. That is, a system that ensures social justice for all:

> "Education has advanced a great deal and students have become the real protagonists of the classroom, where subject matters are adapted to their own personal educational needs." (INVTIC15-R48)

Code *2.3.2. Legislative Stability* is less frequent (10.97%) and stands for future societies in which a legislative pact is made so that teachers' views are taken into account before any educational law is changed or implemented, and there is a political commitment to not change educational laws so often:

> "Thanks to this reform, the students' mothers and fathers, the teachers, and even the students themselves can now have a say in all the decisions schools make." (INVTIC20-R19)

2.3.3. Environmentalism is not very frequent either, and it reflects a commitment to combat climate change: for instance, the creation of more urban green spaces or a decline in paper consumption. In summary, there is a total of 991 negative predictions (AF% 55.18) in contrast to 888 positive predictions (44.82%) in 311 narratives from 11 different courses belonging to the Master's Degree in Secondary Education, whereas there are 165 negative predictions (43.19%) and 217 positive predictions (56.81) in 78 stories from 5 courses belonging to the Master's in Educational Research.

CONCLUSIONS

In 2007, Nurmilaakso (2009) conducted research involving university students about education in 2030, where the participants were asked three questions about how they envisioned their profession in the future. Although the analysis and results were excellent, at that time –close to the beginning of our research– the conclusion reached was that the students were too traditional. From our point of view, using science fiction to generate stories about education in the future can offer a much richer and more comprehensive vision. As the results reported in our study show, we must be cautious and not perceive the future as a continuation or mere extension of the present time. The dichotomy between continuity and discontinuity prevents us from focusing on the fragments that define our postmodern context (Ingerflom, 2019), making us consider solely a continuous and uniform progress.

Furthermore, the importance of the teaching figure in the sub-codes *Clandestine*, *Substitute* or *Mediator* is an indicator of a new context that does not only concern the ideas of progress or regression, but also constitutes a new vision of the teaching practice in which all the determinant factors are equally important. Disruptive teacher training (Marcelo & Vaillant, 2018), despite its apparent discontinuity, does not culminate in the aforementioned dichotomy, but rather explores all the elements of the teaching-learning process that can establish a bond between the future and the knowledge of humanities. That bond is defined to a great extent by the means of communication that are available, in one way or another, to the participants in the process.

Virtual and blended learning are progressively becoming more prominent and they shed light on both positive and negative characteristics and outcomes for online education (Area-Moreira, 2020), as evidenced by our analysis of the corpus of selected narratives. Over the course of recent years, digital transformations have led to a significant change in the semantics of education and, of all the new terms that have emerged, we prefer *Distance Education* (García Aretio, 2020). Nevertheless, while many of those transformations portrayed in the narratives convey a critical view of our present ways, they are regarded as potential or even desired pathways to follow. Sub-codes *Work improvements, Inclusive education and Environmentalism* are proof of that. These features are constantly addressed in research, as is the case with inclusive education (Ortiz Jiménez & Carrión Martínez, 2020) or environmentalism, regarding its relationship with literary education (García-Única, 2017). The idealistic nature often associated with these elements may evidence the distance that separates us from a satisfactory situation regarding these concepts.

Another negative element worthy of mention, and perhaps the one that provides a more comprehensive view, refers to the organization of a dehumanised system. One of the most basic attributes of dystopia lies in the establishment of an education system that maintains the prevailing order (Mahida, 2011). The presence of that spectre of oppression in the stories challenges us as a society, and demands immediate action in order to guide our itinerary. We understand this research as an approach to a sizeable text corpus that keeps on growing every academic year. This analysis will enable us to carry out subsequent and more comprehensive studies on specific elements of the matter. Concepts like the internationalization of education (Wit & Altbach, 2021), the integration of technologies into a sustainable education system (Burbules et al., 2020) from an ethical perspective (Flores-Vivar & García-Peñalvo, 2022), or the challenges posed by the growing presence of artificial intelligence (Parreira et al., 2021) are creating new notions such as *Education 4.0* (Aziz, 2018; Keser & Semerci, 2019) that must become an integral part of teaching training (Rovira-Collado, 2020b). The reality of everyday life is something that has yet to be taken into account in the analysis of our corpus of narratives, as it may be an influencing influence factor. A technological innovation, an educational claim, or a world pandemic can suddenly and dramatically change the entire meaning of the stories. The integration of technology in education must be approached with a critical mindset, to accomplish things that could not be done otherwise (UNESCO, 2023), and we consider that this study is an example of that. After the digital transformation brought about by Covid-19 (Area-Moreira et al., 2020; Mesa Rave et al., 2023) we can revisit some of the stories to check whether some of the predictions did actually come true. Other stories will remain as simple science-fiction tales. Artificial intelligence tops the list of emerging technologies in 2023 (García Peñalvo et al., 2024), and it was already foreseen in science fiction of all times, both in optimistic and pessimistic ways. Finally, some other elements to be studied in these stories about the future are environmental challenges and sustainable development.

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Virtual Escape Rooms: a gamification tool to enhance motivation in distance education

Escape Rooms virtuales: una herramienta de gamificación para potenciar la motivación en la educación a distancia

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ABSTRACT

This study addresses the challenge of student demotivation in distance higher education and how it affects content assimilation. Moreover, it proposes an innovative solution through the application of the Attention, Interest, Desire, and Action (AIDA) model and the design and creation of a Virtual Escape Room, which focuses on the content of the International Trade subject. The AIDA model was implemented to capture students' attention, arouse their interest through challenges, maintain their desire to learn, and promote action in solving the necessary questions to advance to the next level and obtain a reward. To measure how respondents perceived this tool, a self-managed survey was launched at the end of the Escape Room, both to UCAM students and an external group of various nationalities via social media. The results show a significant increase in the commitment and motivation of the students, which translates into better content assimilation. The Virtual Escape Room proved to be an effective tool to increase students' interaction with study materials. The findings suggest that the application of the AIDA model in distance education can offer a revolutionary approach to teaching in higher education. The Virtual Escape Room, as a means to implement this model, demonstrates its potential in combating student demotivation and improving content assimilation.

Keywords: AIDA model; gamification; motivation; online learning; distance education; higher education.

RESUMEN

Este estudio aborda el desafío de la desmotivación del alumnado en la educación superior a distancia, y cómo afecta la asimilación de contenidos. Además, propone una solución innovadora a través del modelo de Atención, Interés, Deseo y Acción (AIDA) y la creación de una *Escape Room* Virtual. Se diseñó una *Escape Room* Virtual centrada en los contenidos de la asignatura Comercio Internacional. El modelo AIDA fue implementado con el fin de captar la atención de los estudiantes, despertar su interés a través de retos, mantener su deseo de aprender y promover la acción en la solución de las preguntas necesarias para pasar al siguiente nivel y obtener la recompensa. Para medir cómo los encuestados percibían esta herramienta se lanzó una encuesta autogestionada insertada al final de la *Escape Room*, tanto a alumnos de la UCAM como a un grupo externo de diversas nacionalidades a través de redes sociales. Los resultados muestran un incremento significativo en el compromiso y la motivación de los estudiantes, lo que se traduce en una mejor asimilación de los contenidos. La *Escape Room* Virtual resultó ser una herramienta eficaz para incrementar la interacción de los estudiantes con los materiales de estudio. Los hallazgos sugieren que la aplicación del modelo AIDA en la educación a distancia puede ofrecer un enfoque revolucionario para la enseñanza en la educación superior. La *Escape Room* Virtual, como medio para implementar este modelo, demuestra su potencial en la lucha contra la desmotivación del alumnado y la mejora en la asimilación de contenidos.

Palabras clave: modelo AIDA; gamificación; motivación; enseñanza online; enseñanza a distancia; educación superior.

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INTRODUCTION

In today's digital age, distance education has become an essential component of the global educational landscape (Pesántez et al., 2021). Increasing accessibility of the Internet and digital technologies have facilitated the expansion of education beyond the physical classroom, allowing students to learn at their own pace and in their own space. However, despite its advantages, distance education also poses unique challenges, especially in terms of student engagement and motivation (Trinidad, 2020). In this context, innovative teaching methods that can enhance the distance learning experience are of great interest to educators and researchers.

One such innovation is gamification, which involves the application of game elements in non-game contexts to increase motivation and engagement (Arufe et al., 2022). In education, gamification can take many forms, ranging from points systems and leaderboards to full games integrated into the curriculum. Virtual Escape Rooms are an example of the latter (Vergne et al., 2020). These games, which require players to solve a series of challenges to 'escape' from a virtual environment, can provide an active, student-centred learning experience that is very different from traditional forms of teaching (Streiner et al., 2019).

Despite the growing interest in virtual Escape Rooms and gamification in education, there is still much we do not know about how these strategies can be used effectively in distance education (Ouariachi & Wim, 2020). How do students perceive virtual Escape Rooms in a distance learning environment? How does participation in a virtual Escape Room affect student motivation and engagement? How can educators design and implement virtual Escape Rooms effectively in their distance education courses? These are some of the questions that this study aims to answer.

The aim of this study is to examine students' perceptions of gamification in distance education through the usage of virtual Escape Rooms. Specifically, we will use the AIDA model of sales, which refers to consumers' Attention, Interest, Desire, and Action, as a framework to analyse students' responses to the virtual Escape Room. Through this study, we hope to provide a greater understanding of how virtual Escape Rooms can be used to enhance the distance learning experience.

The remainder of this article is organised as follows: the next section provides a literature review on distance education, gamification and virtual Escape Rooms. This is followed by a description of the study methodology, including the sample selection, the design of the virtual Escape Room and the data collection instrument. Then, the results of the study are presented and discussed in the following sections. Finally, it concludes with a summary of the main findings and implications for practice and future research.

LITERATURE REVIEW

Research on distance education and gamification

Distance education has been the subject of much research in recent decades, especially with the rise of digital technologies that have facilitated its implementation and expansion. Studies have shown that distance education can offer a number of benefits, such as flexibility in terms of time and place, the possibility to learn at a

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personalised pace, and the opportunity to access resources and learning experiences that may not be available in a traditional classroom setting (Castro & Tumibay, 2021). However, a number of challenges have also been identified, such as a lack of face-to-face interaction, a sense of isolation, and the need for self-discipline and time management skills (Lee et al., 2022).

In this context, gamification has emerged as a potential strategy to enhance the distance learning experience. Educational gamification refers to the application of game elements in non-game contexts with the aim of increasing learner motivation and engagement (Castillo-Mora et al., 2022). In education, gamification can take various forms, from point systems and leaderboards to full games integrated into the curriculum. Research has shown that gamification can have positive effects on student motivation, engagement in learning, and academic performance (Manzano-León, Camacho-Lazarraga et al., 2021). Several authors have shown that gamification methodology has benefits such as the development of critical thinking, creativity, social skills, and improved problem-solving skills, among others, but to be truly effective, it must be properly planned and developed (Pacheco, 2019; Martina & Göksen, 2022).

Research on Escape Rooms in education

In the context of university distance education, teachers face the challenge of adapting to the profile of students, who are accustomed to new technologies and audiovisual formats. Therefore, it is essential to provide materials that are attractive and facilitate their teaching-learning process, while minimizing demotivation (Álvarez-López & Sampablo-Buezas, 2020; López & Ortega, 2020).

Virtual Escape Rooms are an example of gamification that has gained popularity in recent years. These games, which require players to solve a series of puzzles to "escape" from a virtual environment, can provide an active, student-centered learning experience. Studies have shown that virtual escape rooms can enhance student motivation, foster critical thinking, and improve problem-solving skills (Duggins, 2019; Makri et al., 2021).

Escape rooms, both in their face-to-face and virtual versions, have emerged as an innovative educational tool. However, it has been the virtual version that has experienced significant growth in recent years, largely driven by the Covid-19 pandemic (Salvador-Gómez et al., 2022; Manzano-León, Aguilar-Parra et al., 2021). According to López and Sánchez (2019), Universidad Rey Juan Carlos I pioneered the implementation of this virtual tool with their students in 2018. The results evidenced its usefulness as a motivational resource to reduce demotivation and assess collaborative work (Salvador-Gómez et al., 2022; Zarco et al., 2019). This student-centered approach and the integration of innovative digital technologies are key aspects to improving the learning experience in distance higher education.

Zarco et al., (2019) and Segura-Robles and Parra-González (2019) highlight several key elements for the effective design of an educational Escape Room. These include the consideration of time, which should be divided into three distinct phases (before, during and after the game); the difficulty of the activities, which should be balanced to suit the level of the players; the learning objectives, which should be established beforehand and evaluated afterwards; the theme and space, which should be adapted to motivate the participants; the riddles, which are the core of the game and should be engaging and creative; the technology and materials, which can enhance the experience if used appropriately; the assessment, which provides feedback on learners' progress; and the rehearsal, which should be conducted at least once before starting the game. Cordero (2018) adds that the success of the Escape Room depends on the initial cognitive shock and conflict that occurs in the learner's mind, which underlines the importance of designing an attractive and novel game start.

On the other hand, authors such as Salvador-Gómez et al., (2022); López-Pernas et al. (2019) and Gordillo et al., (2020) establish a series of stages and requirements for its correct development: in the first stage, the objectives and competencies to be addressed with the test are selected. In the second stage, the argumentative thread is developed. Taking into account the characteristics of the course and the students, the scenario, the story and the riddles must be correctly designed so that they connect with the students. Thirdly, general aspects are specified, such as whether the activity will be played in groups or individually, through which platform and which devices, the specific materials they will need to solve the riddles, and whether it will be carried out with or without monitoring, among other aspects. Fourthly, the best software to develop the application must be selected. Among the different tools available on the market, the most appropriate one must be selected, for example, Google, Google Forms, BreakEdu or Genially. Fifth, the challenges are chosen and constructed. The riddles must be balanced to the level of the players and the selection of the sequence to solve them is crucial. There are three main types of sequences: linear, open-ended and hybrid. In the linear sequence, the challenges follow a specific order, where the solution of each challenge unlocks the next one until the final solution is reached. This type of sequence may be suitable for the educational context, as it encourages teamwork. In the open-ended sequence, there is no specific order and students can tackle the challenges in any order they see fit. Finally, the hybrid sequence combines elements of both, with some challenges needing to be unlocked through smaller challenges, but without a specific order for the final resolution (Salvador-Gómez et al., 2022). Sixth, thought must be given to the construction of clues to prevent students from becoming demotivated and abandoning the game because they are unable to go through the riddles. When designing them, it will be decided whether they are internal or external clues and also how to design penalty mechanisms to prevent them from overusing clues. In the seventh stage, the immersion scenario is developed, seeking to make it attractive and to connect with the interests and preferences of the students. In the eighth stage, the instructions that will be necessary to work on the challenges are detailed. And in the ninth stage, the Escape Room is tested to correct possible failures during its implementation.

Research on AIDA model in education

The AIDA model, which refers to the Attention, Interest, Desire, and Action of consumers, has been widely used in the marketing field to analyze consumer responses to products and services (Kulkarni et al., 2020). However, its application in education is relatively new. Some studies have begun to explore how the AIDA model can be used to analyze student responses to teaching and learning strategies, although only at a theoretical level and as a method to explain training choices (Shala, 2020; Polk, 2018).

The design of Escape Rooms should be planned to maximize these benefits, so it is considered necessary to follow specific guidelines. In this sense, looking for a methodology that facilitates this planning could ensure that the virtual Escape Room allows the obtaining of these benefits. Accordingly, the AIDA model could be useful both for planning and for its own assessment.

The AIDA model has been used as a marketing tool to develop effective communication strategies for the sale of goods and services. This model proposes that consumers respond to marketing messages following cognitive (interest), affective (desire) and conative (action) sequences, so first it is necessary to capture their attention and then to maintain their interest in order to create a desire which finally leads them to purchase actions.

The first step in the cognitive hierarchy is focused on finding ways to attract and retain the consumer's attention, using striking images, colors, shapes and attractive characters. If this phase is done properly, the potential buyer will want to know more. But attention alone will not lead to sales. This attention must be maintained to generate interest in the product. Demonstrations, explanations and information conveyed to the buyer are important in this phase. Next, desire must be generated. To do this, it is very important to know how to connect the buyer's interests and needs with the product's features. Finally, for the process to be complete, potential buyers or consumers must be motivated to make the purchase. In this phase, emphasis is placed on the benefits to be obtained by the buyer and a sense of urgency is generated by offering discounts, prizes and other promotional strategies.

These identified phases of the AIDA model can be used to design an active teaching-learning tool (Polk, 2018), such as, for example, an Escape Room:

1. Once the learning objectives and competencies to be addressed have been chosen, creating an engaging story can serve as bait to capture the learners' interest and achieve an immersive experience. The use of engaging visual and auditory resources will capture the learner's attention, and the use of a stimulating story and context will maintain interest in following the process. This means that, in addition, the duration of the activity, the place of development, the materials needed, the software, the formats and the function within the course have been clearly delimited (Gómez et al., 2022).
2. To generate interest, the student must have all of the above and the necessary information for the successful fulfilment of this activity. The instructions and game rules are very important in this phase since, if the student does not understand how it works or does not have the resources to succeed, they will become demotivated.
3. In the affective stage, desire, the challenges and their difficulty must be well selected. It is important that their sequence allows the achievement of the learning objectives, but also stimulates the learner to continue with the activity until its completion. A major difficulty can lead to demotivation, but this is also the case if the challenges are too easy. Increasing difficulty in the challenges can be attractive if accompanied by additional clues when the learner stalls or by the possibility of returning to an unsuccessful previous challenge.
4. Finally, in order to get the learner to perform the activity and thus achieve the established objectives, it is very important to correctly establish the rewards of the

game. Students must know how the performance of the activity will affect their assessment in order to promote their action.

Another benefit of this model is that it also allows for the evaluation of satisfaction with the actual resource (Manafe & Pramita, 2022; Polk, 2018), as a questionnaire can be created based on the objectives to be achieved in each phase described in the model.

Despite the growing research in these areas, there are still gaps in the literature that this study aims to fill. In particular, there is a lack of research on how virtual Escape Rooms are perceived by students in a distance learning environment and how these perceptions can be analysed using the AIDA model. Furthermore, although gamification has been studied in the context of distance education, most studies have focused on more general gamification strategies, such as point systems and leaderboards, and there is a lack of research on the application of whole games, such as virtual Escape Rooms, in this context. This study aims to fill these gaps by providing an in-depth exploration of students' perceptions of virtual Escape Rooms in distance education and using the AIDA model as a framework for analysis.

In summary, the existing literature provides a strong foundation for research on distance education, gamification and virtual escape rooms. However, there is still much we do not know about how these strategies can be used effectively in distance education. This study aims to contribute to the existing literature by providing a greater understanding of how virtual Escape Rooms can be used to enhance the distance learning experience.

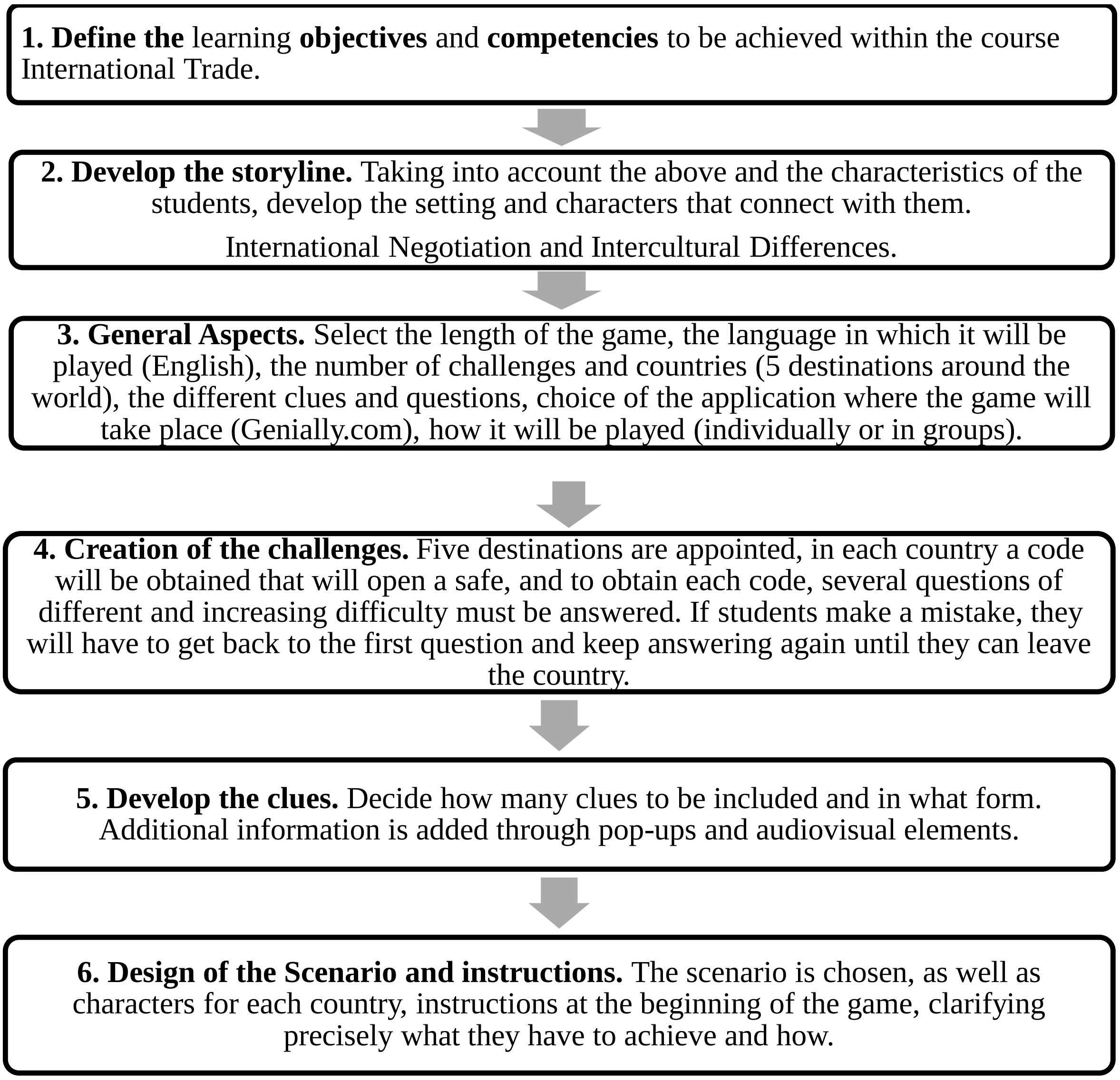
METHODOLOGY

Our research adopts a mixed methodological approach, combining quantitative and qualitative elements, to explore the effectiveness of Escape Rooms as a learning tool in distance higher education (Creamer, 2018; Shannon-Baker, 2015). This approach, which has proven effective in higher education research (Stupnisky et al., 2014; Vogelsang et al., 2020), allows for a richer and more nuanced understanding of the learning experience, combining the objectivity of quantitative data with the depth of qualitative data (McCrudden et al., 2019; Tobi & Kampen, 2018; Gobble, 2018). For the quantitative approach, numerical data were collected and analysed through surveys and statistical analysis. For the qualitative approach, direct observations were conducted and textual data were collected through interviews and group discussions.

The study was divided into two phases. In the first phase, the material was prepared and the Escape Room was created based on the experience of Salvador-Gómez et al. (2022). In terms of course typology, the methodology is especially relevant in those that have a complex and multidimensional nature, in this case the study focused on intercultural differences between countries when negotiating. To this end, an exhaustive literature review was carried out to document the behaviour of certain countries, avoiding hackneyed clichés. Finally, five countries were selected: Mexico, Brazil, Spain, Saudi Arabia and Japan, for their peculiarities and exoticism. The choice of these destinations is justified because they represent a wide range of cultures and traditions, providing a rich context for exploring intercultural differences in negotiation. This cultural diversity can help students develop a greater awareness and understanding of cultural differences, which is essential in an increasingly globalised world. In addition, these countries also offer a good geographical representation, covering North America, South America, Europe, the Middle East and Asia. This broad geographical representation can help students develop a more global perspective and better understand the differences and similarities between different regions of the world. In summary, the inclusion of these five countries in the Escape Room is justified by their cultural diversity, relevance to distance higher education, quirks and exoticism, and geographical representation. For each destination, interactive questions and clues were designed, allowing students to interact with various audio-visual elements. This student-centred design fostered active and autonomous learning. Figure 1 below details the process of creating the Escape Room and the different phases into which it was divided.

Figure 1

Stages in the development of the Escape Room



Source: compiled by authors based on Salvador-Gómez et al. (2022, pp. 17-19).

Once the Escape Room was created, it was tested with a control group of 20 students, from the Master's Degree in International Negotiation from the University of Avignon, with different nationalities, during the 2022-23 academic year. Throughout this phase, a direct observation was carried out, where interaction among students and their collaboration with each other to solve the questions were analyzed. Based on this observation, their comments were collected to improve the learning experience, noting down the following points: number of codes obtained, time to complete the game and relevance of teamwork for the achievement of the objectives. Students also participated in a self-assessment process, reflecting on their own learning and performance after completing the Escape Room. This feedback was used to improve the implementation in the subsequent phase.

The second stage consisted of improving the Escape Room based on the information obtained through the analysis developed in Avignon and its translation into Spanish, thus generating two Escape Rooms. A single questionnaire was created in English and Spanish through Google Forms, to collect student feedback on the experience, and enclosed in the virtual Escape Rooms developed with Genially. Finally, we disseminated these Escape Rooms through the students' virtual campus of the Catholic University of Murcia, within the Marketing and Business area in the 2022-23 academic year and to an external control group.

The virtual Escape Room was designed using an application called Genially (Jiménez et al., 2020), promoting active and student-centered learning. Participants had to travel to 5 countries and solve 3 questions in each destination; also, within the Escape Room clues were included through dropdowns. If the player made a mistake, the game would return to the starting point of the previously selected destination, until the correct answer was provided, and consequently obtaining one of the necessary codes that would allow them to open the safe. Once the code was obtained, the player could then travel to the next destination. Finally, the student who obtained all the codes from the 5 destinations and placed them in the correct order could open the safe and finally complete the survey.

To collect the data, we used two surveys designed to measure Attention, Interest, Desire, and Action (AIDA), one for the students and one for the control group, both based on the survey conducted by Wei and Lu (2013). The items corresponding to the AIDA model, in five-point Likert format, were 12 in total, three for each phase of the model, to which a section called "Outcomes" was added, assessing their experience with the game. The difference between the questionnaires for students within the study and the control group is due to the control questions, since we needed more sociodemographic data from the control group, as it was randomly created through responses on Social Networks.

In the sample, therefore, there are responses from very different geographical areas. The majority, 57%, come from Spain (mainly due to the group of university students), but 30.7% are from Latin America, 5% are of other European nationalities (French, Dutch, Italian) and the remaining 7.1% come from Asia, Africa or the USA. The majority of respondents are between 18 and 23 years old (70%), so they are digital natives. Regarding the education of the respondents, most of them currently study for higher education degrees (70.3%), 16.4% have an undergraduate or vocational training certificate and 13.3% have a postgraduate degree.

To process and analyze the information collected, we used Excel and IBM SPSS statistical software for Microsoft V.23. Our analysis focused on understanding how students interact with a virtual Escape Room and how it can be used as a learning tool. This approach allowed us to collect both quantitative and qualitative data, providing a complete picture of the effectiveness of our methodology.

To process the quantitative data: first, the psychometric properties of the measurement scales of the AIDA model are tested (reliability in terms of internal consistency through Cronbach's Alpha coefficient and its dimensionality through principal component analysis). Next, the average variables of each of the components of the model are constructed and descriptive statistics are calculated. Finally, mean difference tests are performed, taking into account whether or not there is normality of the variables, according to gender, age and type of education.

To measure the effectiveness of the Escape Room, we aim to check the usefulness of this activity in improving the teaching-learning process in the future. This will be done by comparing the results obtained by the students in the mid-term exam, prior to the Escape Room, and the final exam; thus, measuring whether the experience has facilitated the assimilation of content. In order to anticipate the possible results of this part of the process, given that it was necessary to wait for the final exam, it was decided to include in the questionnaire a section about results, where the students expressed their opinion on their experience of use.

RESULTS

This section describes the results obtained from the empirical study carried out through the survey distributed among the Escape Room participants, as described above in the methodology.

With regard to the measurement scales of the AIDA model, the following results were obtained as shown in Table 1.

Table 1

Validation of the measurement scales of the AIDA model

Variables	Properties of the scale
Attention	Cronbach's Alpha = 0.935 Factorial = 1 factor Variance explained = 88.511% Sig. Bartlett = 0.000 KMO = 0.763
Interest	Cronbach's Alpha = 0.940 Factorial = 1 factor Variance explained = 86.350% Sig. Bartlett = 0.000 KMO = 0.765
Desire	Cronbach's Alpha = 0.897 Factorial = 1 factor Variance explained = 82.994% Sig. Bartlett = 0.000 KMO = 0.728

Variables	Properties of the scale
Action	Cronbach's Alpha = 0.928 Factorial = 1 factor Variance explained = 87.450% Sig. Bartlett = 0.000 KMO = 0.760

Source: prepared by authors.

As shown in Table 1, all the scales meet the requirements: alphas above 0.7, recommended for exploratory studies (Nunnaly, 1967; Hair et al. 2006). In addition, the concept validity, performed by means of principal component factor analysis, yields very good results; namely, unidimensionality of the three composite scales of the AIDA model; low determinant of the correlation matrix; Bartlett's test of sphericity with significance under 0.05; KMO (Kaiser-Meyer-Olkin Index) over or equal to 0.50; and diagonal of the anti-image correlation matrix with values greater than 0.5 (Pérez & Medrano, 2010).

Below we show the descriptive results of the variables that integrate the AIDA model, both of its individual items and of the global variable (Table 2).

Table 2

Descriptive statistics

	N	Minimum	Maximum	Mean	Standard deviation
A1	98	1.00	5.00	4.1735	.97416
A2	98	1.00	5.00	4.0204	1.08390
A3	98	1.00	5.00	4.1224	1.03809
ATTENTION	98	1.00	5.00	4.1054	.97106
I1	98	1.00	5.00	4.1224	.99758
I2	98	1.00	5.00	4.1531	.94544
I3	98	1.00	5.00	4.1122	.99362
INTEREST	98	1.00	5.00	4.1293	.92519
D1	98	1.00	5.00	4.1735	.90844
D2	98	1.00	5.00	4.2551	.86527
D3	98	1.00	5.00	4.2449	.88587
DESIRE	98	1.33	5.00	4.2245	.80772
AC1	98	1.00	5.00	4.2449	.88587
AC2	98	1.00	5.00	4.0816	1.02216
AC3	98	1.00	5.00	4.1429	1.03545
ACTION	98	1.00	5.00	4.1565	.91719
N valid (according to list)	98				

Source: prepared by authors.

As can be seen in Table 3, the results are very favorable. In all individual items, as well as in the global scales, the mean is higher than 4 and there are no very large standard deviations. This means that most of the respondents have shown great attention in the activity (mean = 4.1054; Dev. = .97106); great interest (mean = 4.1293; Dev. = .92519); great desire (mean = 4.2245; Dev. = .88587) and very positive action (mean = 4.1565; Dev. = .91719).

Next, the difference in means was calculated as a function of the independent variables, i.e., gender, age, and type of studies. Results are shown in the following tables (Tables 3 to 6). Since the dependent variables do not show a normal distribution (according to the Kolmogorow-Smirnov test), nonparametric tests were used: the Mann Whitney U test in the case of comparing two groups and the Kruskal-Wallis test in the case of comparing three or more groups.

In the sample, composed of 34 men and 64 women, descriptive statistics show that attention varies between men and women. Specifically, women show an average range of attention of 53.80, while men show an average range of 41.40. The Mann-Whitney U test yields a U value of 812.500 and a Z value of -2.116, with a significance of 0.034 (Table 3). This indicates that there is some statistically significant difference in attention between males and females, which supports the descriptive observation. As for interest, some differences between men and women can also be seen, as reflected in Table 3, where the significance is 0.006 in the Mann-Whitney U test. In the case of desire and action, on the other hand, no significant differences are found.

Table 3

Mann-Whitney U test – Gender-AIDA

Grouping variable: GENDER	ATTENTION	INTEREST	DESIRE	ACTION
Mann-Whitney U	812.500	729.000	841.000	942.500
Wilcoxon W	1407.500	1324.000	1436.000	1537.500
Z	-2.116	-2.764	-1.900	-1.121
Asymptotic Sig. (2-sided)	.034	.006	.057	.262

Source: prepared by authors.

44% percent of the respondents are aged 21 years or younger, 44% are between 29 and 34 years old, and the rest are older than 35 years old. The average ranges of attention vary from 43.25 to 69.65, indicating that there is some variation in attention to virtual Escape Rooms among different age groups. The Kruskal-Wallis test yields a Chi-square value of 6.563 with 4 degrees of freedom and a significance of 0.161, indicating that such differences are not statistically significant in attention among the different age groups (Table 4). The same applies for interest, desire and action.

Table 4

Chi Square- Age-AIDA

Grouping variable: AGE	ATTENTION	INTEREST	DESIRE	ACTION
Chi square	6.563	8.601	7.096	10.424
d.f.	4	4	4	4
Asymptotic Sig.	.161	.072	.131	.034

Source: prepared by authors.

Regarding the type of training, 15.3% of the respondents have followed or are following some type of online training, while 84.7% have received it face-to-face. In this case, no significant differences are observed between the two groups in either case (Table 5).

Table 5

Mann-Whitney U test – Type of training-AIDA

Grouping variable: TYPE OF TRAINING	ATTENTION	INTEREST	DESIRE	ACTION
Mann-Whitney U	431.500	529.000	499.500	526.500
Wilcoxon W	3917.500	4015.000	3985.500	4012.500
Z	-1.940	-.952	-1.251	-.978
Asymptotic Sig. (2-sided)	.052	.341	.211	.328
Exact Sig. (2-sided)	.052	.346	.214	.333
Exact Sig. (1-sided)	.025	.173	.107	.168
Point probability	.000	.001	.001	.004

Source: prepared by authors.

As already mentioned, the total sample is integrated by the respondents of the survey carried out on the UCAM students and another control sample made up of those who responded through social networks in a totally online manner. By comparing means, it can be seen that the distribution of the factors of Attention, Interest, Desire and Action is the same between the two groups (Table 6).

Table 6

Mann-Whitney U test – Groups (face-to-face, distance)-AIDA

Null hypothesis	Test	Sig.
The distribution of ATTENTION is the same in the 2 groups.	Mann-Whitney U test	.097
The distribution of INTEREST is the same in the 2 groups.	Mann-Whitney U test	.066
The distribution of DESIRE is the same in the 2 groups.	Mann-Whitney U test	.107
The distribution of ACTION is the same in the 2 groups.	Mann-Whitney U test	.115

Source: prepared by authors.

Therefore, it seems reasonable to conclude that virtual Escape Rooms are an attractive and versatile learning tool that can be effective in engaging a broad typology of learners. These findings provide strong support for the use of virtual Escape Rooms in distance education.

Finally, from the qualitative analysis conducted with the students and control group, the following emerged: first, the majority managed to successfully complete the Escape Rooms by getting all 5 codes of the game. Secondly, the majority of the respondents were of the opinion that the time to complete the activity was sufficient and all of them emphasized that working in a team was a help/advantage to successfully complete the game. And thirdly, all agree that it is a useful tool for online teaching, which is interesting, since 40.8% of the respondents have followed or are following some type of online training.

DISCUSSION

This paper contributes to the existing literature on gamification in distance education, specifically through the implementation of virtual Escape Rooms. Findings support the increasing evidence that gamification strategies can improve student motivation and engagement, as claimed by authors such as Manzano-León, Camacho-Lazarraga et al. (2021) and Hamari et al. (2016).

The results of this study provide valuable insight into how students perceive virtual Escape Rooms in a distance learning environment. The use of robust statistical techniques, including testing the psychometric properties of the measurement scales and conducting Mann-Whitney and Kruskal-Wallis U-tests, reinforces the validity of the findings (McCrudden et al., 2019).

In addition, the Escape Room design process is presented, additionally disclosing how it was improved through feedback from Avignon students. As Salvador-Gomez et al. (2022) and Deterding et al. (2011) have pointed out, the effectiveness of gamification is highly dependent on its proper planning and development.

Overall, results indicate that most students find virtual Escape Rooms motivating, which is in line with available literature suggesting that gamification can improve student motivation and engagement (Hanus & Fox, 2015).

These findings have important implications for educational practice and distance education theory. In practical terms, they suggest that virtual Escape Rooms can be an effective tool for enhancing motivation and the learning experience in distance education. Educators may consider incorporating virtual Escape Rooms into their distance education courses to provide a more active and student-centered learning experience (Area-Moreira, 2018).

However, as Ouariachi and Wim (2020) and Kapp (2012) have pointed out, there is still much we do not know about how these strategies can be used effectively in distance education. Therefore, more research is needed to explore how virtual Escape Rooms can be optimally designed and implemented in different educational contexts.

For future research, it would be useful to replicate this study with a larger and more diverse sample of students. It would also be interesting to further explore how different elements of virtual Escape Rooms (e.g., riddle difficulty, room theme) may affect student motivation and engagement. In addition, longitudinal studies could be conducted to examine the long-term effects of virtual Escape Rooms on motivation and performance of distance learners.

In theoretical terms, these results contribute to our understanding of how gamification strategies can be used in distance education. In particular, they provide empirical evidence of the applicability of the AIDA model in this context, which is an area that has received little attention in the existing literature (Shala, 2020; Polk, 2018).

Our findings adhere to the widening literature on gamification in distance education. Although we found no significant differences in interest according to age and type of instruction, this does not mean that virtual Escape Rooms are ineffective as a learning tool. In fact, our findings suggest that virtual Escape Rooms can be equally engaging for a broad typology of learners, making them a versatile and accessible learning tool. These are in line with previous studies that have found that gamification can improve student motivation and engagement in distance education (Castillo-Mora et al., 2022; Manzano-León, Aguilar-Parra et al., 2021; Zichermann & Cunningham, 2011; Hanus & Fox, 2015).

However, not everything is advantageous in the usage of Escape Room. The use of this tool can involve a great investment of time for the teacher (Markopoulus et al. 2015), so it would also be necessary to analyze the cost-benefit that its use entails for the development of the teaching-learning process.

CONCLUSIONS

In summary, this study found that most students perceive virtual Escape Rooms as a motivating activity in a distance learning environment. These findings support the existing literature on gamification in education and provide additional evidence of the applicability of the AIDA model in this context.

The studies conducted revealed relevant findings. In terms of interest according to age and type of instruction, we found no significant differences. This suggests that age and type of training do not influence students' interest in virtual Escape Rooms. In practical terms, this means that virtual Escape Rooms can be equally appealing to students of different ages and types of instruction.

This study contributes to the existing literature by exploring an area that has so far received little attention: the application of the AIDA model in distance higher education. Through this study, we have demonstrated that virtual Escape Rooms can be an effective tool to enhance student motivation in distance education.

Finally, we recommend educators consider incorporating virtual Escape Rooms into their distance education courses. We also urge researchers to continue to explore this area and to deepen our understanding of how gamification strategies can be used effectively in distance education.

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ANNEX

Figure 1
Front page of the Escape Room in Spanish and English

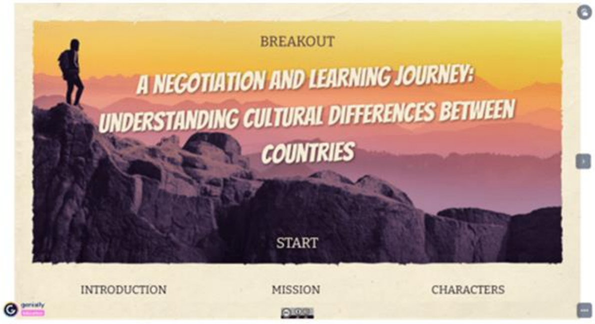

Figure 2
Missions to be completed by the students in order to get the code for the safe

Figure 3
Introduction to the destination Mexico in English

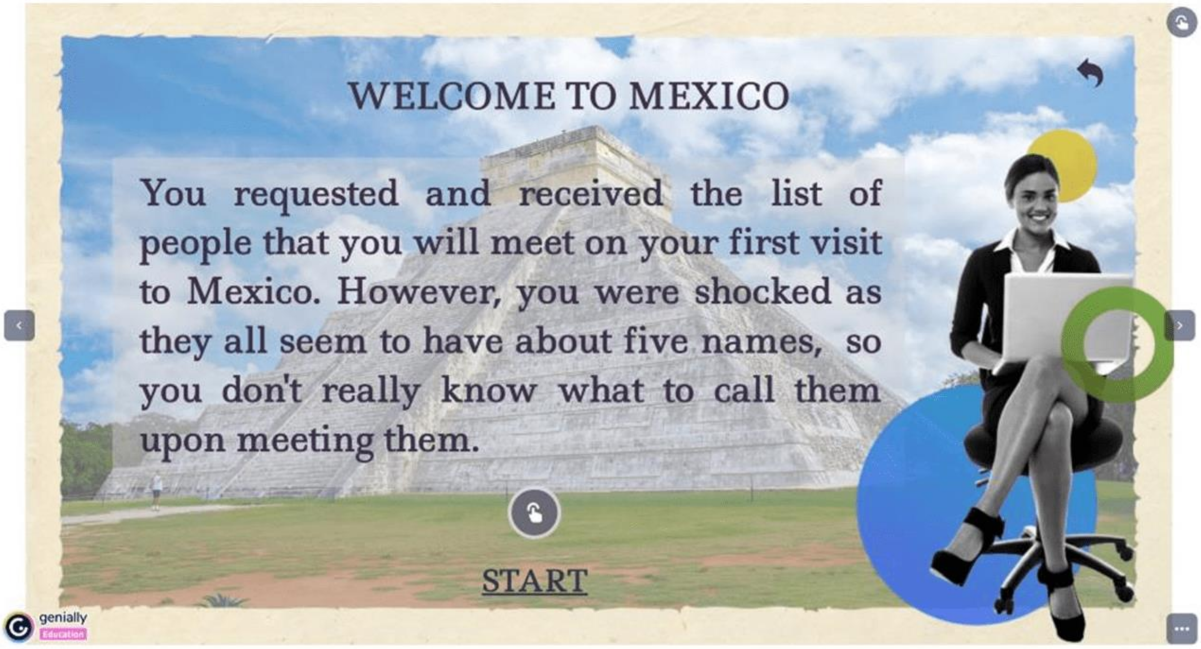

Figure 4
Question from the destination Brazil in Spanish

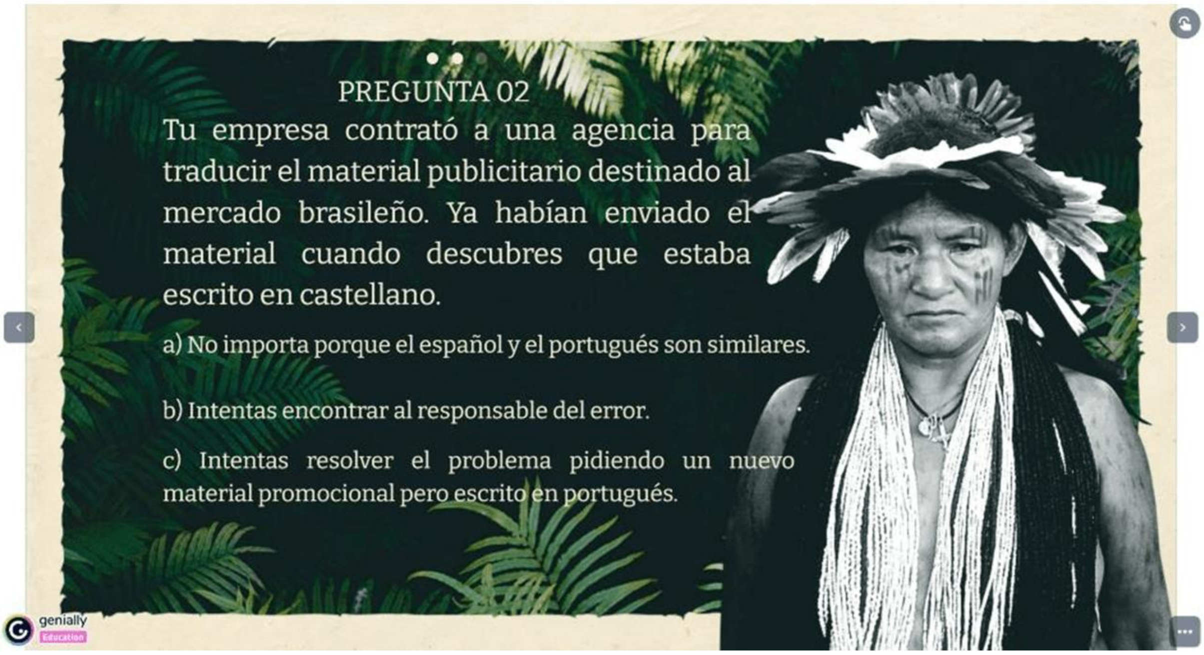

Figure 5
Achievement of the code after fulfilling the challenges of the destination

Figure 6
Safe

Date of reception: 1 June 2023
Date of acceptance: 22 August 2023
Date of approval for layout: 1 September 2023
Date of publication in OnlineFirst: 20 September 2023
Date of publication: 1 January 2024

Pedagogy Wheel for Artificial Intelligence: adaptation of Carrington's Wheel

Rueda de la Pedagogía para la Inteligencia Artificial: adaptación de la Rueda de Carrington

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ABSTRACT

The effective integration of Artificial Intelligence (AI) in education is necessary to harness its benefits in the teaching and learning process. This article proposes the adaptation of Carrington's Pedagogy Wheel into an AI Pedagogy Wheel, aiming to provide a pedagogical framework for integrating AI in education. The research methodology employed is based on a systematic review and mapping, coupled with a bibliometric study of term co-occurrence analysis, to identify relevant thematic clusters that scientifically support the need for the adaptation of the Wheel. The new wheel addresses the four obtained clusters (Integration of AI to enhance education, Use of educational technologies in the teaching and learning process, Pedagogical design and innovation, and Sustainable and Ethical Education) and presents concentric rings that explain how to gradually incorporate AI across different cognitive levels (Bloom's Taxonomy) and technological integration (SAMR Model), both adapted for AI. The wheel includes examples of tools and applications to illustrate the implementation. Furthermore, a Reflective-Metacognitive level is included that addresses ethics and responsibility in the use of AI. In conclusion, the wheel adapted to AI is a viable option to enhance the effectiveness and efficiency of education, provided that educators engage in the planning and execution of the teaching and learning process to ensure its success. It is worth mentioning the importance of keeping the wheel updated due to the constant emergence of new applications.

Keywords: artificial intelligence; disruptive technologies; Carrington's Wheel; Bloom's taxonomy; SAMR model.

RESUMEN

La integración efectiva de la Inteligencia Artificial (IA) en la educación es necesaria para aprovechar sus beneficios en el proceso de enseñanza-aprendizaje. Este artículo propone la adaptación de la Rueda de la Pedagogía de Carrington a una Rueda de la Pedagogía para la IA, con el fin de ofrecer un marco pedagógico para integrar la IA en la educación. La metodología de investigación utilizada se basa en una revisión y mapeo sistemático junto a un estudio bibliométrico del análisis de co-ocurrencia de términos para identificar los clusters temáticos relevantes que respalden científicamente la necesidad de la adaptación de la Rueda. La nueva rueda atiende a los cuatro clusters obtenidos (Integración de la IA para mejorar la educación, Uso de tecnologías educativa en el proceso de enseñanza y aprendizaje, Diseño e innovación pedagógica y Educación Sostenible y Ética) y presenta anillos concéntricos que explican cómo incorporar gradualmente la IA en diferentes niveles cognitivos (Taxonomía de Bloom) e integración tecnológica (Modelo SAMR) ambos adaptados a la IA, con ejemplos de herramientas y aplicaciones. Además, se incluye un nivel Reflexivo-Metacognitivo que aborda la ética y responsabilidad en el uso de la IA. En conclusión, la rueda adaptada a la IA es una opción viable para mejorar la eficacia y eficiencia de la educación, con la condición de que los docentes participen en la planificación y ejecución del proceso de enseñanza y aprendizaje para garantizar su éxito. Cabe mencionar la importancia de mantener la rueda actualizada debido a la aparición constante de nuevas aplicaciones.

Palabras clave: inteligencia artificial; tecnologías disruptivas; Rueda de Carrington; taxonomía de Bloom; modelo SAMR.

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INTRODUCTION

In recent years, technology has transformed the way in which modern-day teaching and learning takes place. Nevertheless, education has evolved to incorporate an emerging disruptive technology: Artificial Intelligence (hereinafter 'AI'), understood as 'a field of study that combines the applications of machine learning, algorithm productions, and natural language processing' (Akgun & Greenhow, 2022, p.1). It is, therefore, crucial to adapt to these changes in the field of education and consider how we can effectively integrate AI in education. A clear example of AI inclusion is that which is sparked by ChatGPT (Cooper, 2023; Duha, 2023); recent studies suggest that the proper use of such a tool could boost teaching and learning (Baidoo-Anu & Owusu, 2023; Skavronskaya et al., 2023).

In line with Huang et al. (2021), AI technology has the potential to improve students' cognitive ability and learning, as well as the efficiency of the teaching and learning process. It is therefore essential to effectively consider AI integration in education in order to leverage its transforming power with regard to improving the quality of education and student development.

At present, AI integration in education is regarded as a highly relevant tool for improving the learning process, given its ability to personalise teaching and learning, provide automated feedback and offer more objective, accurate assessments (Castaneda, 2023). According to Chen et al. (2020), AI could revolutionise the education sector by providing new opportunities for personalised learning, student assessment and educational research.

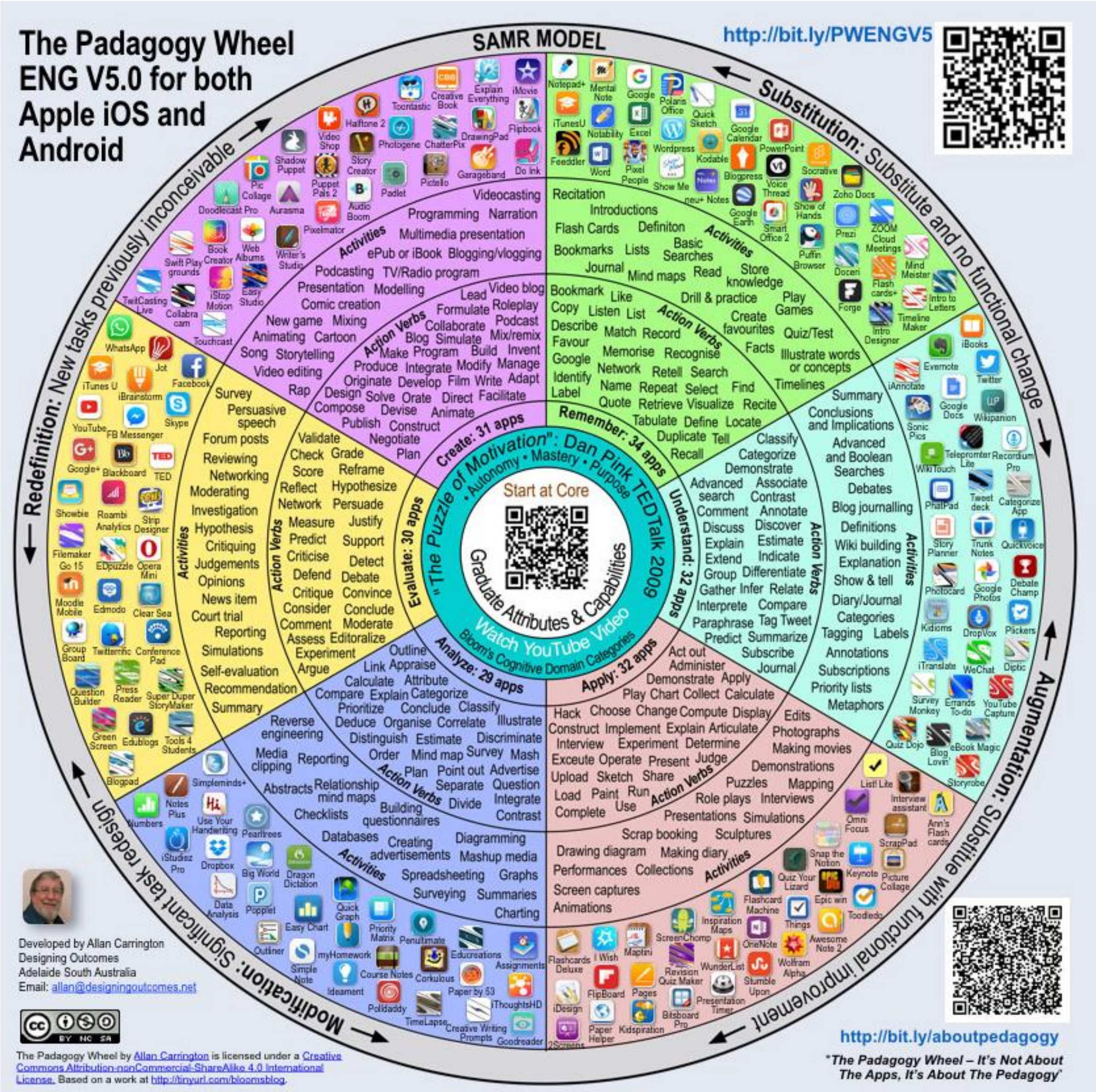
It is fundamental to highlight that, although AI offers many opportunities for education, it is not a blanket solution for all educational issues. Therefore, it is essential for it to be used consciously and reflectively in line with the educational context in question, in order to make the most of its potential benefits. Accordingly, it is necessary to reflect critically and thoroughly in order to ensure the effective and responsible use of AI in education. In this regard, teachers play a fundamental role in the integration of AI in education. Celik (2023) suggests that teachers should have specific knowledge of AI-related technology and pedagogy in order for it to be effectively integrated in education. They should also have an understanding of ethics to assess AI-based decisions and ensure they use it responsibly and fairly.

This idea has already been developed by Carrington (2016) through his Pedagogy Wheel (Padagogy Wheel) for technology integration, a tool he designed to help teachers integrate technology in their pedagogical practice, with a focus on pedagogy as opposed to technological applications. The reason this wheel works as a tool for improving the design and assessment of student-centred learning is because all the sections of the wheel are interconnected, thus indicating that learning is not a linear process, but rather a process in constant evolution (Carrington, 2015).

In this regard, Allan Carrington's Pedagogy Wheel features several concentric rings: 1) a central ring featuring the six cognitive levels of Bloom's Taxonomy, 2) a subsequent ring with the four levels of technology integration according to the SAMR Model and 3) outer rings containing examples of technology tools and apps that may be used for each cognitive and technology integration level.

Based on these ideas, the Pedagogy Wheel proposed by Carrington (2017) combines the two theoretical frameworks mentioned above (Bloom's Taxonomy and SAMR Model) in a visual representation (see Figure 1) that allows for the selection of appropriate technology tools and strategies for each level of cognitive skill and technology integration.

Figure 1
Pedagogy Wheel v5



Source: Carrington (2016). https://designingoutcomes.com/english-speaking-world-v5-0/

Allan Carrington's Pedagogy Wheel has proven to be an effective tool for improving the quality of teaching (Zhang et al., 2018) and learning (Matta et al., 2016) in the context of technology. However, the wheel does not consider AI as a technology that can be integrated in teaching and learning.

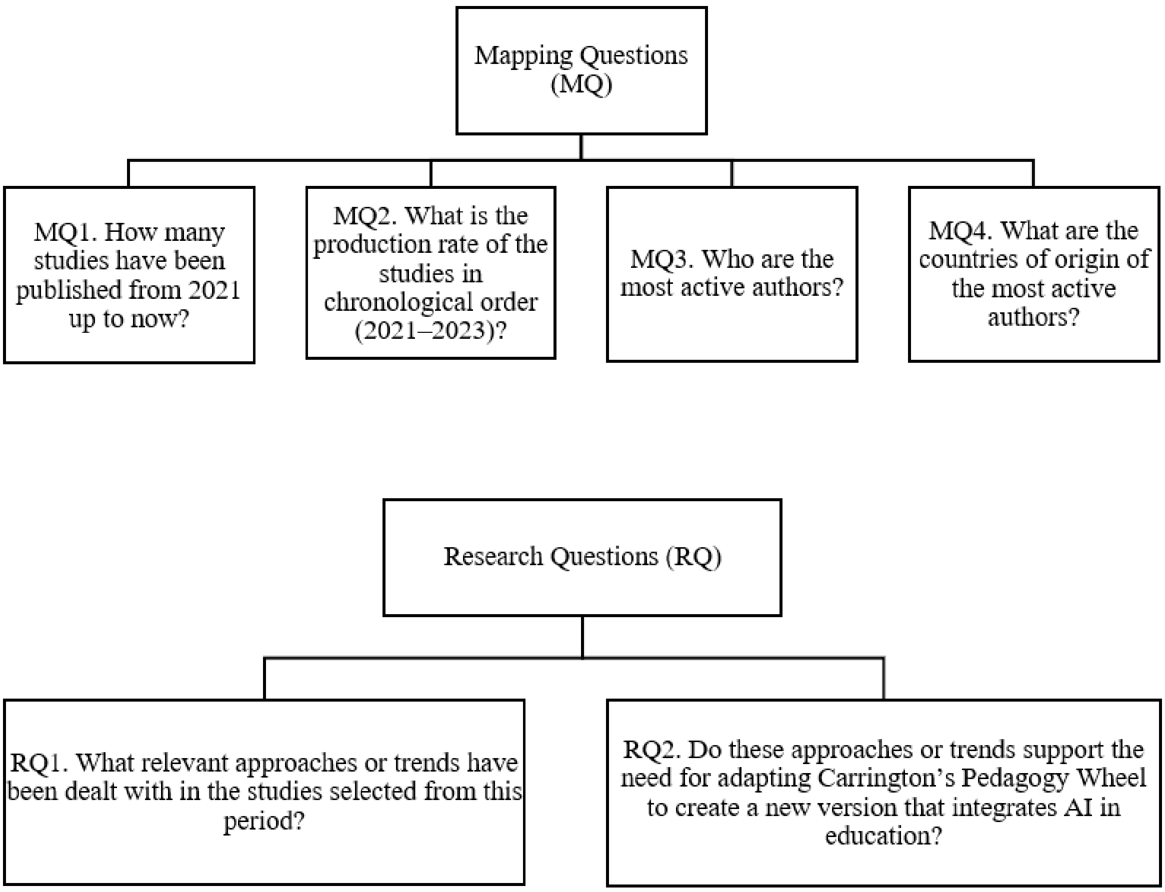
Therefore, in light of the changes being triggered by AI in the field of education, this study proposes an adaptation of Allan Carrington's Pedagogy Wheel (2017) in the form of a new AI Pedagogy Wheel that allows for the effective AI integration in education at all stages. This proposal is based on the premise that AI has the potential to substantially transform and improve education, so long as it is used in a responsible and conscious manner (Wiley, 2023). For this reason, the creation of an AI Pedagogy Wheel, as adapted from Allan Carrington's original model, is crucial in order to harness the benefits of this emerging technology in the teaching and learning process, as it facilitates the selection of appropriate technological AI tools and strategies for each level of cognitive skill and AI technology integration. The aim is to create a more personalised, interactive and effective educational environment in line with the needs and expectations of students in today's digital and technological era.

METHODOLOGY

To ensure scientific rigour in the article and justify the need for the adapted AI Pedagogy Wheel, a research method based on a systematic mapping review was followed in order to answer the following mapping questions (MQ), together with a bibliometric study involving co-occurrence analysis of terms in order to answer the following research questions (RQ) shown in Figure 2.

Figure 2

Mapping Questions (MQ) and Research Questions (RQ)



Source: own elaboration.

A systematic review of the literature was carried out in line with the guidelines set out in the PRISMA Statement. An exhaustive search of academic databases (Web of Science/WoS and Scopus) was conducted using the following search phrase: 'artificial intelligence' AND 'education' AND 'integration' AND 'learning', taking into account the title, summary, author keywords and KeyWords Plus. The studies were collected selected according to the eligibility criteria shown in Table 1:

Table 1
Eligibility criteria for studies

Reasons	Search	Inclusion criteria	Excluded works	
			WoS	**Scopus**
1	Date of publication		98	420
2	Language	English and Spanish	4	12
3	Type of document	Research articles	48	240
4	Type of publication	Full-text articles published in peer-reviewed journals	39	55
5	Subject Area	Educational Research/ Social Sciences	73	91

Source: own elaboration.

Out of the 280 articles found on WoS, 262 were excluded following the application of the relevant filters, leaving 18 articles to be analysed. Meanwhile, of the 861 articles found on Scopus, 818 were excluded according to the established criteria, resulting in the analysis of 43 studies. Of the 61 articles (18 studies from WoS and 43 from Scopus), 17 duplicates were eliminated, leaving a total of 44 articles to be analysed that provide us with a current view of the state of research published in this area in recent years (2021–2023).

For the bibliometric study based on co-occurrence analysis of keywords, the programme VOSviewer was used. The analysis was simplified by taking into account only those keywords with a frequency of occurrence of at least 2. Thus, a square matrix of N x N elements representing the co-occurrence between pairs of keywords was formed and a bibliometric network of the relationships between the keywords through nodes and links was created in graph form. This allowed for the visualisation and analysis of the connections between keywords.

RESULTS

Results of the systematic mapping review

The mapping questions (MQ) set out in this study are answered below. With regard to the first question MQ1. 'How many studies have been published from 2021 up to now?', Table 2 shows a summary of the 44 references analysed in this review, together with an identifier used for referencing throughout the analyses.

Table 2
References of the systematic review

N.º	References of the systematic review
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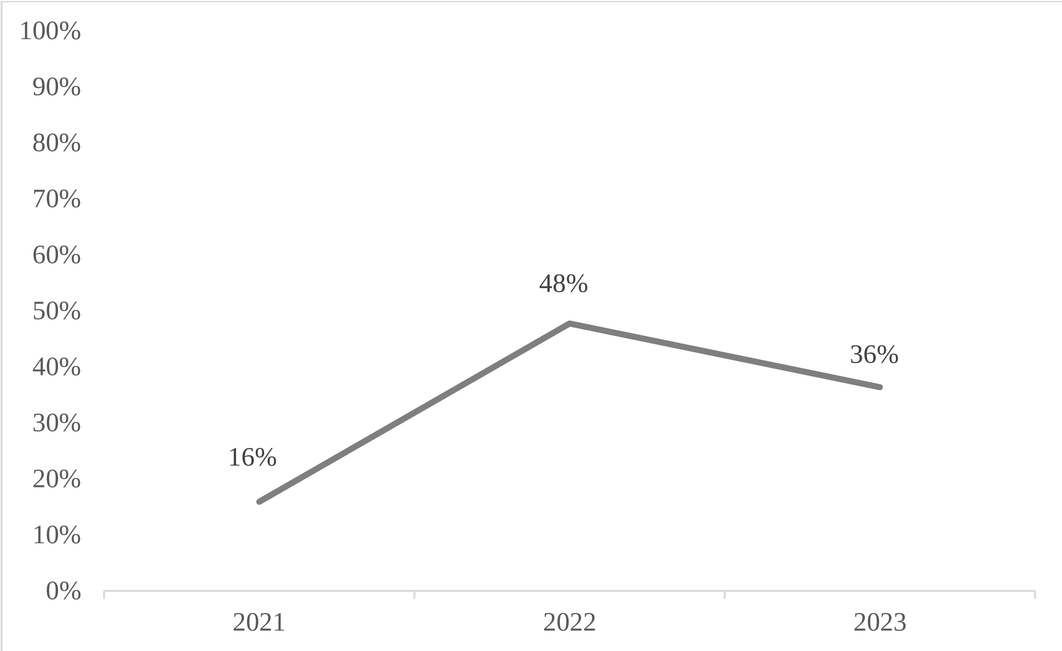
Source: own elaboration.

Next, an answer is provided for question MQ2. 'What is the production rate of the studies in chronological order (2021–2023)?'; the results are shown in Figure 3. Out of the three years under analysis, the greatest proportion of articles (48%) corresponds to the year 2022. It is important to bear in mind that the year 2023 has not yet concluded at the time of writing, yet it already represents 36% of the total number of articles. This suggests a clear trend of increased interest in the field, evidenced by the significant increase in publications since 2021.

Figure 3

Production rate of the studies in chronological order



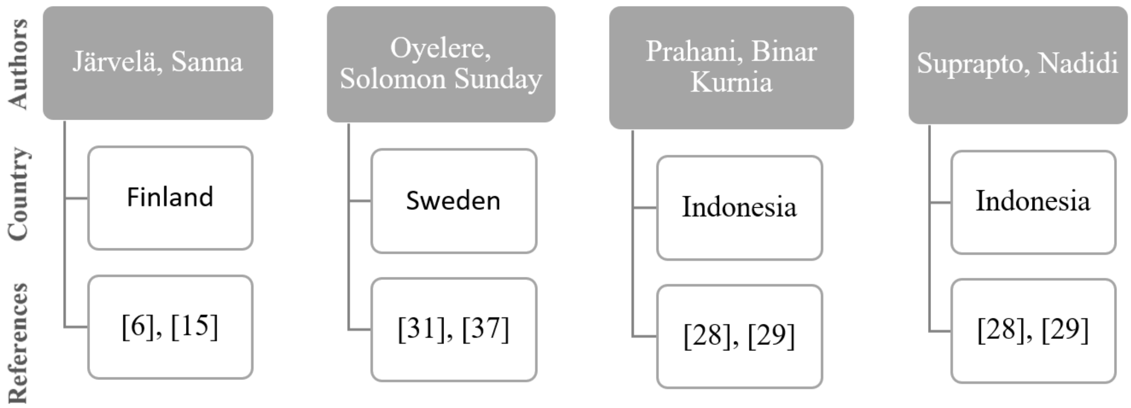
Source: own elaboration.

With regard to questions MQ3. 'Who are the most active authors?' and MQ4. 'What are the countries of origin of the most active authors?', the results are shown in Figure 4.

Within the group of 173 authors of the 44 works selected for the systematic literature review (see Table 2), 4 authors stand out as they have each contributed 2 publications, thus establishing themselves as the most active contributors. The countries of origin of these authors are Indonesia, Finland and Sweden.

Figure 4

Authors and countries of origin of the most active authors



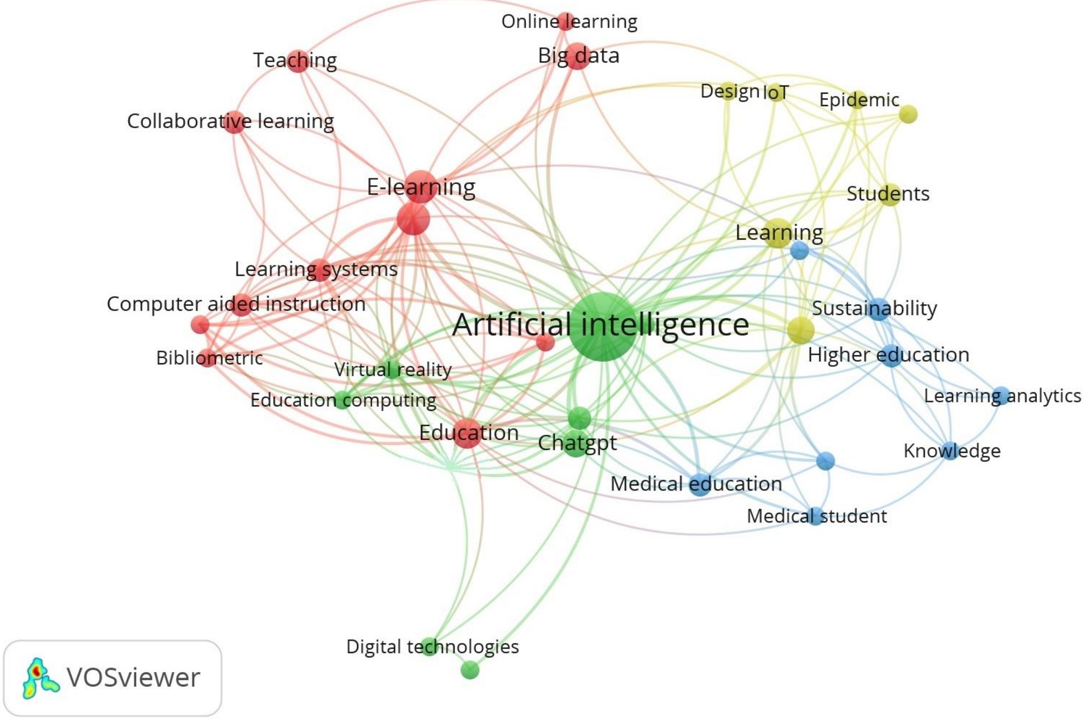
Source: own elaboration.

Results of the keyword co-occurrence analysis

The main objective of keyword co-occurrence analysis is to identify the relevant research topics related to AI and education. To achieve this, co-occurrence analysis was carried out for the keywords extracted from the 43 articles under analysis. A frequency of occurrence threshold of a minimum of 2 times was set in order to select the most significant keywords. From the 332 initial keywords, a total of 36 keywords met this criterion and will be analysed in detail.

To ensure consistency and coherence in the topic groups, a minimum number of 5 keywords was set to form a cluster. Based on these settings, the resulting co-occurrence network is shown in Figure 5. This Figure shows how many times the keywords appear together in the texts analysed and how they are grouped into four clusters corresponding to the colours red, green, blue and yellow. These clusters were formed based on the similarity between keywords, allowing us to identify the research topics related to AI and education addressed in the articles under analysis.

Figure 5
Map of co-occurrence of terms



Source: own elaboration.

The research questions (RQ) set out in this study are answered below. Specifically, question RQ1. 'What relevant approaches or trends have been dealt with in the studies selected from this period?' is answered in Table 3, which shows a summary of the network, the topic categories created based on the keywords and the references related to each topic category (some articles may fall under more than one cluster, but they have been grouped according to the specific area dealt with in the article).

Table 3
Groups of keywords based on co-occurrence

Cluster	Topic categories	Cluster description	Keywords (frequency of occurrence)	References of the systematic review
Cluster 1 (green)	AI integration to improve education	Represents the integration of artificial intelligence in education with the aim of improving the educational experience.	Artificial intelligence (25), Chatgpt (4), Generative AI (3), Digital technologies (2), Education computing (2), Foreign language learning (2), Sustainable development (2), Virtual reality (2).	[2], [4], [6], [7], [12], [13], [15], [16], [19], [20], [21], [23], [25], [26], [27], [29], [30], [32], [35], [36], [41], [43]
Cluster 2 (red)	Use of educational technologies in the teaching and learning process	Represents aspects related to the use of digital technologies in the teaching and learning process.	E-learning (6), Engineering education (6), Education (5), Big data (4), Collaborative learning (3), Computer aided instruction (3), Learning systems (3), Teaching (3), Bibliometric (2), Bibliometrics analysis (2), Online learning (2), Scopus database (2).	[3], [5], [9], [22], [28], [31], [37], [38], [40], [44]
Cluster 3 (yellow)	Pedagogical design and innovation	Approach centred on learning and curriculum design in order to explore how disruptive technologies can impact and improve education in different contexts.	Learning (5), Students (5), Curriculum (4), Design (2), Epidemic (2), Internet (2), IoT (2).	[1], [11], [14], [17], [24], [33]
Cluster 4 (blue)	Sustainable and ethical education	Approach based on improving education, taking into account ethics and sustainability in the education and training of professionals.	Higher education (3), Medical education (3), Sustainability (3), Humans (2), Knowledge (2), Learning analytics (2), Medical student (2), Sustainable education (2).	[8], [10], [18], [34], [39], [42]

Source: own elaboration.

Adapting Carrington's Pedagogy Wheel to an AI Pedagogy Wheel is justified based on the topic clusters identified in the analysis. These clusters highlight the importance of technology, knowledge integration and innovation in the field of education.

Taking into account the topic clusters identified in the analysis, we may now answer the following question: RQ2. Do these approaches or trends support the need for adapting Carrington's Pedagogy Wheel to create a new version that integrates AI in education?

The first cluster focuses on AI integration and therefore provides opportunities for exploring how this innovative technology can optimise education and improve students' learning at various levels in different contexts. Therefore, this cluster is key for the adapted wheel, since it offers a theoretical basis for AI integration in the context of pedagogy. The second cluster focuses on the integration of digital technologies in education with the aim of improving and enriching the teaching and learning process. This group of keywords covers different areas, with the use of technologies in the educational context as their common denominator. Adapting the wheel to an AI version would involve integrating pedagogical approaches based on emerging technologies, fostering efficiency, personalised learning, responsible use of technological resources and a solid digital infrastructure to implement AI in the teaching and learning process. The third cluster, 'pedagogical design and innovation', highlights the value of adapting educational approaches and curriculums to new technologies and emerging trends. The adapted wheel would integrate AI and emerging technologies in pedagogical design and innovation, with the aim of developing more efficient and up-to-date educational approaches in line with the latest trends in technology to improve teaching and learning experiences. Finally, the cluster 'sustainable and ethical education' places emphasis on sustainability and ethics in education. In this regard, the wheel adapted to include AI would underline the importance of taking into account questions of ethics and sustainability in education by means of reflective, metacognitive approaches that allow for critical reflection on the use of AI in education.

In summary, the adapted AI Pedagogy Wheel is justified because these topic clusters show how AI can influence and transform different aspects of education, from teaching and learning to curriculum design. The outcome of the analysis underlines the importance of integrating educational technology in the teaching and learning process, harnessing the potential of AI to improve education, promoting the ethical and sustainable use of AI and fostering pedagogical design and innovation. This will enable the development of a more up-to-date and relevant perspective of pedagogy in the age of AI and digital technologies.

Allan Carrington's Pedagogy Wheel adapted to the Artificial Intelligence Pedagogy Wheel

As mentioned above, Allan Carrington's Pedagogy Wheel does not consider AI as a technology that can be integrated in teaching and learning. For this reason, the creation of an AI Pedagogy Wheel, as adapted from Allan Carrington's original model, is necessary because it allows for the effective integration of AI in the teaching and learning process by providing a solid, well-structured pedagogical framework. This would provide a response to the clusters obtained previously, which reflect the relevance and necessity of integrating AI into the teaching and learning process.

In the case of the AI Pedagogy Wheel, like the original, it is composed of several concentric rings showing how AI can be gradually integrated into teaching and learning at different cognitive and technology integration levels.

The central ring shows Bloom's Taxonomy (Bloom & Krathwohl, 1956), a hierarchical structure of six cognitive levels used to design and classify learning objectives. In ascending order of complexity, the levels are: remember, understand, apply, analyze, evaluate and create.

The AI Pedagogy Wheel proposed by the authors in this paper adapts the cognitive skill levels of Bloom's Taxonomy to AI, thus providing a structured and clear approach that allows teachers and learners to work towards more advanced and in-depth learning goals. Along these lines, Lameras and Arnab (2021) propose a taxonomy of AI applications in education linked to teaching and learning practice. This taxonomy is divided into four categories: (1) support for teaching and learning, (2) evaluation and feedback, (3) personalised learning and (4) classroom management. However, although there is no AI-specific Bloom's Taxonomy, the authors have chosen to adapt Bloom's Taxonomy and to create an AI Pedagogy Wheel with the same theoretical underpinning as Carrington's Pedagogy Wheel, in order to make the adaptation as accurate as possible.

Table 4 shows some examples of how to use Bloom's Taxonomy as a guide for both the teaching process and the learning process through activities that effectively integrate AI.

Table 4
Bloom's Taxonomy for Artificial Intelligence

Cognitive skill levels		Description	Description applied to AI	Examples with AI
	Remember	At this level, the student should be able to remember information they have learned previously. This includes the ability to recognise and retrieve information such as details, terms, events and concepts.	At this level, AI can help students to remember information more efficiently through the use of memory and information retrieval systems.	*Teaching process*: AI can be used to create question and answer systems that allow students to revise concepts and remember important information. *Learning process*: Students use AI tools to make automatic text summaries or create mind maps that help them to remember key information.
	Understand	At this level, the student should be able to understand information. This implies the ability to interpret the meaning of information, make inferences and explain ideas in their own words.	At this level, AI can help students to understand more complex concepts by providing examples and analogies that are easy to understand.	*Teaching process*: AI can be used to create interactive simulations or visual material to help students understand difficult concepts. *Learning process*: Students use AI tools to translate texts to other languages or obtain definitions of unfamiliar words.
	Apply	At this level, the student should be able to apply the information they have learned previously to new or different situations. This includes the ability to use acquired knowledge to solve problems, complete tasks and make decisions.	At this level, AI can help students to apply what they have learned to real-world situations through the use of virtual simulations and scenarios.	*Teaching process*: AI can be used to create personalised recommendation systems that suggest specific activities or exercises for students to apply what they have learned. *Learning process*: Students use AI tools to create multimedia presentations or to design creative projects in which they apply the concepts they have learned.

Analyze	At this level, the student should be able to break down information into smaller parts and study the relationships between these parts. This implies the ability to identify patterns, detect errors and evaluate rationale.	At this level, AI can help students to analyse complex information more efficiently by identifying patterns and relationships in large datasets.	*Teaching process*: AI can be used to analyse student data and provide detailed information on their progress, strengths and weaknesses. *Learning process*: Students use AI to analyse large datasets or to identify patterns in complex information.
Evaluate	At this level, the student should be able to make critical judgements and evaluations about information. This implies the ability to compare and contrast, judge and evaluate the quality of information.	At this level, AI can help students to evaluate their own learning and progress through the use of evaluation and feedback systems.	*Teaching process*: AI can be used to create automatic evaluation systems that provide instant feedback to students and teachers about student performance. *Learning process*: Students use AI tools for self-evaluation and to receive feedback on their own performance.
Create	At this level, the student should be able to use the information obtained to create something new. This implies the ability to generate new ideas, come up with creative solutions to problems and create unique products.	At this level, AI can help students to create original content through the use of content generation tools.	*Teaching process*: AI can be used to create immersive, personalised learning environments that enable students to create original content and express their creativity. *Learning process*: Students use AI to create multimedia content or to come up with innovative solutions to complex problems.

Source: own elaboration.

The following ring represents the SAMR Model proposed by Puentedura (2014). This model is a reference framework for technology integration in teaching and learning, i.e. it focuses on how technology is used in teaching and learning, from simple substitutions to redefinition of the way in which the educational process is carried out. In ascending order of complexity, the levels are: Substitution, Augmentation, Modification and Redefinition.

This model provides a guide for the effective integration of technology in the classroom and for improving the quality of learning according to these four levels of technology integration in teaching and learning (Garcia-Utrera et al., 2014), which emerged as a relevant topic in the four clusters obtained from the keyword co-occurrence analysis.

In terms of AI, Lameras and Arnab (2021) use this model as a framework for understanding how AI can be used at different levels to improve education. However, this study goes beyond by exploring this approach further, with Table 5 showing a detailed description of the five levels of integration, as well as some examples of how the SAMR Model can be used as a guide for AI integration in the teaching and learning process.

Table 5
SAMR Model for Artificial Intelligence

		Description	Description applied to AI	Examples with AI
Levels of integration	**Substitution**	At this level, technology is used as a direct substitute for traditional tools without causing any changes to the teaching and learning process. In other words, technology is used simply to carry out the same task that was previously carried out manually or without the use of digital tools.	At this level, AI is used as a direct substitute for traditional tools without causing any significant changes to the teaching and learning process.	*Teaching process:* AI can be used in the form of a chatbot to answer students' frequently asked questions about the course content. *Learning process:* Students use voice-to-text translation tools to take notes during classes, reducing the need to take notes and allowing for better concentration in class.
	Augmentation	At this level, technology begins to improve traditional tools and processes by means of providing additional features that are not found in non-digital tools. This allows students to carry out tasks more efficiently and effectively.	At this level, AI is used to augment and improve existing activity in the teaching and learning process.	*Teaching process:* AI can be used on online teaching platforms with personalised recommendation systems that suggest additional learning resources based on the needs of each student. *Learning process:* Students use an AI application to improve their written grammar by means of automatic revision of their essays.
	Modification	At this level, AI is used to significantly change the teaching and learning process. This implies the restructuring of learning activities to make them more effective through the use of technology.	At this level, AI is used to create new possibilities and transform activity in the teaching and learning process.	*Teaching process:* AI can be used in data analysis and machine learning systems to identify learning patterns and adapt teaching to the individual needs of each student. *Learning process:* Students interact with AI-based chatbots to improve their pronunciation and conversation skills in a foreign language.
	Redefinition	At this level, technology greatly transforms the way in which the teaching and learning process is carried out. Technology allows students to create, collaborate and share ideas in ways that were not previously possible.	At this level, AI is used to significantly modify existing activity in the teaching and learning process.	*Teaching process:* AI can be used in machine learning systems to personalise the syllabus for each student and adapt it according to their progress and individual needs. *Learning process:* Students use an adaptive learning platform that automatically adjusts the difficulty level of content according to each student's performance.

Source: own elaboration.

The outer rings of the AI Pedagogy Wheel contain examples of AI tools and apps that can be used for each cognitive and AI technology integration level. These suggested AI tools and applications available for each cognitive level are just a sample and are by no means an exhaustive list, given the growing number of applications that are currently emerging.

Finally, the proposed AI Pedagogy Wheel includes an additional ring featuring a new aspect: the Reflective-Metacognitive level (covered by the fourth cluster: sustainable and ethical education). The inclusion of the Reflective-Metacognitive level in the wheel is important because it allows students and teachers to reflect critically on the use of AI and how it affects their learning and teaching. With regard to the teaching process, teachers at this level can assess how they are integrating technology in their teaching, reflect on the impact this is having on students and make changes where necessary. This implies a reflective and metacognitive approach towards technology, specifically AI, that is more critical and analytical, rather than simply using it as a tool.

With regard to the learning process, students can also reflect critically on how they use it and the impact it is having on their learning. They can assess how they are using AI to learn, identify what is effective and what is not, and make changes to their learning approach where necessary. Here, reflection refers to the process through which students can critically assess and analyse their own learning, while metacognition refers to students' ability to monitor their own learning and understand the learning strategies they use. Both skills are essential for successful lifelong learning, and are particularly important in the context of AI-focused education.

Along these lines, there are several studies that justify the need for reflection and metacognition in the use of AI in education. Luckin (2018) believes that AI can be a valuable tool for improving education, but it is important to reflect on how it is used and what impact it has on students and learning overall. Therefore, she highlights the importance of reflecting on how AI can be used effectively in education, and how it can work alongside human intelligence to improve learning.

Furthermore, Selwyn (2019) underlines how important it is for teachers to carefully consider how AI is integrated in the classroom and how they can use it to improve students' learning. They must also reflect on the potential consequences of AI for teaching and the relationship between humans and machines in the classroom. Siemens and Baker (2012) analyse how AI and data mining can be used in education and the importance of reflecting on the ethical and pedagogical implications of its use. In this regard, reflection on the use of AI for educational data analysis and the collaboration between the actors involved may contribute towards the more effective and responsible use of technology in education.

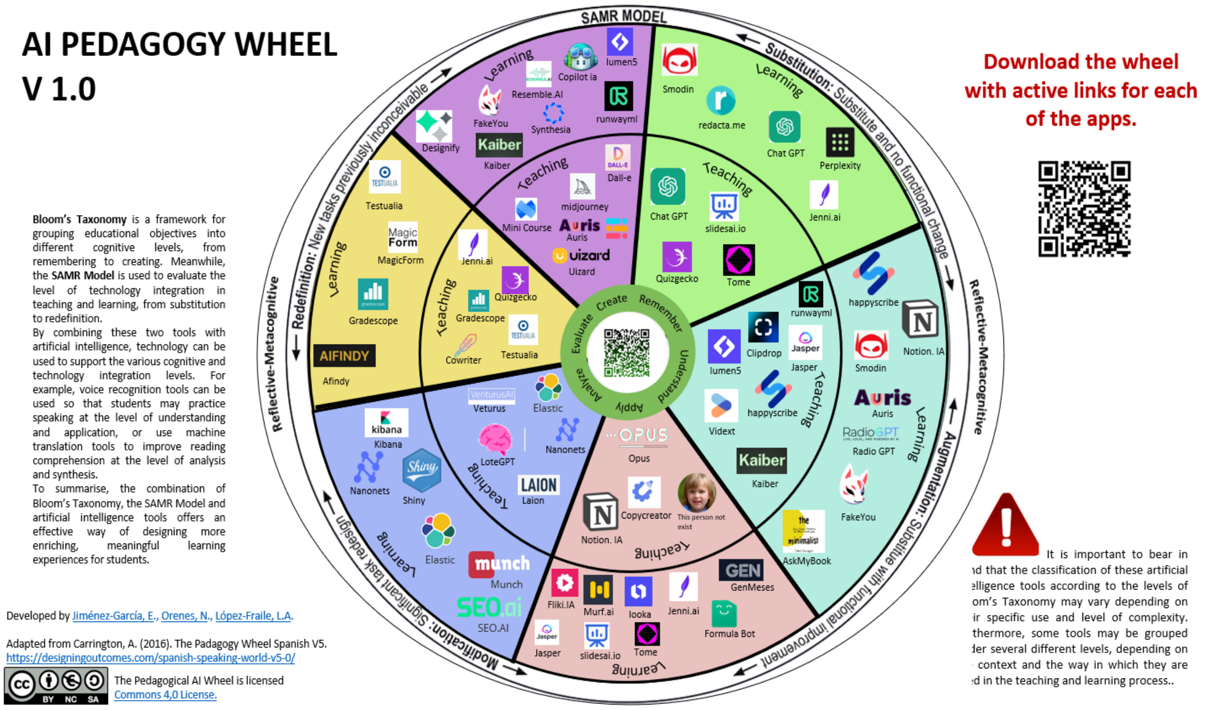
With respect to metacognition, according to Cerchiaro et al. (2021), this refers to the "knowledge that a person has about their own cognitive processes and products, as well as the monitoring and regulation of these processes in terms of the achievement of an objective or goal" (p. 3). Another perspective is that offered by Porayska-Pomsta (2016), who identifies the use of AI as a methodology for supporting educational praxis and teacher metacognition, as it provides personalised, adaptive, real-time feedback to students, while helping teachers to reflect on their pedagogical practice and make informed decisions.

Nevertheless, the proposed inclusion of this Reflective-Metacognitive level refers more to the ethical and responsible use of AI, where educators can discuss these issues with students and foster the responsible and ethical use of AI. In this way, AI allows teachers to design and implement pedagogical strategies that foster reflection and metacognition in their students as key skills for their future learning.

Therefore, including this Reflective-Metacognitive level in the wheel allows for the identification of areas for improvement and opportunities for improving AI integration in the educational process, ensuring the effective and responsible use of technology.

Figure 6 shows the AI Pedagogy Wheel together with Bloom's Taxonomy and the SAMR Model, plus the Reflective-Metacognitive ring featuring a selection of appropriate AI tools and technological strategies for each cognitive skill and AI technology integration level.

Figure 6
AI Pedagogy Wheel



Source: own elaboration. Adapted from Carrington (2016).
(Link to download the wheel with active links for each of the apps)

It must be noted that these are just some examples of AI tools and apps that may be used for each cognitive and integration level. There are lots of other tools and apps available that may be adapted and modified according to the specific needs and objectives of the learning activity in line with students' level of skill and knowledge in terms of AI.

DISCUSSION AND CONCLUSIONS

The relationship between AI and education is a topic that has gained increasing attention in recent years, given the great potential of AI to improve the quality and efficiency of learning. The systematic review of the 43 relevant articles has demonstrated the growing trend in research about AI in education. Specifically, the fact that in 2023 a significant proportion of articles have already been published, despite the year not yet being over, indicates the possibility that research in this field will continue to grow, thus signalling the importance and relevance of the topic.

Furthermore, regarding the authors who have contributed the most (Järvelä, Sanna; Oyelere, Solomon Sunday; Prahani, Binar Kurnia and Suprapto, Nadi) and the geographical diversity of the countries of origin of these authors (Indonesia, Finland and Sweden) demonstrates the international, globalised nature of research in this field.

Meanwhile, turning to AI integration in education, Pedro et al. (2019) explored this relationship in their study and underlined the opportunities and challenges that arise when implementing AI in the area of education to achieve sustainable development. Personalised learning is one of the key opportunities that AI has to offer, as it adapts educational content to the specific needs of each student, allows for the early detection of learning difficulties and offers personalised feedback. Bhutoria (2022) found similar results, where AI is able to take into account the learning requirements and habits of students and optimise learning trajectories.

However, it is important to underline that teachers should be considered a fundamental part of the planning and execution of personalised education with AI. The active involvement of teachers in this process is essential to ensure learning objectives are achieved and that students' needs are observed. Moreover, as already mentioned, this wheel can be a support tool for teachers, but it is important that teachers are trained to use AI appropriately, to understand its limitations and to make the most of these emerging technologies (Salas-Pilco et al., 2022).

In this sense, AI integration in education must be done carefully, and must be part of a broader, more balanced approach that combines technology with pedagogy and teaching expertise. Lameras and Arnab (2021) and Cope et al. (2021) emphasise that AI should be used as a tool for supporting and improving the teaching and learning process, rather than completely replacing teachers or fully automating the educational process. It is therefore important to understand that AI cannot replace the human relationship between teacher and student, which is fundamental to successful learning.

In line with this idea, the clusters identified in the topic analysis (1. AI integration to improve education, 2. use of educational technologies in the teaching and learning process, 3. pedagogical design and innovation and 4. sustainable and ethical education) reveal the key areas in which AI can have a meaningful impact on education. Thus, adapting the Pedagogy Wheel for AI according to these clusters provides an up-to-date, relevant framework that enables educators to effectively consider how to harness AI capabilities in curriculum planning, teaching methodology, assessment and other key areas of the teaching and learning process.

In addition, one of the contributions made is the inclusion of a new outer ring in the AI Pedagogy Wheel: the Reflective-Metacognitive level. The inclusion of such a level could be an important step towards ensuring the effective and responsible use of AI in education. This is due to the need to understand the crucial role of reflection and metacognition in the educational process. Authors such as Bostrom (2014) emphasise the importance of reflecting on the potential impacts of AI on society and the need to develop strategies to ensure that these impacts are positive. In this regard, he addresses the potential risks and benefits of AI and how its development should be handled with caution and reflection. Drigas et al. (2023) propose a meta-learning model that combines metacognition with smart technologies to improve learning outcomes. The model consists of nine layers, with the metacognition layer referring to the learner's ability to reflect on their own learning process. It is therefore essential that students learn to reflect on their own learning process and develop effective metacognitive strategies to enhance their learning, especially in situations where technology tools such as AI are used.

Therefore, the adaptation of this wheel is necessary because the authors seek to ensure the pedagogical use of AI in education. However, it is important to note that AI has limitations and disadvantages that need to be considered. While this technology may improve efficiency and accuracy in several areas, its misuse can have negative effects on society. In education, it is important for ethical, moral and privacy issues to be addressed when it comes to handling personal data, as underlined by Renz and Vladova (2021) and Yuskovych-Zhukovska et al. (2022). It is therefore essential to establish clear policies and protective measures to avoid any discrimination or harm to students. As such, the potential benefits of AI in education can be harnessed without compromising privacy and ethics. Furthermore, it is crucial that students and teachers develop competency for the age of AI, as highlighted by UNESCO (2021). This involves understanding the ethical and social aspects of AI, such as data privacy and security, as well as the impact it may have on society (Arrieta et al., 2020).

Consequently, it is essential that AI is applied responsibly and ethically in education, as this tool has a direct impact on the development and education of students. For this reason, it is crucial to have a theoretical framework supported by pedagogy that enables teachers and students to understand the scope and limitations of AI, as well as to acquire critical skills that allow them to assess the accuracy and reliability of the results it provides.

In this regard, the proposal set out in this article stands as a valuable tool for education. It should be noted that the inclusion of the AI Pedagogy Wheel in this theoretical framework is particularly relevant, as this tool is centred around the effective integration of technology and pedagogy. As such, it seeks to ensure that teaching and learning methods are appropriate for the specific context in which AI is used.

Finally, it is worth highlighting that this AI wheel is just an initial approach towards the proper integration of this technology in the age of AI. However, it is important to consider that given the constant emergence of numerous new AI apps, this wheel should be regularly updated to ensure it remains relevant and useful.

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Exploring singularity in higher education: innovating to adapt to an uncertain future

Explorando la singularidad en la educación superior: innovar para adaptarse a un futuro incierto

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ABSTRACT

This research presents an analytical model designed to detect, organize, and classify singularity in higher education based on futures studies. To achieve this, evidence is gathered to identify distinctive features in the educational field, empowering universities to make strategic decisions in complex environments worldwide. The study is grounded in analytical techniques supported by future research, aiming to identify trends and innovative organizations in various global educational contexts. These singularities are categorized and organized using a mixed methodological approach that combines confirmatory research with the collection of qualitative and quantitative data. The study's findings offer insights into 55 higher education organizations with unique characteristics, emphasizing critical aspects of each. Furthermore, the utility of the developed instrument is validated as a pivotal tool enabling universities to continually review and adapt their educational practices, keeping them current and responsive to social and technological advancements in our ever-changing world. Additionally, the research seeks to stimulate a discussion about the future role of universities as influential entities in a dynamic, complex, and uncertain society. This underscores the vital importance of universities being well-prepared to confront challenges and seize opportunities emerging in this evolving context, ultimately contributing to their sustained relevance and effectiveness in the continuously changing educational landscape.

Keywords: comparative analysis; trend; educational innovation; higher education; future studies.

RESUMEN

Esta investigación presenta un modelo de análisis diseñado para detectar, organizar y clasificar la singularidad en la educación superior basado en estudios de futurización. Para ello, se recopilan evidencias con el fin de identificar rasgos diferenciales en el campo educativo, lo que permite a las universidades tomar decisiones estratégicas en entornos complejos. El estudio se fundamenta en técnicas de análisis respaldadas por investigaciones futurísticas para identificar tendencias y organizaciones innovadoras en diversos contextos educativos. Estas singularidades se clasifican y organizan mediante una propuesta metodológica mixta que combina investigación confirmatoria y la recopilación de datos cualitativos y cuantitativos. Los resultados del estudio proporcionan una visión de 55 organizaciones de educación superior con características singulares, destacando aspectos importantes de cada una de ellas. Además, se valida la utilidad del instrumento desarrollado como una herramienta crucial que permite a las universidades revisar y adaptar constantemente sus prácticas educativas, manteniéndolas actualizadas y respondiendo a los avances sociales y tecnológicos en un mundo en constante cambio. Asimismo, la investigación busca fomentar un debate sobre el papel futuro de las universidades como actores en una sociedad dinámica, compleja e incierta. Esto resalta la importancia de que las universidades estén preparadas para enfrentar los desafíos y aprovechar las oportunidades que surgen en este contexto cambiante.

Palabras clave: análisis de tendencia; innovación pedagógica; enseñanza superior; tecnología de la educación, estudios de futurización.

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INTRODUCTION

In today's complex, dynamic, and uncertain world, universities must constantly review their teaching practices to keep up with the ever-changing needs of society (Guàrdia et al., 2016, 2021; Manetti et al., 2022a, 2022b). Higher education institutions must also strive to provide environments that effectively meet the challenges of modern-day society, focusing on how to improve the university ecosystem as it faces a future characterized by more unknowns than certainties (Baig et al., 2023). To this end, universities need to understand the scale and impact of change in order to create distinctive, transformative spaces that can revolutionize educational systems (Patterson et al., 2022).

This study proposes to achieve this goal by exploring the concept of the "educational singularity" as a conceptual framework for analyzing the factors that make an educational institution a differentiated project. The term "singularity" refers to a hypothetical point in time at which technological growth becomes uncontrollable and irreversible, resulting in unforeseeable changes to human civilization. In the context of education, the educational singularity could be seen as a point in time at which traditional educational systems are disrupted by new technologies and pedagogical approaches, leading to a fundamental transformation of the way we learn and teach. It is important to note that the characteristics defining the emergence of singularity may appear in different ways and go beyond institutions' traditional teaching models. This leads to the urgent need to develop new analytical approaches in the educational field (Cai, 2017; Ramírez-Montoya et al., 2022).

Thus, the basic aim of this research is to establish a study framework that will characterize the concept of singularity in education. The theoretical foundation of this study is based on the seminal paper by Wenham (1987), "Singular Problems in Science and Science Education." To achieve this aim, we propose an analytical model focusing on the identification, organization, and classification of educational singularity based on previous research in Wenham (1987) and Andriushchenko et al. (2020). The ultimate goal of this inquiry is to provide universities with a set of innovative tools enabling them to face and adapt to the challenges of change. This approach is based on the premise that the ability to identify an educational singularity has become an essential element for improving the adaptability of such institutions when dealing with fast-moving changes in the social, cultural, demographic, economic, and technological fields and in the markets (Manetti et al., 2022a) and ultimately, to strengthen their ability to respond to these changes (Gros & Lara, 2009).

This research intends to define singularity in the field of education, as a turning point in the way higher education is conducted and organised. Thus, the study focuses on gathering evidence which helps detect differentiating features in the world of higher education, with the ultimate aim of enabling universities to make strategic decisions in the complex environments in which they operate. Our research is supported by prospective and futures studies (Decoufle, 1974; Godet, 2001; Mojica, 2005; Brown & Kuratko, 2015; Kuosa, 2010, 2016; Berenskoetter, 2011; Ito & Howe, 2016) combined with the theoretical and methodological bases of concept analysis (Meyer & Mackintosh, 1994) to establish an instrument for classifying and organising educational singularities. In brief, we intend to explore trends in higher education as an innovation space in order to deal with the challenges of the new and uncertain global scenario (Guàrdia et al., 2016; Manetti et al., 2022a).

Thus, the main goal of this study is to detect trends in the higher education system which enable the identification of institutions with distinctive practices, which could be considered singular. The results obtained will provide an enriching view of universities which stand out for their unique characteristics, contributing to highlight outstanding aspects of each one. Additionally, it is hoped that discussion of the future of universities as fundamental institutions supporting a society characterised by rapid change, complexity, and uncertainty will be fostered.

RESEARCH METHODOLOGY

This study aims to define the concept of singularity as a distinctive element and driver of change in the context of higher education. It uses a mixed methodology, combining confirmatory research with gathering qualitative data. This method is based on analysis supported by prospective studies to find trends leading to the identification of innovative institutions in various educational contexts (Gough, 1990; Hicks, 2012; Hicks & Slaughter, 1998; Toffler, 1974). We begin with the premise that prospective studies are a process using analytical tools to identify trends and establish possible future scenarios (Manetti et al., 2022b).

In the sphere of higher education, futures studies methodologies are frequently associated with radical changes or substantial reforms in areas such as academic papers, the syllabus, teaching, learning, or technology (Cai, 2017). The scientific literature attests to the robust connection between the concepts of futures studies and education (Menéndez et al., 2022), showing that methodologies for the definition of future scenarios have the potential to profoundly transform education (Bodinet, 2016; Gee & Esteban-Guitar, 2019; Hicks, 2012). Thus, a clear and robust association is established between prospective methods and such concepts as "education", "learning", "training programmes", "syllabus", "literacy", and "teaching", alongside other terms like "centres", "university", "lecturers", and "students" (Menéndez et al., 2022).

The proposed steps of the research are described below:

- Identification of key themes and concepts relating to innovative trends and practices in higher education.
- An exhaustive bibliographic review of studies on these themes and concepts.
- Selection of a representative sample of studies for qualitative analysis, basing the selection on pre-established criteria such as research quality, relevance of results, and diversity of sources.
- Extraction of relevant qualitative data from the selected studies via the codification and categorisation of the gathered information.
- Analysis of the qualitative data using thematic analysis and/or content analysis, to identify patterns, trends, and relationships between the key concepts.
- Development of a rubric based on the results of the qualitative analysis.
- Design of expert interviews to complement and/or validate the results of the qualitative analysis.
- Presentation of the results of the analysis.
- Discussion and conclusions about the implications for higher education.

In short, this research process follows a series of sequential steps, each with a specific objective. Essentially, the research will look for trends relating to unique practices in higher education, for later in-depth analysis of educational institutions. The following research questions, taken as a whole, explore how to detect trends, identify unique institutions, and determine the level of singularity of a university:

RQ1. How can we identify trends in higher education?
RQ2. Can we discover new models of higher education based on the identified trends?
RQ3. How can we organise and classify the higher education institutions with differentiating characteristics?
RQ4. How can we establish the level of singularity of a university?

Answering these questions will enable us to validate a rigorous, systematic approach for exploring singularity, futurology, and higher education, in order to offer a system for organising and classifying differentiating practices in higher education institutions.

RESULTS

The research begins with the identification of key themes and concepts relating to trends in higher education, with a special emphasis on looking for unique practices in education, based on the review of the literature produced in the period 2015-2020. We examined the ERIC database with the following search equations: “Higher education AND Innovative practices AND Research reports”, which offered 107 documents in the period mentioned; “Higher education AND Innovative practices AND Descriptive reports”, giving a result of 49 documents; “Higher education AND Trends AND Technology AND Research reports”, with a total of 170 papers; and “Higher education AND Trends AND Technology AND Descriptive reports”, giving us 64 documents. The corpus of documents was completed with searches in Google Scholar, which has been shown to be valid for this type of research approach, both in terms of coverage for systematic reviews (Gehanno et al., 2013), and in academic terms of precision, authority, objectivity, topicality, inclusion, and relevance (Howland et al., 2009).

The Mendeley reference management system was used to store and share files and create notes in the documentary analysis phase. Next, we selected a representative sample of studies for qualitative analysis. The screening stage eliminated duplicate documents and established selection criteria, such as whether the reports have participants from various countries or institutions, contain meta-analysis, and offer large samples for specific case studies. Once the outstanding themes were identified, it could be established that the key trends were those appearing in more than two sources. It should be pointed out that here we were more interested in studying the institutions linked to the trends than in examining the trends in more depth.

During the data extraction process the information gathered was codified and categorised using content analysis techniques, in order to identify trends in the higher education system which would help us find institutions with practices that could be considered unique. These analyses identified 25 trends (Table 1) linked to 110 institutions in Europe, the USA, Canada, and Australia, and in supraterritorial organisations. In the analysis process we observed that several universities mentioned in the reference documents are considered inspiring institutions by other centres, leading us to resize the sample to 55 universities, which third parties consider to be competitive leaders in the worldwide university system (Table 2).

Table 1
Higher education trends identified

Self-regulated learning	Inquiry-based learning	Project- and problem-based learning (PBL)	Rhizomatic learning	Authenticity
Community of interest and practice	Skills-oriented education	Metacognitive approach to learning	Smart learning environment	Personal learning environment
E-portfolio	Gamification	Digital badges	Artificial intelligence	The Internet of Things
Serious games	Modularity	Virtual mobility	Virtual worlds	Data portability
Augmented reality	Virtual reality	Recognition of open and informal learning	Social networks for education	Robotics applied to education

Source: by the authors.

Once the trends were identified, we identified the institutions linked to them and began the research stage, to develop and design a rubric to serve as an instrument of reference to analyse the differentiating elements of each organisation. The purpose of this rubric was to establish the disruptive contribution of higher education to society, and to study the innovation, development, and knowledge transfer models of the analysed centres.

In the first exploration, to construct the measurement indicators, we consulted papers on the quality of innovation in higher education (Beran & Violato, 2005; Fernández, 2008; Vásquez et al., 2023). During this process, we observed a general lack of suitable indicators for measuring innovative elements in the quality of education (Velasco et al., 2019). This results in a dependency on indicators which often over-simplify or are taken out of context (Loukkola et al., 2020). The well-known international college rankings offer very little of use for studying unique practices. Also, the disparity of models and measurement options, which also entail diverse and sometimes different dimensions and indicators (Guerrero, 2018) for assessing quality in teaching innovation processes, reveals the need to establish common frameworks of reference for evaluating educational innovation.

Given that the observation process particularly emphasises how higher education organisations approach and institutionalise major challenges, and the evident difficulty of finding examples, other sources are needed to establish the singularity variables in the rubric to be presented below. One supporting reference is the working model of the Sustainable Development Goals, which establishes far-reaching and transformative universal goals (Southern, 2020). Another is the Global Innovation Index, which classifies world economies according to their innovation level (Torres-

Samuel et al. 2020). This report uses around 80 indicators to capture the different dimensions of innovation. These sources give us a solid base for assessing and analysing the innovation programmes, strategies, and plans of higher education institutions.

Table 2
Institutions selected for analysis

Arizona State University (Global F. A, M-Open edX)	Berlin School of Creative Leadership	Coursera	DigiPen Institute of Technology	Duke-NUS Medical School (National University of Singapore)
ECIU University	École 42	edX	Estonian Entrepreneurship University of Applied Sciences	Fabrica Benetton
Harvard University	Hyper Island	IE University	Kaospilot	Karolinska Institutet
Knowmads Business School	Lomonosov Moscow State University	Massachusetts Institute of Technology (MIT)	McGill University	Minerva Schools at KGI
Monash University	Mondragon Unibertsitatea / Team Academy LEINN	NASA Int.	Open Universities Australia	Pontificia Universidad Católica de Chile
Princeton University	Queen's University	Queensland University of Technology	Quest University	Royal Melbourne Institute of Technology (RMIT Creds)
Royal Roads University	Schumacher College	Stanford D.School. Hasso Plattner Institute of Design	Tecnológico de Monterrey	The CERN Accelerator School, School of Computing + Student Opportunities
The Hebrew University of Jerusalem	The Open University (Badged Courses OpenLearn, Open degree)	The Schulich School of Business	The Sustainability Institute	The University of Auckland
The University of Tokyo (Todai)	The Wharton School. University of Pennsylvania	THNK. School of Creative Leadership	Tsinghua University	Udacity
Universidad de los Andes	Universidad Peruana de Ciencias Aplicadas	University of Alberta (for credit MOOCs)	University of Bradford (School of Pharmacy and Medical Sciences)	University of Buckingham
University of Cape Town	University of Melbourne	University of the People	University of Toronto	Western Governors University

Source: by the authors.

Based on the results of a synthetic analysis of the above papers, we began laying the foundations for the rubric, using futures studies methodologies in higher education (Menéndez et al., 2022). We opted for in-person workshops based on research skills, critical and creative thinking, and teamwork. These workshops used the DeflyCompass method, which allows us to generate future scenarios combined with the discipline of design for the challenges envisaged (Manetti et al., 2022b). These working sessions used the Manual Thinking mind-map technique with movable tags (Huber & Veldman, 2015), an effective tool for visualising processes, contextualising ideas, and organising thoughts, which facilitates teamwork and is useful for the phases of creating, exploring, prioritising, organising and prototyping scenarios in a dynamic yet structured way. Next, we used a dot-voting system, distributing a limited number of dots so that each participant could vote. By placing their dots, workshop participants voted individually on the importance of the scenarios.

By the end of two work sessions three fields of interest were established: the teaching model, organisation management, and the service experience, defined by 15 factors (Table 3) linked to 9 megatrends: increasing business volatility, change in global economic power, constant growth in the world population, rising life expectancy, the crisis in systems of governance, the democratisation of personalisation, the standardisation of cultural patterns, new technologies and especially those linked to artificial intelligence, and hyperconnectivity. Based on prospective investigation, three scenarios were established, as shown below.

Table 3

Innovative trends based on scenarios

Training model	Organisation management	Service experience
A1. Syllabus approach	B1. Processes	C1. Recipients/Ecosystem
A2. Learning design	B2. Agents and roles	C2. Student services
A3. Assessment model	B3. Organisational structure	C3. Enrolment
A4. Teaching action	B4. Relational model	C4. Student certification
A5. Learning resources	B5. Disruptive commitment	C5. Educational outreach

Source: by the authors.

To complement and validate the results of the qualitative analysis, we consulted 25 experts on education and learning technologies to identify additional areas of interest, through a focus group session based on the workshop on future teaching scenarios (Manetti et al., 2022b). The goal of this session was to imagine future learning scenarios in higher education. Consulting the participants revealed positive and negative aspects and possibilities of interest in future scenarios, plus a brainstorming session on emerging practices in higher education. A summary of the configuration of scenarios defined based on the workshops and expert interviews is presented below.

Teaching model

In this scenario the goal is to identify differences between the various higher education institutions in terms of strategy and syllabus design. We looked for signs of agile update implementation or real-time adaptation of the educational portfolio to the qualifications demanded in the 21st-century labour market. We also took into account factors such as diversity and flexibility in study plans and programmes, and personalised, adaptable and modular content. In this scenario we analysed:

- Learning design and planning and the integration of innovative methodologies such as active learning, flipped classrooms, etc.
- Use of collaborative learning, diverse educational resources in different formats such as immersive, gamified, etc., and a multimodal assessment system including hetero-, self- and co-evaluation.
- The combination of technology and teaching in the classroom, study plans, and the centre's physical and digital infrastructure to create value for students.
- The impact and benefits of new ways of organising and conducting teacher accompaniment adapted to each educational model.

Organisation management

The indicators focus on investigating the non-teaching processes which have a transformational component, whether technological, organisational, or to do with knowledge generation, and which visibly contribute to changing the institution's activity and performance in an original and disruptive way. The following elements, among others, were considered:

- Key chain configuration processes: assessing the internal processes considered critical for the functioning of the institution and which directly impact its speciality or singularity.
- Strategically outsourced processes which can have a profound impact on the organisation: new figures, performance roles and forms of intermediation contributing to conducting academic activity or management in a different way, encouraging more interaction between both dimensions.
- New models of relationship and participation between people and/or communities which add value to the institution: outstanding groups in knowledge generation and transfer which contribute to academic excellence and the advancement of the institution.
- An organisational and decision-making structure which allows interaction aligned with the strategic goals and complexity of the techno-educational context, with a special focus on open, innovative organisations. This involves fluid, autonomous decision-making based on data.
- A disruptive profile of the institution, transforming its environment and society.

Service experience

The analysis of this area sought to identify a series of special characteristics among new intake students, and common skill features among graduates. Some examples of these features include creative abilities, ecological awareness, and the ability to be change agents, among others. Another important factor is the innovation catalyst model; in other words, the institution's strategy for driving creation and knowledge transfer in an agile and transparent way for maximum impact. We also evaluated the organisation's networks of influence, analysing its ability to attract "inputs" such as enrolment, funding, talent, employers, partnerships, etc., and the impact of its programmes and activities on the communities of the educational institution. Among services for students, we paid special attention to admission processes, enrolment management, and other services supporting students' careers, encouraging the development of their vocation from the start. We also explored forms of offering students guidance and personalised strategies which improve students' experience, making use of technologies like data mining, analytics, artificial intelligence, electronic services, virtual assistants, and online resources and websites. In enrolment, we investigated flexible, simplified, personalised processes focusing on students' needs. We also examined financial aid programmes for students to increase and promote inclusion. Our metrics also included accreditation systems and extended learning registers, using flexible, open, modular certification systems such as micro-credentials, which meet new social and employment demands without compromising education quality.

Creating the rubric

While constructing the components of the rubric for measuring the singularity factors in relation to the scenarios mentioned above, we were interested in new classification systems centred on innovation, which go beyond the traditional metrics. Here, we referred to the WURI ranking model (World's Universities with Real Impact). This ranking evaluates universities' research and teaching programmes, considering their innovative contributions and creative approaches (Steiner & Posch, 2006; Manzoni, 2022; Peris-Ortiz et al., 2023). One aspect of WURI which attracted our attention and which matched the goals of our research is that, as well as considering traditionally accredited universities, it also included those with less conventional educational models, such as Minerva Schools at KGI in the USA and Ecole 42 in France, which offer innovative teaching models and attract strong enrolment demand among young people interested in the new digital professions of the fourth industrial revolution. Also, the three criteria of innovation, implementability and impact used by WURI to measure each of its six analysis categories: industrial applications, entrepreneurial spirit, ethical value, student mobility and openness to exchange, crisis management, and the fourth industrial revolution, served as inspiration to establish the dimensions of our rubric.

The rubric is divided into three dimensions: Implementation, Innovation, and Impact, with three scoring levels. These dimensions help us measure each singularity factor. To form a basis for the scores, we took information mainly from institutional reports, policies and regulations (academic, organisational, personnel, etc.); strategic plans (on education, research, innovation, environmental sustainability, digitisation, internationalisation, etc.); yearbooks and reports on the state of the centre and its premises; programme catalogues, manuals, publications and news items; academic articles, and all types of public documents linked to the organisation.

Implementation

This dimension focused on the level of institutionalisation of the singularity factors in the context of the analysed element, and the resources used for it to function. Like the other dimensions, this was evaluated broadly to determine if the factor was at the planning or pilot stage, or if it had already been institutionalised in the internal structures of the organisation. Although this task was complex, we also wanted to find out how the factor connected to the centre's strategy and policies, its relationship with other processes of the model, the local services it activated, its apparent sustainability, and whether it had been introduced gradually through internal initiatives or externally driven.

Innovation

This dimension was based on the definition given by the OECD and Eurostat (2005), which describes innovation as the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations. In our evaluation, we assessed the innovation component present in each of the factors of the element, whether they were new creations (novelty), and whether the innovations they contained had been adopted. For example, we wanted to identify the addition of new or transformed educational services or products, approaches and teaching methods, organisation of work and personnel, or the integration of information and communication technologies (ICT) in educational processes. Thus, our goal was to confirm that the innovation generated changes in the institution's model, contributing a differential value which facilitated its adaptation to contexts of accelerated change (Marcet, 2016).

Impact

The goal of this dimension was to verify and evaluate the effects of the singularity factor on the analysed element, and its influences on the other domains of the model. We wanted to determine how the apparent results satisfied social, organisational educational and other demands, and whether they had a positive impact on the organisation's fame, reputation, and positioning. To evaluate these models we assigned a numerical singularity level. These levels are:

Level 1. The element is not differential. The university presents a standard version of this element, or the element is not applicable because it does not exist or no data are available for it.
Level 2. There is some differentiation from the norm but this level of singularity does not significantly influence the differentiation of the university. This singularity is probably a knock-on effect of another more significant singularity.
Level 3. The differentiation from the norm is a differential feature with a significant impact on the differentiation of the university.

Application of the rubric

After establishing the dimensions and levels of the rubric, we began the process of analysing the 55 institutions compiled in the trend detection process, seeking and gathering information about the chosen centres in order to describe their characteristics in more depth and establish the differential features of the different contexts analysed (Table 4). It is important to note that the three scenarios established for analysing the organisations are closely interrelated, as can be seen in most of the

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analysed cases. In general, we found that a unique teaching model is usually accompanied by a particular organisation management system and service experience. To be able to identify and evaluate the uniqueness of each of these three models, we established a standard reference situation for universities as a basis for recognising singular centres. Once the three dimensions were defined, we developed the singularity rubric, complete with the name and description of each factor or indicator, the standard elements, and the levels of singularity to consider in each case.

Table 4
Application of the rubric

	A 1	A 2	A 3	A 4	A 5	B 1	B 2	B 3	B 4	B 5	C 1	C 2	C 3	C 4	C 5
1	2	3	3	2	2	2	2	3	1	2	3	1	2	2	3
2	3	3	2	3	2	2	2	2	2	3	3	2	3	2	3
3	3	3	2	2	2	2	2	2	2	3	3	2	3	2	3
4	2	3	3	2	3	2	2	3	2	3	3	2	3	3	3
5	2	3	3	2	2	2	2	2	2	3	2	2	3	2	2
6	2	3	2	2	2	3	2	1	2	3	2	2	3	2	2
7	2	3	2	3	2	2	3	2	2	3	3	2	3	2	3
8	2	3	3	2	2	2	2	2	1	3	3	1	3	2	3
9	3	2	3	2	2	3	2	2	2	3	2	2	3	2	2
10	3	2	2	2	2	3	2	2	1	3	3	1	3	2	3
11	3	2	2	2	2	2	3	2	2	3	3	2	3	2	3
12	3	3	2	3	1	2	2	2	2	2	2	2	2	1	2
13	3	2	2	3	2	2	2	2	1	3	2	1	3	2	2
14	2	3	2	2	2	2	3	2	3	3	2	3	3	2	2
15	2	2	3	3	2	2	2	2	2	3	2	2	3	2	2
16	2	3	2	3	2	3	3	2	1	2	3	1	2	2	3
17	2	2	2	2	2	3	2	1	2	2	3	2	2	2	3
18	2	2	2	3	3	3	2	2	2	3	2	2	3	3	2
19	3	3	2	3	3	3	2	2	1	2	2	1	2	3	2
20	3	3	2	2	2	2	2	3	2	3	3	2	3	2	3
21	2	3	3	2	2	3	2	2	1	2	3	1	2	2	3
22	2	3	2	3	2	2	2	2	1	3	3	1	3	2	3
23	2	3	2	2	2	2	3	2	2	3	3	2	3	2	3
24	2	2	2	2	2	2	2	3	2	2	3	2	2	2	3

	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5
25	3	3	3	2	2	2	2	2	2	3	3	2	3	2	3
26	3	3	2	2	2	2	3	2	2	3	3	2	3	2	3
27	2	3	2	2	2	3	2	2	2	3	3	2	3	2	3
28	2	3	3	2	2	2	2	2	2	3	2	2	3	2	2
29	2	3	2	2	2	3	2	2	2	3	3	2	3	2	3
30	2	3	2	3	2	2	3	2	2	2	2	2	2	2	2
31	2	3	3	2	2	2	2	2	2	2	3	2	2	2	3
32	3	3	2	3	2	2	3	2	2	2	3	2	2	2	3
33	2	3	2	3	2	3	2	2	3	2	3	3	2	2	3
34	2	3	2	2	2	2	2	3	2	3	3	2	3	2	3
35	2	2	2	2	2	2	2	2	3	3	3	3	3	2	3
36	2	3	2	3	2	3	2	2	1	3	3	1	3	2	3
37	2	2	2	1	1	3	1	3	1	2	2	1	2	1	2
38	2	3	2	2	2	2	2	3	1	3	3	1	3	2	3
39	3	2	2	2	2	3	2	2	2	3	3	2	3	2	3
40	3	3	2	2	3	2	2	2	2	3	3	2	3	3	3
41	3	2	2	2	2	2	3	2	2	2	2	2	2	2	2
42	3	2	2	2	3	2	2	2	2	3	2	2	3	3	2
43	3	3	2	2	2	2	2	2	2	3	2	2	3	2	2
44	2	3	2	2	3	3	2	2	2	2	3	2	2	3	3
45	3	3	2	3	2	2	2	2	3	2	3	3	2	2	3
46	3	3	3	2	3	2	3	2	1	2	2	1	2	3	2
47	3	3	2	2	3	3	2	2	2	2	2	2	2	3	2
48	3	3	2	3	2	1	3	2	2	2	3	2	2	2	3
49	3	2	2	2	2	3	2	2	2	3	2	2	3	2	2
50	3	3	2	2	2	3	2	2	1	2	3	1	2	2	3
51	2	3	3	2	2	3	2	2	1	3	2	1	3	2	2
52	3	2	2	2	2	3	2	2	2	3	3	2	3	2	3
53	2	3	3	2	2	2	2	3	1	2	3	1	2	2	3
54	2	2	2	2	3	3	2	2	1	2	3	1	2	3	3
55	2	2	2	2	2	3	2	1	2	3	3	2	3	2	3

Source: by the authors.

After obtaining the results of the qualitative sampling of singularity in the selected higher education centres, the next step was a mathematical analysis of the scores assigned in the model for the characterisation and classification of unique institutions. Next, we checked their viability mathematically as the basis for our analytical instrument. It should be noted that the classification model for these profiles was intended to cover all the aspects where a given higher education institution could be considered unique or singular, as described above. To do this, first we constructed a mathematical model for comparing the codified information and using it to formally establish the relationships between the universities involved in the model.

In this case, we applied a principal component analysis (Jolliffe & Cadima, 2016) to our initial database in order to reduce the number of significant variables from the original 15. This analysis provided a procedure for determining the appropriate number of variables to describe the data. Using the R programming language, we calculated the correlation matrix for the values of the 15 initial variables, considering all the sampled institutions. In the programme results the variables were labelled from X1 to X15, in the order they were initially entered, and grouped in categories A1 to C5. When examining this matrix directly, no very strong relationships were observed between the different variables, as shown in Table 5. Therefore, it did not seem appropriate to exclude any of the initial variables using this criterion, validating the proposed analysis model.

Table 5
Correlation matrix relating to the initial variables

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15
X1	1.000	0.230	0.088	0.136	0.127	-0.225	-0.205	0.377	0.209	0.165	0.197	0.091	0.136	0.503	0.205
X2	0.230	1.000	0.164	0.249	0.141	0.084	-0.012	0.195	0.392	0.000	0.289	0.251	-0.005	0.017	0.206
X3	0.088	0.164	1.000	-0.063	-0.007	-0.223	-0.145	-0.202	0.077	-0.173	0.021	-0.004	-0.253	-0.223	-0.091
X4	0.136	0.249	-0.063	1.000	0.130	0.066	-0.168	0.521	-0.072	0.130	-0.011	-0.199	-0.148	-0.155	-0.282
X5	0.127	0.141	-0.007	0.130	1.000	0.110	0.335	0.246	0.087	-0.024	0.167	0.087	0.178	0.325	0.158
X6	-0.225	0.084	-0.223	0.066	0.110	1.000	0.198	-0.132	-0.202	-0.134	0.075	0.289	-0.020	0.045	0.168
X7	-0.205	-0.012	-0.145	-0.168	0.335	0.198	1.000	-0.041	-0.133	-0.131	0.449	0.381	0.141	0.286	0.399
X8	0.377	0.195	-0.202	0.521	0.246	-0.132	-0.041	1.000	0.085	0.398	0.076	0.067	0.199	0.146	0.031
X9	0.209	0.392	0.077	-0.072	0.087	-0.202	-0.133	0.085	1.000	0.187	0.447	0.132	0.285	0.333	0.073
X10	0.165	0.000	-0.173	0.130	-0.024	-0.134	-0.131	0.398	0.187	1.000	0.335	0.113	0.201	0.329	-0.047
X11	0.197	0.182	0.021	-0.011	-0.062	-0.058	-0.034	0.166	0.447	0.335	1.000	0.386	0.331	0.328	0.314
X12	0.091	0.289	-0.004	-0.199	0.167	0.075	0.449	0.076	0.398	0.109	0.544	1.000	0.310	0.302	0.625
X13	0.136	0.251	-0.253	-0.148	0.087	0.289	0.381	0.067	0.132	0.113	0.544	0.365	1.000	0.474	0.510
X14	0.503	-0.005	-0.223	-0.155	0.178	-0.020	0.141	0.199	0.285	0.201	0.331	0.351	0.435	1.000	0.027
X15	0.205	0.017	-0.091	-0.282	0.325	0.045	0.286	0.146	0.333	0.329	0.328	0.474	0.435	0.248	1.000

Source: by the authors.

DISCUSSION

The purpose of this paper is to invite the academic world to discuss the concept of singularity in education, in order to create a new framework for study and analysis according to this perspective, which transcends singularity in technology, economics, mathematics, or physics. To achieve this, we had to search the academic literature in which the concepts of education and singularity are closely linked, yet unfortunately, there are very few examples. As we have indicated, our research was based on Wenham's (1987) "Singular Problems in Science and Science Education", published in the Journal of Philosophy of Education, which deals with the need to develop the concept of singularity in the field of education. This article represents one of the few documents establishing a framework for studying singularity in the educational sphere, and its theoretical basis inspired us to create an analytical model facilitating its detection, organisation and classification, enabling us to characterise singularity in higher education. Once the theoretical part was established, we began the process of characterising singularity in education, looking to identify changes and illustrate examples with institutions presenting differentiating features in their educational practice.

Meanwhile, we found a problem relating to the close link between trends and technology, which shifted our approach to the concept of singularity in the field of education. For example, when concepts such as future scenarios and futures studies are included, this might give the impression that we are talking exclusively about the technological singularity. However, it is important to note that these terms do not necessarily refer to the technological singularity, as is the case in this paper. There is extensive literature associating trends, future scenarios and future studies with the field of the social sciences (Decoufle, 1974; Godet, 2001; Mojica, 2005; Brown & Kuratko, 2015; Kuosa, 2010, 2016; Berenskoetter, 2011; Ito & Howe, 2016), and more specifically, with the field of education (Menéndez et al. 2022; Manetti et al., 2022b).

Our results enable us to offer the following answers to our research questions:

RQ1. How can we identify transformative trends in higher education?
Identifying transformative trends in higher education requires an exhaustive analysis of changes and progress in various relevant areas. Higher education is constantly evolving to adapt to the changing demands of society, technological advances, and the needs of the labour market. Through reviewing research projects, reports, and case studies, we identified 25 emerging patterns, innovations in teaching, and significant changes in how higher education is delivered.

RQ2. Can new models of higher education be identified based on the observed trends?
By finding and analysing transformative trends in higher education, we initially identified 110 educational organisations, which were then reduced to 55 which are implementing incremental or disruptive changes. These trends reflect transformations in teaching and learning, and in the structure and organisation of educational institutions. By observing these trends, we can identify new forms of higher education and understand how the educational environment is being transformed.

RQ3 How can we analyse the ways in which universities introduce singularity?

To analyse the introduction of singularity in universities we must examine in detail the elements of the teaching model, the organisation and service models they use. Each university has its own unique and differentiated approach to teaching, organising its structure, and offering student services. By studying these aspects, we can understand their differences and how they create singularity compared to other institutions. This involves reviewing their academic programmes, management strategies, organisational structure, approaches to teaching and learning, and the quality and diversity of the services offered to students.

RQ4. How can we evaluate the level of singularity of universities?

Evaluating the level of singularity of universities involves analysing various aspects which distinguish them from other institutions. This includes considering their unique approach to teaching, how their organisational model differs from other universities, the originality of the services and programmes they offer, and how third parties perceive their leadership and excellence in the university sphere. The level of singularity can be determined through a comparative analysis of relevant indicators such as educational innovation, academic reputation, graduate employability, and impact on society. We can also take into account external assessments, recognitions and awards received by the university relating to its singularity and its contribution to the field of higher education.

CONCLUSIONS

The search for differentiation in higher education is a phenomenon which is reconfiguring how education is perceived by students, teaching staff, and education centres. This transformation is strongly influenced by an amalgam of social and technological factors, which means that universities must be ready to adapt to these changes. Therefore, an exhaustive analysis is needed of the factors influencing this search for singularity, and a deep understanding of how these changes impact education access and quality. Only through this comprehensive approach can university institutions foresee and prepare for a future in which singularity becomes a reality.

As explained above, singularity, closely linked to innovation and technology in education, represents one of the components which can raise the quality of teaching and enable educational institutions to stand out successfully. Through our research framework, we have arrived at an in-depth understanding of the social and technological trends which may influence higher education. Thus, we have seen how the educational environment is altered by the adoption of new models, and we have identified, organised, and classified the elements of singularity in higher education. This covers the analysis of how singularity is impacting the university ecosystem and how universities can prepare to adopt singularity effectively. In this context, our paper seeks to stimulate debate, approaching singularity according to the conceptualisation of Wenham, with the idea of involving as many academics as possible in the characterisation of singularity in order to encourage substantive changes in higher education.

For future lines of work, we envisage the creation of an analytical tool which can transform the singularities found into crucial elements for implementing changes in higher education institutions. We also hope that this paper will contribute to beginning a process of creating work groups specialising in this subject, establishing an academic network for futures studies and singularity in higher education institutions.

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Assessment of immersive technologies and STEM focus in initial teacher training

Valoración de tecnologías inmersivas y enfoque STEM en la formación inicial del profesorado

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ABSTRACT

In recent years, there has been a growing interest in the integration of various Emerging Technologies in the field of Education, especially immersive technologies such as Virtual Reality (VR) and Augmented Reality (AR). This research aims at assessing the perceived usefulness of these technologies by pre-service teachers at the Faculty of Educational Sciences of the University of Granada, specifically in the STEM field, and how they evaluate their potential for integration into their future teaching practices. A mixed-methods approach was used, including a pre-questionnaire administered to the entire population (N=544) to describe the participants' perceptions, followed by a post-test conducted with a subset (N=58) after having participated in a Complementary Training program focusing on the creation of immersive educational resources using the CoSpaces platform. The results revealed a high perceived utility of immersive technologies, highlighting their potential for enhancing teaching and learning in the STEM domain. However, challenges related to ease of integration and the lack of adequate training in the use of these technologies were identified. The importance of promoting teacher training and digital literacy to fully leverage the benefits of these emerging technologies in education is emphasized. Further research is suggested to delve into teacher training strategies and explore other educational contexts to expand the understanding of the implications and advantages of immersive technologies.

Keywords: scientific education; educational technology; educational innovation; teacher education; didactics; STEM education.

RESUMEN

Durante los últimos años se ha detectado un progresivo interés por la integración de diversas Tecnologías Emergentes en el ámbito de la Educación, especialmente aquellas de tipo inmersivo como la Realidad Virtual Inmersiva y Realidad Aumentada. En la presente investigación se tiene por objetivo valorar la utilidad que le atribuyen los docentes en Formación Inicial en la Facultad de Ciencias de la Educación de la Universidad de Granada a este tipo de tecnologías, específicamente en el ámbito STEM, y cómo evalúan la capacidad de integrarlas en sus futuras prácticas docentes. Se utilizó una metodología mixta, donde se aplicó un cuestionario previo a toda la población (N=544) para describir las valoraciones de los participantes, seguido de un post test a una submuestra (N=58) luego de participar de una Formación Complementaria para la creación de recursos educativos inmersivos desarrollados con la plataforma CoSpaces. Los resultados revelaron una alta utilidad atribuida a las tecnologías inmersivas, destacando su potencial para mejorar la enseñanza y el aprendizaje en el ámbito STEM. Sin embargo, se identificaron desafíos relacionados con la facilidad de integración y la falta de formación adecuada en el uso de estas tecnologías. Se enfatiza la importancia de promover la capacitación docente y la alfabetización digital para aprovechar plenamente los beneficios de estas tecnologías emergentes en la educación. Se sugiere la realización de futuras investigaciones que profundicen en estrategias de formación docente y que aborden otros contextos educativos para ampliar el conocimiento sobre las implicaciones y ventajas de las tecnologías inmersivas.

Palabras clave: educación científica; tecnología de la educación; innovación pedagógica; formación de profesores; didáctica; educación STEM.

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INTRODUCTION

In the field of education, particularly in the teaching of Sciences, the STEM (Science-Technology-Engineering-Mathematics) approach has gained increasing relevance in recent years. This approach focuses on promoting interdisciplinary integration of these knowledge domains to foster critical thinking, problem-solving, and creativity in students (Martín-Páez et al., 2019; Thibaut et al., 2018; Toma & Greca, 2018). Among its various goals, STEM education seeks to prepare students to face the challenges of the 21st century, where technology plays a fundamental role in society and the economy (Bybee, 2013; Sanders, 2009). The implementation of STEM education in national and international curricula is grounded in research demonstrating the benefits of these pedagogical approaches for developing fundamental skills in students (Fleer, 2013; Toma & Meneses-Villagrá, 2019; Zollman, 2012).

As this approach strengthens, there is an increasingly recognized importance in integrating emerging technologies as an integral part of Science Education, especially within the STEM framework (Makhoka, 2017; Chng et al., 2023; Ferrada et al., 2020; Silva-Díaz et al., 2021; Xia & Zhong, 2018). The incorporation of Emerging Technologies in STEM education has demonstrated a positive impact on student learning, offering numerous benefits, including improved attitudes toward science (Aguilera & Perales-Palacios, 2018; Cabello et al., 2021; Makransky et al., 2020; Thibaut et al., 2018). Among the most relevant Emerging Technologies are Immersive Virtual Reality (IVR), Augmented Reality (AR), 3D Printing, Educational Robotics, and Sensors, just to name a few (Freeman et al., 2017; Dubé & Wen, 2022; Silva-Díaz et al., 2022).

However, the integration of technology in education has also posed new challenges for teachers (Barroso et al., 2019; Cabero-Almenara, Romero-Tena et al., 2021; Silva-Díaz et al., 2021). In many cases, educators do not feel adequately prepared or lack the necessary competencies to effectively use technological resources in the classroom. This gap between the demand for technology in the educational environment and teacher preparedness has been a subject of concern and debate (Christensen, 2002; Ertmer et al., 2012; Boel et al., 2023; Sanchez-Prieto et al., 2019). The need for developing digital teaching competence has become increasingly evident because educators must acquire skills and knowledge to get the most out of these technological tools and ensure quality teaching within the STEM context (Del Moral et al., 2022; Cabello et al., 2021). Furthermore, it is a must for teachers to develop the ability to design and create innovative technological resources to enrich and enhance their educational activities (Cabero-Almenara, Vázquez-Cano et al., 2021; Cviko et al., 2014; Del Moral et al., 2022). Therefore, teachers can adapt to the demands and challenges of the digital era, promoting more interactive and meaningful learning for their students. However, in order to achieve effective activity design that involves technological integration in STEM education, it is essential to provide teachers with opportunities for training and professional development. Of equal necessity is ensuring the access to technological resources and institutional support needed to effectively implement these tools in the classroom (Buss et al., 2018; Cabero Almenara, Romero-Tena et al., 2021; Nistor et al., 2019).

Regarding the use of Emerging Technologies as didactic resources, several studies highlight their increasing importance all over the world, especially in the context of

STEM education (Freeman et al., 2017; Dubé & Wen, 2022; Hod, 2017; Hung & Khine, 2006; Lui & Slotta, 2014).

Taking into account the insights already mentioned, a research study has been designed stating four objectives:

O1. To characterize the point of view of pre-service teachers towards technology, the use of Virtual Reality (Augmented and Immersive), the ease of use of technologies for STEM learning, and the potential of technologies for learning and teaching.

O2. To analyze perceptions and experiences of pre-service teachers regarding additional training for creating immersive resources with CoSpaces[1].

O3. To identify the benefits and challenges of integrating Emerging Technologies by delivering a seminar and the design of educational resources in the training of future STEM educators.

O4. To provide recommendations for integrating Emerging Technologies into the initial teacher education program in the field of STEM education, considering the findings and results obtained in the research.

METHOD

This study uses a mixed-methods research methodology with a sequential explanatory design of two phases (Hernández Sampieri et al., 2014). In the first phase, a descriptive quantitative approach is used to analyze data collected through a questionnaire. The second phase involves a more specific analysis of a sample of respondents by using the questionnaire's six specific items that assess the ease and potential of using Virtual Laboratories (items 13 and 19), Augmented Reality (14 and 20), and Immersive Virtual Reality (15 and 21). The post-test application is conducted to the specified items because these technologies were only used during Phase 2. The difference between pre-test application to the total sample and post-test application to participant sample of the CoSpaces Immersive Resource Creation Activity (ACRI, being its acronym in Spanish) allows researchers to obtain a deeper understanding of the results obtained in the descriptive analysis. Additionally, a qualitative approach is used based on content analysis for open-ended questions that belongs to the same instrument. The purpose of mixing these approaches is to provide a comprehensive and detailed insight into the study's findings in order to provide some knowledge and understanding in the research field.

Participants

The research was conducted as part of a seminar offered to students from different undergraduate programs. The majority of the students were enrolled in courses related to the Didactics of Experimental Sciences at the University of Granada during the academic years 2020/21, 2021/22, and 2022/23. In relation to the 2020/21 and 2021/22 academic years, it is worth noting that, despite the challenges presented by the COVID-19 pandemic, the University of Granada implemented measures to ensure the continuity of in-person activities. These activities were always carried out under strict safety protocols. In particular, the Department of Didactics of Experimental Sciences decided to deliver laboratory activities in a face-to-face format, adapting laboratory and classroom capacity and making sure that safety protocols were fulfilled to protect both the students and the faculty.

In the first phase, participants were selected through intentional non-probabilistic sampling (Cardona, 2002) due to accessibility criteria. The sample consists of 554 participants who completed the questionnaire in a single application before the seminar was delivered. These participants belonged to 16 class groups (twelve class groups from 3rd year and one from 2nd year of the Primary Education degree, one class group from 2nd year, and two class groups from the Master's degree in Secondary Education, Vocational Training, and Language Teaching).

In the second phase, there is a subsample of 58 participants (62.1% female and 37.9% male, as self-identified), who selected themselves based on their interest of post-seminar autonomous work activities proposed to four class groups (three class groups from the 3rd year of the Primary Education degree – 53.4% of participants – and one class group from the Master's degree in Secondary Education, Vocational Training, and Language Teaching, specializing in Biology and Geology – 46.6% of participants). They completed the questionnaire in a second post-intervention application after completing these activities.

Data collection method

For data collection, the Emerging Technologies in STEM Education Questionnaire (CUTE-STEM, being its acronym in Spanish) was used, which was specifically developed for this study. The questionnaire consists of 27 items, with 23 close-ended questions and four dimensions for quantitative items. Seventeen questions (items 1-5 and 12-23) were rated using a 5-point Likert scale, while the remaining five items were dichotomous (items 6-11). The reliability of the questionnaire was determined by using Cronbach's alpha coefficient for all Likert-type items (17 items), obtaining an acceptable reliability (α= 0.823).

Additionally, four open-ended questions were included: a) to assess attitudes, beliefs, and knowledge related to the integration of technology in STEM education (PA_01); b) to evaluate the differences between Augmented Reality and Immersive Virtual Reality (PA_02); c) to describe the advantages and disadvantages of using Virtual Reality as a resource for STEM education (PA_03); and d) to provide a space for reflection in which students could contribute any observations they consider relevant regarding the inclusion of technology in STEM education (PA_04). Table 1 shows the distribution of questionnaire items grouped by dimensions, and their descriptions.

Table 1

Distribution of Questionnaire Items and Dimensions

Dimensions and Items	Definition
A. Point of View towards technology. (α = 0.806)	
1. I am interested in technology. 2. I use technology for my personal leisure. 3. I use technology in my learning process. 4. I have critical thinking skills when it comes to digital content. 5. I am competent in the use of technology.	This category examines the degree of interest in technology, their personal use of it, and their technological competence for educational purposes. It also involves assessing their critical thinking skills regarding digital content (Internet, social media, etc.).

Dimensions and Items	Definition
B. Use of Virtual Reality (Dichotomous Items)	
6. Augmented Reality for recreational purposes.	This category measures the frequency and purpose of using Virtual Reality for personal entertainment or educational activities. The goal is to assess the extent to which participants integrate technological tools and devices into their daily routines.
7. Augmented Reality for learning in a subject.	
8. Augmented Reality for teaching purposes.	
9. Immersive Virtual Reality for recreational purposes.	
10. Immersive Virtual Reality for learning in a subject.	
11. Immersive Virtual Reality for teaching purposes.	
C. Ease of use of Technologies for STEM Learning (α = 0.734)	
12. Ease of use of 3D Printing.	This category assesses the feasibility of using Emerging Technologies as educational resources. The focus is on evaluating the practicality and potential ease of implementation of these technologies in STEM education.
13. Ease of use of Virtual Laboratories.*	
14. Ease of use of Augmented Reality.*	
15. Ease of use of Immersive Virtual Reality.*	
16. Ease of use of Educational Robotics.	
17. Ease of use of Sensors.	
D. Potential of Technologies as a Resource for STEM Learning (α = 0.847)	
18. Potential of 3D Printing.	This category refers to the assessment of the potential use of specific technologies for teaching and learning in STEM areas.
19. Potential of Virtual Laboratories.*	
20. Potential of Augmented Reality.*	
21. Potential of Immersive Virtual Reality.*	
22. Potential of Educational Robotics.	
23. Potential of Sensors.	

Note: Dimension B consists of dichotomous items, so Cronbach's alpha calculation is not applicable.
* Used for the post-test application (items 13, 14, 15, 19, 20, and 21).
Source: elaborated by authors.

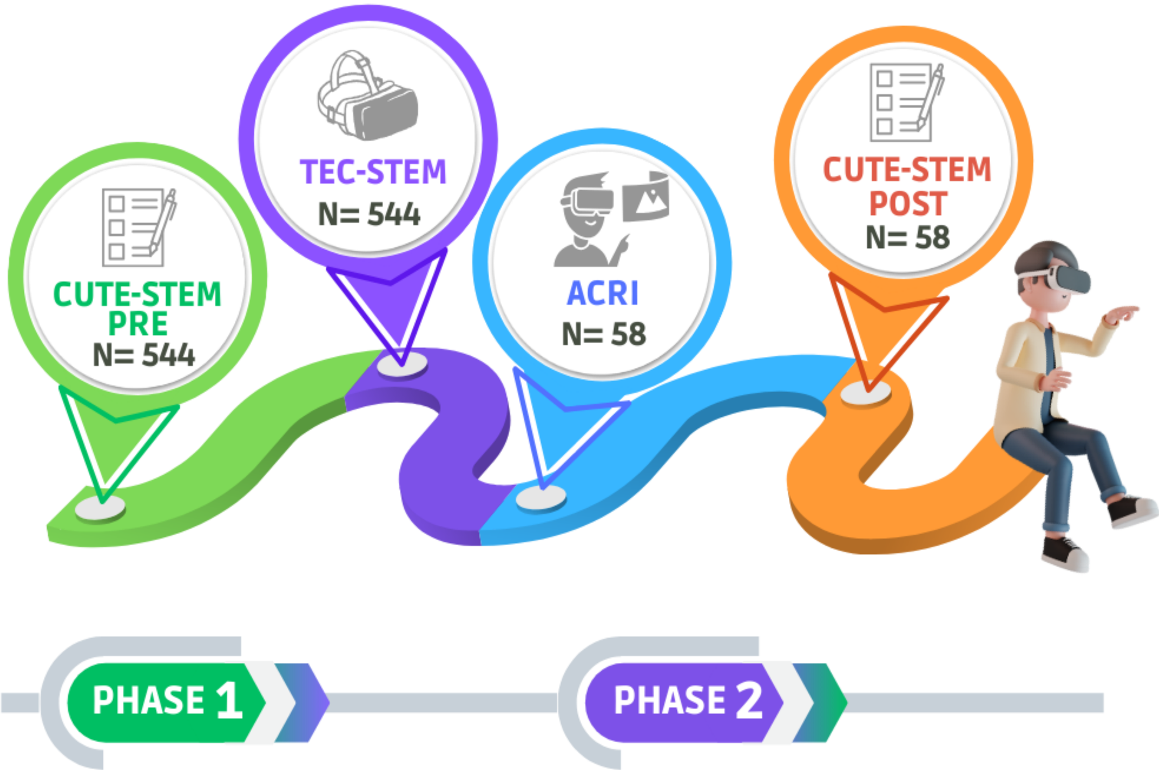
Data Processing

The statistical analysis of the quantitative data in the research was conducted by using SPSS v26 software, while MAXQDA software, version 2020, was used for qualitative analysis.

Procedure

The research was conducted in two phases (Figure 1). The first phase involved the administration of the instrument described earlier, allowing us to characterize the students' needs regarding the design of a training program focused on the integration of Emerging Technologies in STEM education. The initial administration of the CUTE-STEM questionnaire to different courses enabled us to make continuous improvements in the seminars. The second phase was developed based on the identified needs resulting in the design of two formative training sessions for university students.

Figure 1
Phases of Research Implementation



Source: elaborated by authors.

The first of these phases corresponds to a two-hour Seminar conducted in a face-to-face format. It is aimed at providing an overview of Emerging Technologies for STEM education, with an emphasis on Augmented and Immersive Virtual Reality. Additionally, there is an optional and additional training session, in an asynchronous virtual format, offered to participants of the Seminar. In this training session the students have to design an immersive educational resource using the CoSpaces platform. The post-test was administered after completing the activity, with an estimated time frame of three weeks.

Seminar "Emerging Technologies for STEM Education" (TEC-STEM)

In the TEC-STEM Seminar, an overview of technologies, that are being implemented as learning resources, is presented. Within the technologies, didactic activities that involve the use of Immersive Virtual Reality for a learning situation are developed. Students use various Virtual Reality headsets (PlayStation VR, Oculus Go, Oculus Rift-S, Meta Quest 2, Pico Neo 3 Pro, and mobile VR headsets), which allow them to better understand their use and the integration of headsets as learning resources.

Among the activities, the RVI application "Titans of Space Plus"[2] is used with Quest 2 headsets simultaneously. As part of the activity, students are asked to express their previous ideas in regard to the proportional relationships in size and distance among the planets of the Solar System by drawing. Then, they carry out the immersive experience (Figure 2).

To ensure that students understand the proper distribution of technological resources, "collaborative workstations" were set up. Each one comprises of a Quest 2 headset and an Android-based tablet (Lenovo M10). The tablets are used to project the image that students are watching while using the headsets, making it possible to know what students can see whilst using the RVI application and therefore offer to assist them quickly and easily. Additionally, it provides a solution for those students who are not wearing glasses as they "accompany" their peers on the journey through the Solar System. The activity also involves searching for relevant information for subsequent activities, which is contained within the immersive experience. This way, all team members are engaged in the process of searching for and collecting information.

Figure 2

Seminar "Emerging Technologies for STEM Education"

Source: authors' compilation.

In order to replicate the settings used in this research, the authors recommend using an independent wireless connection system. A good solution for this is the use of mobile internet (mobile chip) and a 4G/5G wireless router.

Immersive Resource Creation Activity with CoSpaces

Regarding virtual training, the "Complementary Activity for Immersive Resources with CoSpaces" (ACRI) was implemented asynchronously, and it was offered as part of the TEC-STEM Seminar. This activity was offered voluntarily to students from the four groups participating in this training session. The main objective of this activity was to design an immersive educational resource by using the CoSpaces platform. They were asked to design a 360-degree scene that integrated various objects and elements available on the platform, to apply them to school activities in relation to teaching sciences and STEM approaches. To provide support and guidance, a detailed self-study video was developed and provided to students, outlining step-by-step how to design a scene in CoSpaces. Additionally, a video tutorial developed by the authors of this research was provided. This activity was carried out to promote the use of immersive resources and encourage the practical application of knowledge acquired in the field of experimental science education. Figure 3 provides examples of some activities developed by students.

Figure 3
Immersive Resources developed in CoSpaces

Source: authors' compilation.

RESULTS

The results of this research are presented in relation to the phases and types of analyses conducted. In the first phase, descriptive statistics were performed to characterize the sample. In the second phase, mixed analyses were conducted. In terms of quantitative analysis, non-parametric pre-post comparison tests, using the Wilcoxon test, were applied. The sample did not meet normality criteria. Additionally, effect size was used to complement statistical analysis, evaluating Cohen's delta (d) value.

Regarding qualitative analysis, a content analysis of participants' responses was conducted to identify thematic patterns and gain a deep understanding of their experiences and perceptions.

Phase 1

Four dimensions were analyzed based on the initial administration of the CUTE-STEM questionnaire: A) Point of view towards Technology, B) Use of Virtual Reality, C) Ease of Use of Technologies for STEM Learning, and D) Potential of Technologies for Learning and Teaching.

The mean scores of the questionnaire obtained by the sample of participants in the complementary ACRI training and those who did not participate in it are presented

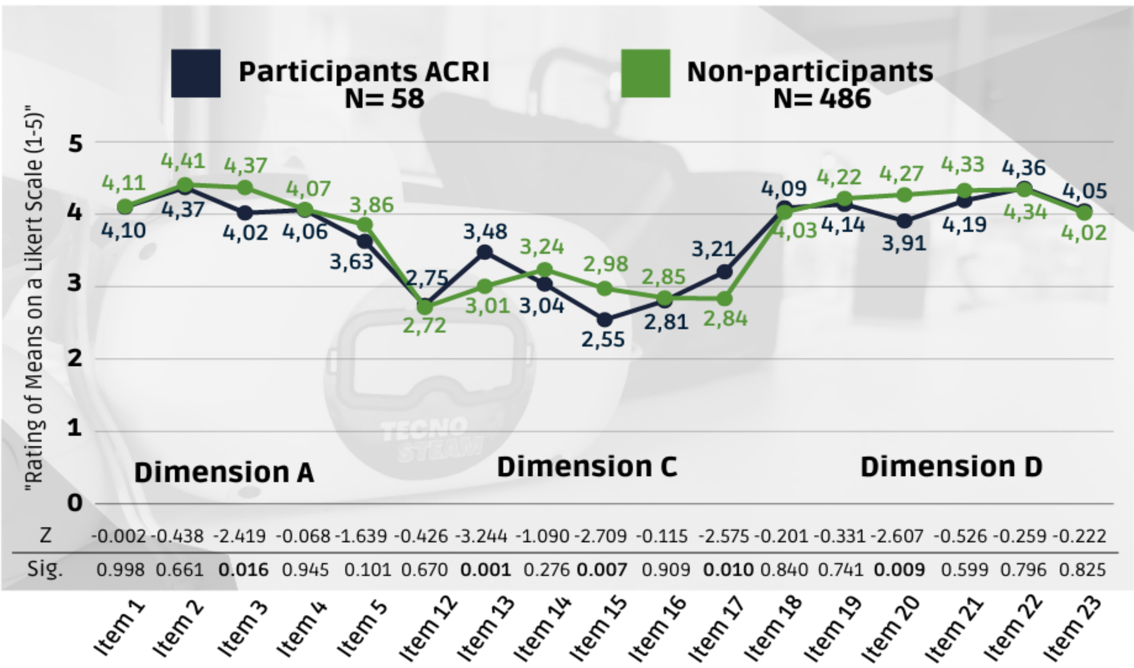
(Figure 4). In order to determine the existence of statistical differences between both groups, the U-Mann Whitney test was applied. The results revealed that there were no significant differences except for five items.

In the item "I use technology in my learning process" (item 3), a statistically significant difference (sig = 0.016) was found between the participant and non-participant groups. The mean score of the participant group (X = 4.02) was lower than that of the non-participant group (X = 4.37), indicating that participants reported that they used technology less frequently in their learning process than the non-participant group.

In the items "Ease of use of Virtual Laboratories" (item 13), "Ease of use of Immersive Virtual Reality" (item 15), and "Ease of use of Sensors" (item 17), statistically significant differences were also found (sig = 0.001, sig = 0.007, and sig = 0.010, respectively). While participants rated items 13 and 17 favorably compared to non-participants, in the case of item 15, the non-participant group reported a better mean score.

Figure 4

Mean Scores per Likert Scale Item of the CUTE-STEAM Instrument



Source: elaborated by authors.

Finally, in the item "Potential of Augmented Reality" (item 20), a statistically significant difference was found (sig = 0.009). However, in this case, the mean score of the participant group (X = 3.91) was lower than that of the non-participant group (X = 4.27), indicating that participants perceived less potential in Augmented Reality compared to the non-participant group.

These results suggest that although there are differences between both groups, these differences are slight, and they do not show a great divergence in the responses to the initial questionnaire by those who participated in the ACRI training compared to those who did not. This allows us to determine that the post-test results are likely representative of the initial sample. In the following section, the initial results for the four dimensions of the questionnaire are presented.

Point of view towards Technology (Dimension A)

High mean scores were observed in all evaluated items. Participants demonstrated a strong interest in technology (X = 4.11), indicating that they used it in their leisure time (X = 4.41) as well as in their learning process (X = 4.34). They also showed a thoughtful attitude towards digital content (X = 4.07). However, their perception of competence in using technology was slightly lower (X = 3.84) (Table 2 and Figure 4).

Table 2

Frequency, Mean, and Standard Deviation of Items in the "Point of View towards Technology" dimension of the CUTE-STEM Instrument

	N	1	2	3	4	5	X	SD
1. I am interested in technology.	489	1	12	119	156	201	4.11	0.872
2. I use technology for my personal leisure.	489	1	5	55	160	268	4.41	0.744
3. I use technology in my learning process.	489	0	9	63	172	245	4.34	0.770
4. I have critical thinking skills when it comes to digital content.	489	3	14	94	213	165	4.07	0.834
5. I am competent in the use of technology.	489	2	24	148	191	124	3.84	0.875

Note: Likert Scale: 1: Very Little; 2: Little; 3: Intermediate Level; 4: Much; 5: Very Much. X = Mean; SD = Standard Deviation.
Source: elaborated by authors.

Ease of Use of Technologies for STEM Learning (Dimension C)

Differences in mean scores were observed for the evaluated items. Participants perceived greater difficulty in using 3D Printing (X = 2.72). On the other hand, they considered the use of Immersive Virtual Reality (X = 2.94), Virtual Laboratories (X = 3.06), and Augmented Reality (X = 3.22) slightly easier (Table 3 and Figure 4).

Table 3

Frequency, Mean, and Standard Deviation of Items in the Ease of Use of Technologies for STEM Learning Dimension of the CUTE-STEM Instrument

	N	1	2	3	4	5	Na	X	SD
12. Ease of use of 3D Printing.	544	50	168	170	88	21	47	2.72	1.006
13. Ease of use of Virtual Laboratories.	544	33	124	171	132	45	39	3.06	1.060
14. Ease of use of Augmented Reality.	544	24	96	185	140	56	43	3.22	1.032
15. Ease of use of Immersive Virtual Reality.	544	42	122	168	118	29	65	2.94	1.045
16. Ease of use of Educational Robotics.	544	68	136	157	123	34	26	2.84	1.125
17. Ease of use of Sensors.	544	43	131	179	115	22	54	2.88	1.010

Note: Likert Scale: 1: Very Difficult; 2: Difficult; 3: Intermediate Difficulty, Neither Easy nor Difficult; 4: Easy; 5: Very Easy. X = Mean; SD = Standard Deviation. Na = Does Not Know / Did Not Answer.
Source: elaborated by authors.

Potential of Technology for STEM Learning (Dimension D)

High average scores were obtained in all the evaluated items. Participants recognized the high potential of Sensors (X = 4.03), 3D Printing (X = 4.04), Virtual Laboratories (X = 4.21), Augmented Reality (X = 4.23), and, above all, Immersive Virtual Reality (X = 4.31) and Educational Robotics (X = 4.34) as valuable resources for STEM learning (Table 4 and Figure 4).

Table 4

Frequency, mean, and standard deviation of items in the Potential of Technology for STEM Learning dimension of the CUTE-STEM instrument

	N	1	2	3	4	5	Na	X	SD
18. Potential of 3D Printing.	544	5	17	117	202	186	17	4.04	0.888
19. Potential of Virtual Laboratories.	544	4	13	84	193	231	19	4.21	0.852
20. Potential of Augmented Reality.	544	1	13	74	208	220	28	4.23	0.799
21. Potential of Immersive Virtual Reality.	544	1	12	61	178	243	49	4.31	0.795
22. Potential of Educational Robotics.	544	4	10	48	192	252	38	4.34	0.793
23. Potential of Sensors.	544	2	25	99	187	167	64	4.03	0.895

Note: Likert scale: 1: Not useful at all; 2: Slightly useful; 3: Somewhat useful; 4: Quite useful; 5: Very useful. X = Mean; SD = Standard Deviation. Na= Don't know / No answer.

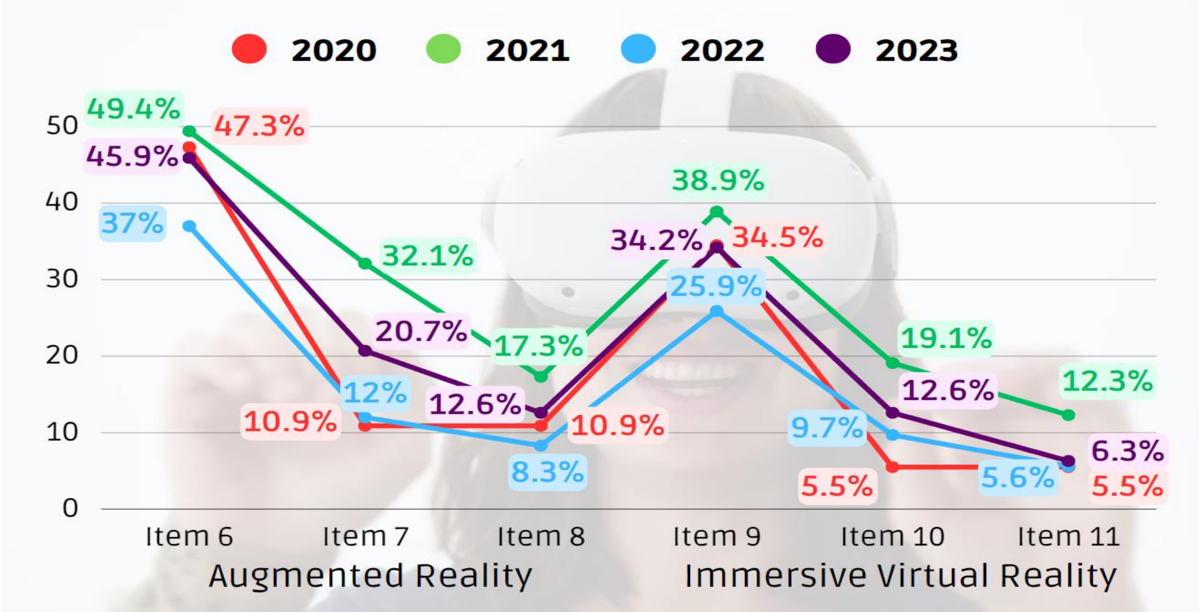
Source: elaborated by authors.

Use of Virtual Reality (Dimension B)

In terms of the dichotomous items, related to Augmented Reality, a considerable participant percentage (43.6%) indicated that they have used it for recreational purposes, while a much smaller proportion (19.7%) has used it as a learning tool for a specific subject. Additionally, only a small participant number (12.1%) has used Augmented Reality for teaching purposes in their role as teachers.

Regarding Immersive Virtual Reality (IVR), a similar frequency of use is observed compared to Augmented Reality. Approximately one-third of the participants (32.4%) have used Immersive Virtual Reality for recreational purposes, while a much smaller percentage (12.7%) have used it as a learning resource in a subject. In relation to the use of Immersive Virtual Reality for teaching purposes, the frequency is even lower, with only 7.7% of participants declaring they have used it in their role as teachers (Table 5 and Figure 5).

Figure 5
Evolution of the Frequency of Use for Augmented and Immersive Virtual Reality for each Year



Note: Values expressed in percentage.
Source: elaborated by authors.

An examination of the responses related to the use of Augmented and Immersive Virtual Reality that were divided into the year of application of the instrument, reveal that no clear trend of evolution over time is shown, regardless of the fact that ratings may vary to a certain extent. Additionally, a "sawtooth" distribution is observed with peaks in the use of Augmented Reality and Immersive Virtual Reality in recreational contexts, but with a lower evaluation in educational contexts.

Table 5
Frequency and standard deviation of the items in the Virtual Reality Use dimension of the CUTE-STEM instrument

	N	Sí	No	X	SD
6. Augmented Reality for recreational purposes.	544	237	307	1.56	0.496
7. Augmented Reality for learning in a subject.	544	107	437	1.80	0.398
8. Augmented Reality for teaching purposes.	544	66	478	1.88	0.327
9. Immersive Virtual Reality for recreational purposes.	544	176	368	1.68	0.468
10. Immersive Virtual Reality for learning in a subject.	544	69	475	1.87	0.333
11. Immersive Virtual Reality for teaching purposes.	544	42	502	1.92	0.267

Note: X = Mean; SD = Standard Deviation.
Source: elaborated by authors.

The results presented suggest a positive attitude and a favorable perception towards the use of technology in STEM education. However, areas for improvement were also identified, such as the perception of competence in using technology and the difficulty that participants experienced in using some technologies. Regarding technologies assessed in this research project, it is clear that their application in the educational field is still limited. Although, this study revealed that participants were more familiar with Augmented and Immersive Virtual Reality and that they also had more experience using them in recreational contexts, it is evident that much effort is needed to promote the use of these technologies as teaching and learning tools, both in specific subjects and in teaching practice.

Phase 2

The results obtained in the items that assess the ease of use of Virtual Laboratories, Augmented Reality, and Immersive Virtual Reality (items 13, 14, and 15) are presented (Table 6). Likewise, the items that evaluate the potential of these technologies as resources for teaching and learning in the STEM field in Primary/Secondary Education (items 19, 20, and 21) are shown (Table 6). Due to the data collection method being optional, there is variability in the sample. Additionally, in the case of items 14 and 20, which were specifically focused on the evaluation of Augmented Reality, it is stated that only one group designed activities based on this technology, so the post-test instrument application was limited to that group.

Table 6

Results of the Wilcoxon test and effect sizes for CUTE-STEM items pretest and post-test

	Pretest						Post-test							
	N	∑	X	Min	Max	Mo	N	∑	X	Min	Max	Mo	Sig	d
item 13	56	195	3.5	1	5	4	56	195	3.5	2	5	4	0.906	0
item 14	25	67	2.7	1	5	2	27	100	3.7	1	5	4	0.005**	0.975
item 15	51	130	2.6	1	5	2	58	176	3.0	1	5	3	0.019*	0.461
item 19	58	240	4.1	1	5	5	57	257	4.5	3	5	5	0.024*	0.460
item 20	27	99	3.7	1	5	4	26	101	3.9	1	5	4	0.302	0.199
item 21	53	222	4.2	1	5	5	58	247	4.3	1	5	5	0.742	0.068

Note: N = participants; ∑ = sum; X = mean; Min = Minimum; Max: Maximum; Mo = Mode; Sig = Bilateral significance (0.05); d = Cohen's delta.
Source: elaborated by authors.

Regarding the results, in item 13 (virtual laboratories), results for pre and post-tests with a sample of 56 participants were obtained. The pretest mean score (X = 3.5) indicates a perception of intermediate difficulty in using virtual laboratories, while in the post-test, the same value is obtained (X = 3.5), indicating consistency in the perception of difficulty. Both the Wilcoxon test (p = 0.906) and the Effect Size (d = 0) did not reveal significant differences between pre and post scores.

In relation to item 14, which assessed Augmented Reality, there were 25 participants in the pretest and 27 in the post-test. The pretest mean suggests a certain perception of difficulty (X = 2.7), while the post-test mean (X = 3.7) shows a significant improvement in the perception of ease. The Wilcoxon test revealed significant differences between pre and post scores (p = 0.005), with a large Effect Size (d = 0.975), indicating a substantial improvement in the perception of ease of use of Augmented Reality as a resource for STEM learning and teaching in Primary/Secondary Education.

Regarding item 15, which evaluated IVR, there were 51 participants in the pretest and 58 in the post-test. The pretest mean (X = 2.6) indicates a perception of difficulty, while the post-test mean (X = 3.0) reflects a slight improvement in ease of use. The Wilcoxon test revealed significant differences between pre and post scores (p = 0.019), with a moderate Effect Size (d = 0.461), indicating a statistically significant improvement in the perception of ease of use for IVR.

On the other hand, regarding the potential of these technologies (items 19, 20, and 21), high mean scores were observed both in the pre and post-tests.

The results reveal several important findings about participants' perception of the use of Virtual Reality (Augmented and Immersive) in educational settings. Participants assessed positively the potential of these technologies in both the pretest and post-test, demonstrating recognition of their educational and learning possibilities. These high mean scores on items that evaluate the potential of technologies (items 19, 20, and 21) support the idea that participants perceive their relevance and value in educational contexts.

Differences in the perception of the ease of use of emerging technologies were observed. Regarding the use of virtual laboratories (item 13), the results indicated a perception of intermediate difficulty both in the pretest and post-test, where no significant differences were found. This suggests that the perception of difficulty remained constant over time, indicating some need to address aspects related to the accessibility and usability of virtual laboratories in educational contexts.

However, a significant improvement in the perception of ease of use was observed in the post-test compared to the pretest regarding Augmented Reality (item 14) and Immersive Virtual Reality (item 15). These results indicate that the complementary training (TEC-STEM + ACRI) had a positive impact on participants' perception of the ease of use of these technologies. The presence of significant differences between pre and post scores, based on substantial effect sizes, emphasizes the importance of providing appropriate training to promote the adoption and effective use of these emerging technologies in educational contexts.

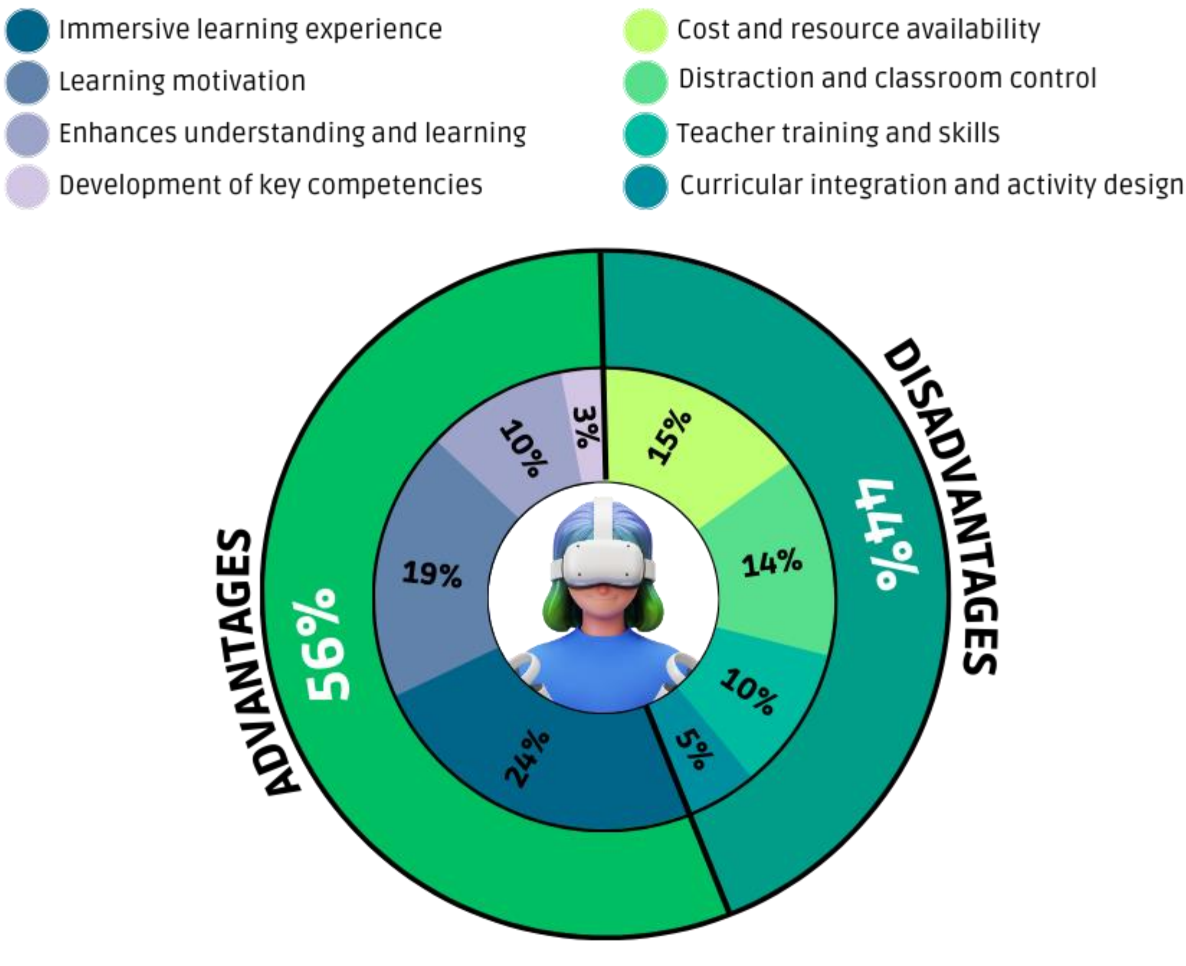
Content Analysis (Open-Ended Questions)

The qualitative evaluation of the questionnaire was conducted through inductive coding of responses (N=58) to understand reality from the participants' perspectives and discover new insights from them. Figure 6 presents the results of the open question (PA_03): In your opinion, what advantages or disadvantages do you think the use of Immersive Virtual Reality can have in teaching Sciences in Primary/Secondary Education?

In general, the responses reflect a positive perception of Immersive Virtual Reality in educational contexts. For example, some responses indicate that *"the use of Immersive Virtual Reality significantly increases student motivation and engagement, so learning sciences would be easier."* (P_41). Furthermore, it is observed that immersive experiences serve as a facilitating resource in the acquisition of abstract or complex concepts because *"Among the numerous advantages of this resource, it has the advantage to make abstract or hard-to-access concepts/facts easier to understand by students..."* (P_42).

Nevertheless, there are also some concerns and challenges related to cost and resource availability. For example, among the responses, it is mentioned that *not all* *schools can afford necessary resources to work with Immersive Virtual Reality, making some disparities between different schools.* (P_28). On the other hand, the potential loss of control during classes concerns teachers, because it could become a distractor during the teaching process: *it is a very distracting element, depending on the type of student, you can use it or not, you must be aware of every detail in class...* (P_10). Another important factor in the use of Immersive Virtual Reality relates to the shortcomings in Teacher Training: *"Limited teacher literacy to deliver classes" (P_57), because "Not all teachers have the skills to use this type of tool."* (P_33).

Figure 6
Qualitative Results



Note: Values expressed in percentage.
Source: elaborated by authors.

DISCUSSION AND CONCLUSIONS

The quantitative results obtained in this research are supported by the qualitative assessments provided by the participants. These qualitative assessments highlight a positive perception of Immersive Virtual Reality in educational contexts, emphasizing its impact on student motivation and engagement. These results are aligned with other research that has also concluded that the use of Augmented Reality (Del Moral et al., 2022; Nikimaleki & Rahimi, 2022; Martínez Pérez & Fernández Robles, 2018) and Immersive Virtual Reality (Álvarez et al., 2023; Radianti et al., 2020; Silva-Díaz et al., 2021) significantly enhances student motivation and engagement. It may also improve the learning process, especially in the field of science. Furthermore, it has been identified that immersive experiences can be beneficial for understanding abstract or complex concepts and suggests that these technologies make these concepts more comprehensible to students (Chang et al., 2019; Cheng & Tsai, 2020; Liu et al., 2020).

Moreover, concerns and challenges related to the use of Virtual Reality, especially Immersive Virtual Reality, in education are also evident. One of the main challenges that has been identified relates to the cost and availability of the resources required to implement technology, which can create inequalities among educational institutions. These concerns have already been observed in previous studies (García-Vandewalle et al., 2022; Silva-Díaz et al., 2021). Additionally, there is some concern about the potential loss of classroom control by teachers during lessons, as Immersive Virtual Reality can become a distracting element in the teaching process if it is not managed properly (Barroso et al., 2019; Nistor et al., 2019). Another relevant aspect to be considered is the lack of teacher training in the use of these tools. This study shows evidence of promoting digital literacy training for teachers to fully leverage the potential of Immersive Virtual Reality in educational settings (Boel et al., 2023; Del Moral et al., 2022; Nistor et al., 2019; Pellas et al., 2019).

Overall, the qualitative assessments complement and support the quantitative findings by providing a more detailed and contextualized perspective of participants' perceptions. These assessments reveal the importance of considering both the benefits and challenges associated with the use of Immersive Virtual Reality in education. They also emphasize the need to address aspects such as accessibility, resource management, classroom control, and teacher training to maximize the benefits of this emerging technology in the teaching and learning processes.

The main findings of this research provide relevant information in the design of strategies that promote the development of technological skills and better integration of technologies in educational contexts in order to foster learning and teaching in the STEM field.

To conclude, there is significant interest in future teachers in the use of various Emerging Technologies, and the high potential attributable to technology, especially in immersive technologies. This demonstrates that their integration into educational environments can enhance motivation, engagement, and content comprehension, and promote more immersive and meaningful learning experiences.

Furthermore, the importance of developing Initial Teacher Training strategies that introduce students to these types of technologies, and also allow them to understand how to integrate them into the classroom is emphasized. It also highlights the need to incorporate these technologies into teacher training programs to improve pedagogical practices.

In future research, the evidence suggests the exploration of innovative approaches for teacher training and addressing the practical implications and advantages of immersive technologies in various educational contexts.

It is important to consider the following limitations when interpreting the results of this research. Firstly, the Seminar (TEC-STEM) on Emerging Technologies in Education has experienced some changes over time, which may have affected the results in different phases of the study. Secondly, the variability in the sample size in the pre and post measurements should be considered. However, it is important to mention that measures were taken to minimize any bias related to sample size variation (application of the Wilcoxon test, which considers differences in sample size when comparing pre and post mean scores).

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NOTES

1. https://cospaces.io/edu/
2. https://www.oculus.com/experiences/quest/2359857214088490/

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Development of virtual and augmented reality apps for language teaching: A case study

Desarrollo de apps de realidad virtual y aumentada para enseñanza de idiomas: Un estudio de caso

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ABSTRACT

Technological advances in recent decades and their increasing accessibility pose a constant challenge to teachers. This paper is based on our experience of using digital tools in language teaching, with a particular focus on German as a foreign language. The paper illustrates how we have responded to digital trends in education by gradually incorporating technological resources to facilitate students' acquisition of language knowledge and skills. In addition, the need to integrate such resources without having specific programming skills and without depending on the support of information technology (IT) staff encouraged us to explore and use development tools, turning us from technology users into developers of our own virtual (VR) and augmented reality (AR) apps. In this context, a case study of 72 university students is presented. The study analyses and compares the educational and motivational potential of the two apps developed by the authors using CoSpaces and ARTutor. The research instrument used was a questionnaire based on the technology acceptance model by Davis (1989), and the results were statistically analysed using SPSS V27. The results of the Wilcoxon test show the suitability and great potential of the developed apps, with no significant differences between them in terms of usefulness or motivational potential. The long-term use of these apps will allow us to analyse their impact compared to other resources, leading to the design of possible improvements.

Keywords: educational technology; new technologies; language teaching; university studies; case study.

RESUMEN

Los avances tecnológicos de las últimas décadas y su creciente accesibilidad, suponen para los docentes un reto permanente. El presente trabajo se basa en nuestra propia experiencia con el uso de herramientas digitales para la enseñanza de idiomas, concretamente para el alemán como lengua extranjera. Se muestra cómo hemos respondido a las tendencias digitales de los últimos años en el ámbito educativo, incorporando progresivamente recursos tecnológicos para facilitar a nuestros estudiantes la adquisición de conocimientos y destrezas lingüísticas. Integrar estos recursos, sin tener conocimientos de programación y sin el constante apoyo de personal informático, nos ha llevado a explorar y usar herramientas de desarrollo, convirtiéndonos de usuarios de las tecnologías en desarrolladores de nuestras propias apps de Realidad Virtual (RV) y Realidad Aumentada (RA). En este contexto, se presenta un caso de estudio llevado a cabo con 72 estudiantes universitarios, en el que se analiza y compara el potencial educativo y motivador de dos apps creadas recientemente por los autores de este artículo con CoSpaces y ARTutor. Como instrumento de investigación se utilizó un cuestionario basado en el Technology Acceptance Model de Davis (1989), realizando con SPSS V27 un análisis estadístico de la información obtenida. Los resultados manifiestan la idoneidad y el enorme potencial de las apps desarrolladas, no existiendo entre ellas diferencias significativas con respecto a la utilidad o al potencial motivador (Test de Wilcoxon). El uso prolongado de estas apps nos permitirá analizar su impacto frente a otros recursos y diseñar las posibles mejoras.

Palabras clave: tecnología de la educación; nuevas tecnologías; enseñanza de idiomas; estudios universitarios; estudio de caso.

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INTRODUCTION

Technological advances in recent decades and their increasing accessibility have changed, and in many cases even revolutionised, the way we live, work, interact and communicate. Concepts such as artificial intelligence (AI), big data, algorithms, e-learning, facial recognition, digital citizenship, quantified self, ChatGPT and the metaverse have inundated our daily lives.

The potential of digital technologies, which focus on reducing and overcoming obstacles related to time, distance and/or space, is key in improving all areas of society in this process of constant change.

In this sense, international organisations such as UNESCO (2018), the European Union and the UN (2019) have reiterated, on numerous occasions, the need to promote the integration of digital technologies to advance not only work-related, personal or educational areas but also sustainable global development. Finding inclusive solutions and developing digital literacy have become priorities (García Aretio, 2019).

For centuries, education has been characterised by face-to-face teaching, with teaching–learning resources based on manuals and paper-based materials. However, technological advances and the trend towards the use of new resources have hastened the revolutionising and diversifying of teaching and learning models. Moreover, the recent pandemic and global stay-at-home orders have made the need for such digital transformations more visible than ever (López-Belmonte et al., 2023; Zalite & Zvirbule, 2020).

In analysing the technological and digital evolution of recent years, we can see that the creation of Web1 in 1989 and its extended versions (Web2, Web3 and Web4) have opened up a wide range of possibilities for creating new environments based on interaction, collaboration and co-creation between users (Tavakoli & Wijesinghe, 2019), as well as a wide range of possibilities for personalising content.

In this context of technological expansion, new teaching–learning models are being developed and consolidated. Concepts such as e-learning, blended learning (*b-learning or blended learning*) (Souabi et al., 2021), with its best-known pedagogical model, the flipped classroom (López-Belmonte et al., 2021), mobile learning (*m-learning*) (Lazar & Milena, 2013), ubiquitous learning (*u-learning or ubiquitous learning*) (Aljawarneh, 2020) and adaptive/personalised learning (Xie et al., 2019) have become popular topics of research and discussion. At the same time, other technologies are gaining importance:

- E-learning platforms or learning management systems (LMSs) (e.g., Claroline, WebCT, Blackboard, Moodle and Sakai) (Dobre, 2015).
- Interactive apps, commercial video games and educational video games (serious games) that promote entertainment, mass and online interaction and even gamified learning (Jabbari & Eslami, 2019; Peterson, 2016).
- Social networks (e.g., Facebook, Twitter, Instagram and YouTube), which enable communication and the sharing of information (Chartrand, 2012).
- Virtual environments and worlds that configure these new scenarios (Active World, Second Life, etc.), fed by the peculiarities and advantages of mass and online video games (Molka-Danielsen & Deutschmann, 2009).

At the same time, numerous development tools have emerged for the creation of platforms, apps, video games or virtual environments through which educational materials can be shared. Such development tools, initially commercial and aimed at professionals with programming skills but now offered as free or low-cost alternatives, allow for the creation and design of content and materials adapted to the needs of end users without computer skills (Terzopoulos et al., 2021; Vert & Andone, 2019). Digital technologies and tools, that offer different alternatives, are all characterised by their potential for creating new teaching–learning environments as well as new forms of interaction and learning enhancement.

Today, platforms such as Moodle and Blackboard have been well established. The use of audiovisual resources (podcasts, audio and video) and communication via platforms and social networks has become a reality. Every Moodle includes links to video conferencing apps (*Meet, Zoom* or *BigBlueButton*) and allows the sharing of a wide range of resources (text documents, multimedia presentations, video, audio, web pages, blogs, etc.). However, technological developments applicable to the field of education, especially university education, are much broader, especially with the development of virtual reality (VR) apps (Parmaxi, 2023) and, more recently, augmented reality (AR) or mixed reality (MR) apps (Parmaxi & Demetriou, 2020). The incorporation of chatbots, AI-based software capable of simulating real-time conversations (Neumann et al., 2021) or the metaverse, as an environment in which the real and virtual worlds (VWs) coexist, allowing users to move between them simultaneously (Aydin, 2023; López-Belmonte et al., 2023), are here to stay and will become part of the educational process sooner or later.

Technological advances and the creation and expansion of new teaching and learning models and tools have also impacted language teaching. An important milestone in this respect has been the introduction of virtual learning environments (VLEs)/LMSs and the creation of VWs. While the former provide many different tools for individual learning (text documents, multimedia resources, etc.) and collaborative learning (blogs, forums and wikis), the latter offer the possibility of designing environments that are usually difficult to recreate in the classroom and that, in addition, allow for language immersion outside the classroom.

Some implementations, such as those described by Canto et al. (2014), Molka-Danielsen and Deutschmann (2009) and Jauregi and Canto (2012), are examples that highlight the potential of VWs in strengthening learners' oral and intercultural competence. Other authors, such as Melchor-Couto (2017), have also highlighted their ability to reduce factors such as anxiety, which is prevalent among second-language speakers and usually hinders their language acquisition process (Krashen, 2003). Being able to communicate in VWs through an avatar and, therefore, avoiding physical exposure to other speakers, contributes positively to reducing such anxiety for many learners.

Balderas et al. (2017) and Palomo-Duarte et al. (2018) have highlighted the potential of VWs to provide learners with valuable opportunities for target language interaction, collaborative learning and the development of communicative competence. The implementations developed by these authors highlight the benefits of combining two different tools, such as video games and VWs, and exploiting the specificities of each to enhance learning.

Thus, computer-assisted language learning (CALL), which initially focused on the user's interaction with the computer and the software, or learning websites, is being increasingly enriched by the integration of new tools (chat, email, audio and video conferencing programmes, etc.) that facilitate interaction and communication with other speakers of the target language (Levy & Stockwell, 2013).

The growing access to new devices (e.g. mobile phones, tablets, smartphones, VR and AR glasses) and the trend in digital education to use cutting-edge technologies to make learning more attractive and adapt it to learners' pace and lifestyle have contributed to the creation and gradual consolidation of other methodologies, such as mobile language learning (MALL) and language learning through VR (VRALL) and AR (Burston & Giannakou, 2022; Heil et al., 2016; Parmaxi & Demetriou, 2020).

Methodologies such as CALL have greatly increased the number of valuable opportunities to facilitate learners' access to a wide variety of learning resources. However, the use of increasingly sophisticated mobile devices, and later, VR and AR glasses, have further extended and facilitated such learning opportunities, whether through interaction and collaboration with other users (SMS, voice and audio calls) or through interaction with immersive learning environments. In addition, the use of mobile devices has enabled increasingly ubiquitous learning, facilitating access to any material, at any time and from anywhere (Hua & Wang, 2023; Karakaya & Bozkurt, 2022; Kukulska-Hulme & Viberg, 2018).

Despite the enormous potential of VWs and apps designed to capitalise on VR and AR in language teaching, many difficulties are associated with their use and implementation. Czepielewski et al. (2011), Garrido-Iñigo and Rodríguez-Moreno (2015), Palomo-Duarte et al. (2018) and Jauregi-Ondarra and Canto (2022) have highlighted the main drawbacks of using VWs as a teaching and learning tool:

- A powerful server that can ensure a stable connection and good functioning of the VW is needed.
- Information technology (IT) support is required in designing and maintaining the VW and the resources created in it and in monitoring the students and their learning processes.

When it comes to the use of VR and AR, a large number of apps on commercial platforms such as Google Play and the App Store and many other tools allow VR and AR environments to be designed without the need for computer support (Terzopoulos et al., 2021), although they present new difficulties:

- Development software is often incompatible with different operating systems and device versions.
- Much of the current development software that is available for free and easy to use is very basic, with the full version still costing a lot of money.

This work, framed in the context of university teaching, is based on our own teaching experiences. During the last decade, learning to teach has been a challenge. Technological advances and the integration of technology into the university classroom have allowed us to develop digital resources that are partially or fully integrated into the course of academic activity. In just a few years, we have moved from the master class to blended learning, the flipped classroom and collaborative, ubiquitous, personalised and meaningful learning, where the student has become the main and essential actor in the process. Factors such as attitude and motivation are of great importance in achieving learning goals. Bringing the classroom closer to the student's daily reality, to the environment and context that the student knows, manages and is familiar with, both cognitively and affectively, greatly facilitates the learning process. Student-centred learning, using real and tangible contexts, allows for situated and contextualised teaching, which facilitates the acquisition of all the skills, abilities and knowledge required by the curricula.

Today's educational processes need to adapt to these changes and make use of the technological resources available to facilitate and promote lifelong and inclusive learning. However, there are many situations in which the teacher is not prepared to manage such resources or the resources have not been adapted to their needs (Romano et al., 2020) or to the needs of the curricular design. In addition, the integration of these tools often requires an extraordinary amount of time and additional effort, and the benefits of such tools are not always known *a priori*. If we add to this reality the still-existing digital divide, basic ethical principles, such as equal opportunity, and the usefulness, accessibility or scalability of technologies, we find ourselves at the nexus between technological possibility but methodological difficulty. In other words, we find ourselves in a technological world that is advancing at a faster pace than digital education and, of course, at a faster pace than we are ourselves.

DIGITAL EDUCATION IN LANGUAGE TEACHING

Teaching Experience

Today, many language teachers have incorporated digital technology into their teaching, and there are many research studies on the subject. However, it is difficult to determine which are the ideal tools and resources for those who want to learn a language. It is no easier to find such tools for those who teach a language, as many of the commercial resources available do not allow their content to be adapted or implemented to meet teaching and learning needs (Heil et al., 2016). Technological development in the last two decades and our concerns as teachers have led us to gradually explore the use of different technologies, tending to incorporate as many tools as possible to speed up learning as long as it was methodologically and pedagogically possible. However, we have been limited by our ability to design and create them.

Moodle allowed us to supplement our classroom teaching with a wide range of additional materials and resources for self-directed learning outside the classroom. These materials mainly comprise multimedia resources (interactive exercises with integrated feedback, podcasts, videos with native speakers, etc.) and the use of collaborative tools such as forums, chats and glossaries. While the former allowed us to provide our students with important resources to enrich their linguistic input, the latter allowed us to provide them with tools to use and practise the target language by making videos with other classmates and sharing them via a forum with the teacher and other course participants. Although our students' acceptance of these new teaching and learning resources was very positive, as were the results in terms of the language acquisition process, we soon felt the need to explore other environments. This need arose primarily from the attempt to extend the language acquisition process initiated in the classroom to learning outside of the classroom.

In this sense, VWs offered us the opportunity to create learning environments that were not only more attractive, dynamic and interactive than those offered by Moodle or other LMSs but also more similar to the environments in which our learners usually immerse themselves in their free time (video games, online environments, etc.). However, the implementation of VWs that responded to our teaching needs required IT support for their design and administration. Our first experiences with using and implementing VWs were therefore characterised by close collaboration with colleagues and experts in software development. Together, we designed our first video game, the *Supermarket-Game,* in which students have the opportunity, through different individual and competitive activities, to acquire vocabulary related to the products found in a supermarket and then to make a virtual purchase from the list of available products (Figure 1) (Berns et al., 2013).

Figure 1
Supermarket-Game

As a result of to the positive impact of the game on both motivation and student learning, we set out to further explore the potential of VWs to create and implement more collaborative environments. This led to the creation of a shop (*Saturn-Game*), a house (*Hidden-Room Game*) and a cafeteria (Figure 2. *GEFE-Game*). Interaction between players or with a bot in the case of the *GEFE-Game* took place via text chat, a feature that was enabled in each of the games.

Figure 2
GEFE-Game

The high potential of such environments to encourage the use of and interaction with other target language speakers was tested in case studies over several academic years with A1-level German learners at the University of Cádiz (Palomo-Duarte et al., 2018).

The constant development of mobile technologies, together with the spread of smartphones among our students, soon encouraged us to explore new learning environments based on m-learning. The first environment developed was an app called VocabTrainerA1, which focuses on students' acquisition of vocabulary and grammar while enhancing their comprehension, written expression and communicative competence. This environment combines several individual mini-games with a collaborative role-playing game (*Catch me if you can!*) in which players must use previously acquired language skills to jointly catch—through a role-playing game—a serial killer before he commits his next crime. The interactions that occurred on this collaborative app were collected as data on the server hosting the app, allowing us to analyse each student's participation and learning process.

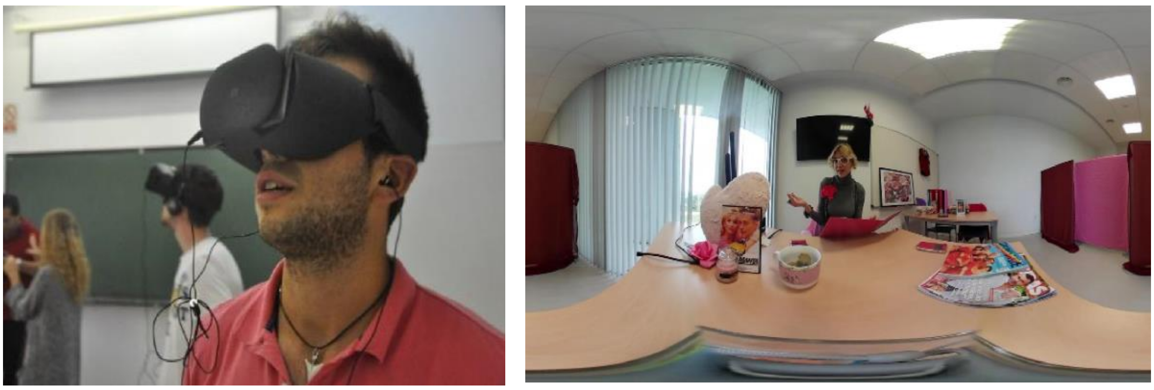
To foster students' acquisition of not only language skills and content (vocabulary, grammar, written comprehension and expression) but also cross-curricular skills (analytical critical thinking or teamwork through peer assessment), we developed a second app, called *Guess it! Language Trainer*. This app provides a gamified and highly dynamic environment based on community learning, which allows the user to both acquire new linguistic input (vocabulary, grammar and language structures) and apply it by creating and adding new content to the app. *Guess it! Language Trainer* is based on a client–server architecture, in which the server coordinates multiple mobile devices. The server's connection to the network and the system makes it possible to identify each user's interactions with the app and to store the data on the teacher's web portal, allowing the teacher to identify any difficulties the students may be having and to evaluate their learning process.

The asynchronous interactions enabled by *Guess it! Language Trainer* led us to design *Terminkalender* as an app model that would allow greater interaction and collaboration between users and, above all, synchronous communication between multiple users in a client–server architecture (Isla-Montes et al., 2022).

To explore the possibilities of immersive environments created through the use of 360º videos and the implementation of a chatbot, we developed the *Let's date!* VR app.

The use of a chatbot allowed us to offer learners new opportunities for language immersion and near-real interaction in the target language, although it cannot completely replace human-to-human interactions. In our *Let's date!* design, a scenario (a dating agency) was recreated using multiple spherical recordings, giving learners the opportunity to immerse themselves in a 'real world' while interacting with 'real people' (a dating agency employee). The app was developed using Visual Environment for Designing Interactive Learning Scenarios (VEDILS), a development tool that, although designed for non-computer scientists (Baena-Pérez et al., 2022), requires basic programming skills.

Figure 3
Let´s date!



Despite the enormous potential of the aforementioned technologies implemented in our classrooms, we encountered many difficulties as non-IT teachers. The foremost difficulty was the constant dependence on IT staff to develop, implement and ensure the proper functioning of any app based on the use of advanced technology (AT). This soon led us to look for more sustainable solutions (i.e., tools capable of facilitating and speeding up both the creation and implementation processes inside and outside the classroom). In this regard, the increasing proliferation and availability of open source apps and development tools (Terzopoulos et al., 2021; Vert & Andone, 2019) provided us with valuable opportunities to easily create VR and AR environments aligned with our teaching needs.

LANGUAGE TEACHING WITH VIRTUAL REALITY AND AUGMENTED REALITY

The Current Challenge

Our previous experience in implementing virtual environments has informed our appreciation of their potential for language teaching, not only giving us new opportunities to create highly immersive and interactive environments but also to make them meaningful and attractive to our students, who are accustomed to the use of AT in their everyday lives. The desire to easily design and implement new environments led us to evaluate development tools to work with. Among the different tools we evaluated, we finally chose CoSpaces[1] and ARTutor[2], which allowed us to move from being users of platforms and apps designed by software development experts to being developers of our own VR and AR apps. As non-IT teachers, it was a challenge to design VR and AR apps. Additionally, as language teachers, it was a challenge not only to create tools that facilitate the learning of the target language but also to get a positive response from the students.

The VR app designed using CoSpaces and the AR app designed using ARTutor are described below, along with the results obtained by implementing, evaluating and comparing them in a case study carried out at the University of Cádiz.

Description of the VR App Built with CoSpaces

The designed VR app (*360º-Sightseeing Tour*) features 22 360º panoramic views, short text files and audio recordings whose aim is to facilitate students' acquisition of different content and language skills (vocabulary acquisition and improvement of oral and written comprehension) through a virtual tour of characteristic places in the city of Cádiz (squares, parks, theatres, cafés and bars, buildings, etc.). The choice of the different scenes that make up the virtual tour is based on the themes and linguistic content included in the curriculum and in the Common European Framework of Reference for Languages (CEFR) for learners at level A1 (e.g., vocabulary related to the place of residence, daily life and leisure activities).

Once downloaded to their mobile devices, learners can work to acquire the target language by interacting with the VR app through the text and/or audio information points created for each scene (Figure 4).

Figure 4
Example of a panoramic view with information points in the 360º-Sightseeing Tour app

Description of the AR App Built with ARTutor

ARTutor, a completely free development tool, allowed us to create *Who am I?* based on a guessing game where students have to describe and guess different characters from a photo. It consists of 20 AR markers hiding photos of different famous people (YouTubers, actors, athletes, etc.).

The activity was designed to correspond to one of the thematic blocks of the subject German I, which focuses on vocabulary related to the professional and personal environment, covering topics such as professions, hobbies, personality or physical appearance. The aim of the activity is to encourage students to practise the vocabulary they had previously worked on in class while developing their oral comprehension and expression.

After downloading the app to their mobile devices, the students worked in pairs, which changed in the different rounds of the game, to describe and guess the characters of their respective AR markers (Figure 5).

Figure 5
Examples of the AR app Who am I?

Aim of the Study

The study aimed to analyse the educational and motivational potential of the VR and AR apps (as examples of digital resources that can be developed without any IT support) among university students. Our inquiry was guided by the following questions:

- Q1. Do VR and AR environments, such as those created using CoSpaces and ARTutor, facilitate students' learning?
- Q2. How do students evaluate the motivational potential of VR and AR environments?
- Q3. Do students' perceptions of the VR app match their perceptions of the AR app?

Study Participants

A case study was carried out with 72 students studying German at the A1 level at the Faculty of Humanities at the University of Cádiz. To be selected for inclusion in the sample, the participating students had to use the developed apps autonomously in at least one session, independently of the one used jointly to familiarise themselves with the apps. A total of 72 students provided their feedback on *360º-Sightseeing Tour* and 70 provided feedback on *Who am I?* Such feedback was used in subsequent analyses.

Research Method and Design

The research method can be summarised in four steps. The first focused on the selection and design of the appropriate instruments to collect feedback from students about their user experience while learning German using *360º-Sightseeing Tour* and *Who am I?* The second focused on data collection and, finally, the third and fourth were dedicated to the analysis of information using statistical techniques that led us to preliminary conclusions and ruminations of their consequences for future implementations.

Research Instrument

A user experience questionnaire based on the technology acceptance model (TAM) (Davis, 1989; Romano et al., 2020) was adapted to our study to observe the students' perceptions in reference to four fundamental aspects: the perceived ease of use (PEU), perceived enjoyment (PE), perceived usefulness (PU) and the intention to use (IU).

The adapted questionnaire (see Table 1) was designed using a 7-point Likert scale (1 = strongly agree, 2 = agree, 3 = more or less agree, 4 = undecided, 5 = more or less disagree, 6 = disagree and 7 = strongly disagree).

Table 1
TAM adapted questionnaire

Items	Description
PEU1	Understanding how to operate the app is easy.
PEU2	Learning how to operate the app is easy.
PEU3	Remembering how to operate the app is easy.
PEU4	Being an expert in the app would be easy for me.
PEU5	Reading the information on the display is easy.
PEU6*	Oral explanations are easy to understand.
PEU7	Overall, I find the app easy to use.
PU1*	The use of the app helps to understand the content and vocabulary very quickly.
PU2	The app increases my attention to the content of the lesson.
PU3	I think that after using the app, I will get better results in the vocabulary test.
PU4	I believe that after using the app, I will get better results in answering the questions on the topic.
PU5	After using the app, I have learned more vocabulary.
PU6	After using the app, I have learned more about the topic in general.
PU7	The app helped me gain a deeper understanding of the topic.
PU8	The app facilitates vocabulary learning.
PU9	Overall, I find the app more useful for learning.
PE1	The app makes learning more fun.
PE2	I enjoyed exploring the designed environment while using the app.
PE3	Doing the activity is captivating.
PE4	Overall, I enjoyed using the app.
PE5	Overall, I think the app was exciting.
IU1	I would like to have this app to learn more language topics.
IU2	I would use this app to learn foreign languages.
IU3	I would recommend the app to other language students.

*Not requested in the analysis of *Who am I?* (AR with ARTutor)

Data Collection

The information obtained was translated into the following variables to be studied: app used (VR or AR), PEU (PEU1 to PEU7), PE (PE1 to PE5), PU (PU1 to PU9) and IU (IU1 to IU3). The information collected was processed for statistical analysis using SPSS V 27.

Analysis and Results

First, there was a high degree of homogeneity among the responses of the 72 participants, as indicated by their quasi deviations ranging from 0.459 (PU1) to 1.254 (IU1) on a measurement scale ranging from 1 to 7. Although these data led to a maximum error in the interval estimation for the mean response of each variable, ranging from 0.109 to 1.2988, an error that can be considered sufficiently small with 95% confidence, it would have been preferable to have included a larger number of participants in our study.

In response to the first question posed (Q1), students agreed that the biggest advantage of both *360º Sightseeing Tour* and *Who am I*? is the opportunity to learn more (PU7) and faster (PU1). Table 2 summarises the overall results obtained with regard to the learning potential and usefulness of the apps, from 49.86% of the students considering the VR app to be very useful (56.07% in the case of the AR app) to more or less useful (10.68% for the VR app and 6.07% for the AR app). None of the participants thought they were either not very useful or useless.

Table 2

Results of the apps' usefulness

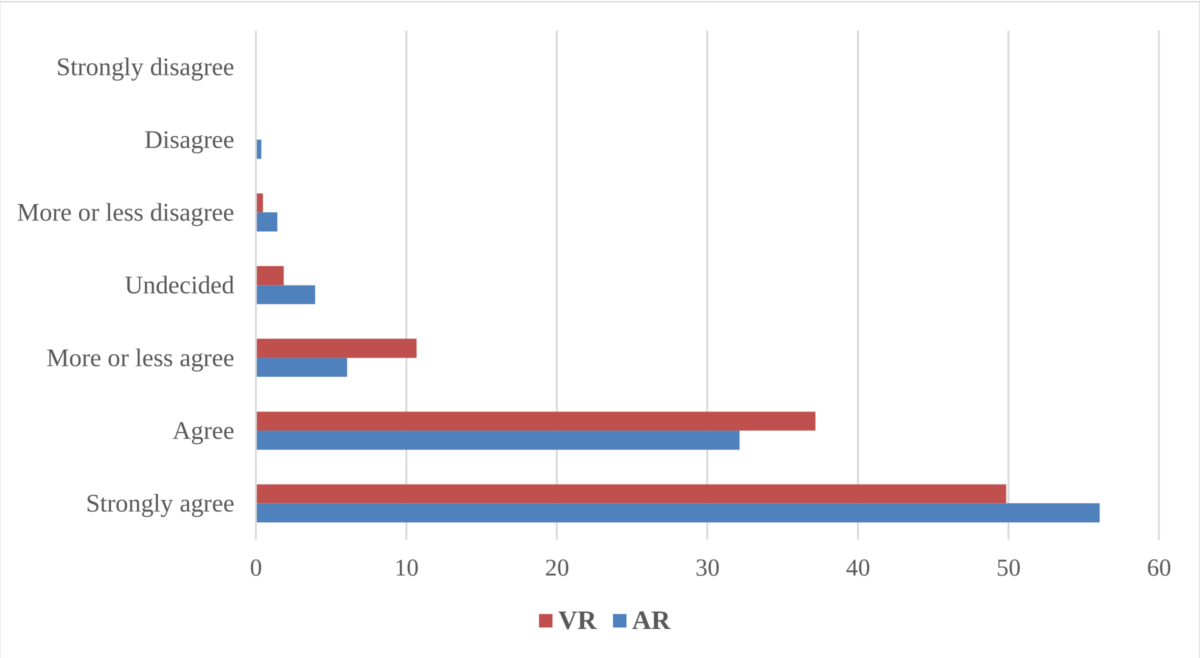
Perception of its usefulness	*360º-Sightseeing Tour - VR*		*Who am I? - AR*	
	Percentage	Accumulated percentage	Percentage	Accumulated percentage
Strongly agree	49.86	49.86	56.07	56.07
Agree	37.17	87.02	32.14	88.21
More or less agree	10.68	97.70	6.07	94.29
Undecided	1.84	99.54	3.93	98.21
More or less disagree	0.46	100.00	1.43	99.64
Disagree			0.36	100.00
Strongly disagree				

Source: own elaboration from the results obtained with SPSS V27.

In summary, 97.70% and 94.29% of the participants considered the VR app and the AR app, respectively, valid for learning (cumulative percentage regarding their usefulness based on the percentage of participants who responded totally agree, agree and more or less agree). Figure 6 illustrates the results of this analysis.

Figure 6

Student perceptions of the apps' learning potential



Source: own elaboration from the results obtained with SPSS V27.

The motivational potential of the two apps analysed (Q2) is revealed through the results collected in Table 3 and presented in Figure 7:

- Regarding PEU, the VR app was even easier and more user friendly than the AR app; 97.64% said *360º-Sightseeing Tour* was easy to use, while 91.25% considered *Who am I?* easy to use.
- Regarding PE, the vast majority of students scored all PE-related items between 1 and 3 on the Likert scale, meaning 94.60% of students enjoyed using *360º-Sightseeing Tour* and 97.99% enjoyed using *Who am I?*
- Regarding IU, 92.40% would recommend or use *360º-Sightseeing Tour* for language learning and 98.19% would use *Who am I?*

Overall, both apps seemed to foster the same level of motivation; 94.88% of the participants who used *360º-Sightseeing Tour* and 95.81% of the participants who used *Who am I?* found these tools to motivate language learning, highlighting their fun, dynamic and interactive character, which makes learning exciting and engaging, as well as easy.

To extend this analysis for the sake of future decisions, we compared the differences between the apps with respect to their educational and motivational potential, responding to Q3. The Wilcoxon test (Table 4) led us to conclude that there were no significant differences in perceptions regarding these apps' usefulness (P-value = 0.9063) or in any of the aspects that make up the motivational potential (P-values = 0.2429, 0.2394 and 0.932 for PEU, PE and IU, respectively). If we consider the potential of the tools as a whole, no significant differences were detected (P-value = 0.961).

Table 3

Results of the apps' motivational perception

Motivational perception	*360º-Sightseeing Tour - RV*							
	Ease of use (PEU)		Enjoyment (PE)		Intention to use (IU)		Motivational perception (PEU+PE+IU)	
	Percentage	Accumulated	Percentage	Accumulated	Percentage	Accumulated	Percentage	Percentage accumulated
Strongly agree	59.99	59.99	49.60	49.60	54.17	54.17	54.59	54.59
Agree	28.96	88.95	35.82	85.42	29.20	83.37	31.33	85.91
More or less agree	8.69	97.64	9.18	94.60	9.03	92.40	8.97	94.88
Undecided	1.50	99.14	3.34	97.94	2.80	95.20	2.55	97.43
More or less disagree	0.57	99.71	2.06	100.00	2.80	98.00	1.81	99.24
Disagree	0.29	100.00			0.00	98.00	0.10	99.33
Strongly disagree		100.00			2.00	100.00	0.67	100.00
	¿Who am I? - AR							
	Ease of use (PEU)		Enjoyment (PE)		Intention to use (IU)		Motivational perception (PEU+PE+IU)	
	Percentage	Accumulated	Percentage	Accumulated	Percentage	Accumulated	Percentage	Percentage accumulated
Strongly agree	57.50	57.50	63.59	63.59	65.76	65.76	62.29	62.29
Agree	22.19	79.69	27.61	91.21	25.01	90.78	24.94	87.22
More or less agree	11.56	91.25	6.78	97.99	7.41	98.19	8.59	95.81
Undecided	3.13	94.38	1.10	99.09	1.39	99.57	1.87	97.68
More or less disagree	2.50	96.88	0.82	99.91	0.42	99.99	1.25	98.93
Disagree	1.88	98.75	0.07	99.98	0.01	100.00	0.65	99.58
Strongly disagree	1.25	100.00	0.02	100.00			0.42	100.00

Source: own elaboration from the results obtained with SPSS V27.

Figure 7
Comparative representation between the potential of both apps

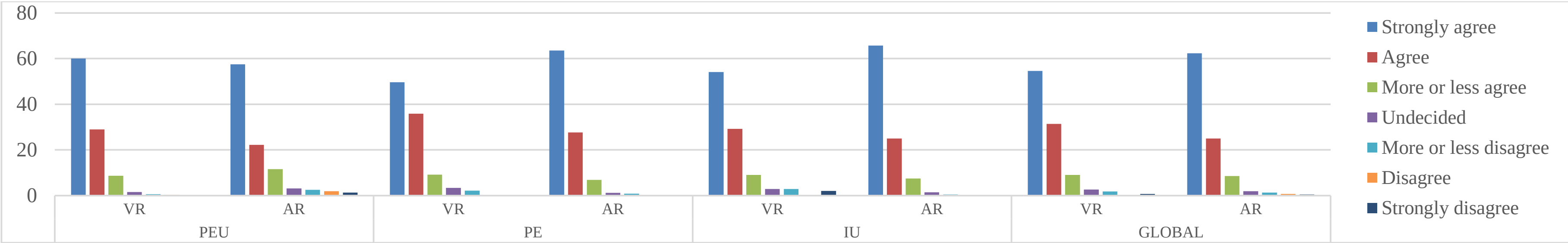


Table 4
Wilcoxon test to compare the perception of VR and AR

	Statistical value (V)	P-Value	Significant differences
Perceived usefulness (PU)	37	0.9063	No
Perceived Ease of use (PEU)	81.5	0.2429	No
Perceived Enjoyment (PE)	137	0.2394	No
Intention to use (IU)	62	0.932	No
Overall potential	1181.5	0.961	No

Source: own elaboration from the results obtained with SPSS V27.

CONCLUSIONS

In an increasingly globalised and diverse society, where students have easy access to many digital resources, effective and engaging learning is essential. The dynamic and interactive nature of the developed technologies and tools helps engage students and motivates them to learn and, in our case, practise the target language.

The results obtained in our study in response to the questions raised (Q1, Q2 and Q3) show the suitability and enormous potential of the apps developed, reaffirming the need to digitalise teaching to improve the teaching–learning process. Being able to develop apps that, according to our own students, facilitate learning and the acquisition of the skills that mastering a language requires, encourages us to continue working in this line.

As the study shows, the type of technology used alone does not determine the educational and motivational potential of digital resources. Deciding how, when and why to integrate technology into our teaching is important, not only to engage students in learning and make it more enjoyable and dynamic but also to prevent negative side effects (Southgate et al., 2019). Balancing the risks and benefits of digital education, even more so with the constant incorporation of cutting-edge technologies, is necessary for the coexistence of traditional learning methods and technology in the teaching process. In this context, the semi-immersive, exploratory and participatory nature of the developed apps, *360º-Sightseeing Tour* and *Who am I?,* as well as their ease of accessibility through devices such as smartphones or tablets, make them suitable for involving students in their learning, as such apps make learning more dynamic and comprehensible. The development tools, both CoSpaces and ARTutor, are easy to use and do not come with additional financial costs. Furthermore, they contribute to and respect the accessibility and scalability of digitisation.

Finally, it is necessary to improve the analysis of the academic impact and effectiveness of the developed apps by involving a greater number of participants in the experience to ensure the external validity of the conclusions. Given the recent creation of the apps, the 2023–2024 academic year offers the perfect opportunity to prolong the use of these tools and to carry out comparative studies that will allow us to analyse their impact compared to other resources, as well as to design possible improvements.

NOTES

1. http://cospaces.io/edu/
2. http://artutor.ihu.gr/home/

Acknowledgements

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Impact of intensive programming training on the development of Computational Thinking in prospective teachers

Impacto de una formación intensiva en programación en el desarrollo del Pensamiento Computacional en futuros/as maestros/as

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ABSTRACT

Training pre-service teachers in their own Computational Thinking (CT) is essential to build with them the discourse of CT didactics and its inclusion in the classroom with children in early childhood and primary education. This research proposes possible solutions to this challenge and analyses the results of an intervention carried out with 71 students from two different cohorts of 2nd year teacher training students. This intervention is based on the intensive practice of coding using visual blocks through a Scratch project during the first part of a semester course. After analyzing the previous and subsequent levels of CT (pre-experimental strategy) by means of a standardized test for its measurement (CTt), it is confirmed that the intensive training experience allows all future teachers to reach a sufficient level of CT, regardless of their previous experience in programming and their initial level of CT (they all end up learning, either by increasing their level of CT or by improving their efficiency). On the other hand, measuring the learning outcomes in the Scratch project, we see a clear relationship between a high resulting CTt level (POST) and a good performance in the block programming learning task, which is evidence that the Scratch project helps to develop the future teachers' CT.

Keywords: computational thinking; programming language; teacher training; evaluation.

RESUMEN

Formar a los profesores en formación en su propio pensamiento computacional (PC) es fundamental para construir con ellos el discurso de la didáctica del PC y su inclusión en el aula con niños de educación infantil y primaria. Esta investigación plantea posibles soluciones a ese reto y analiza los resultados de una intervención llevada a cabo con 71 alumnos de dos cohortes diferentes de 2.º curso de los grados de magisterio. Dicha intervención se fundamenta en la práctica intensiva de programación por bloques visuales en un proyecto de Scratch durante una primera parte de una asignatura semestral. Analizados los niveles previo y posterior de PC (estrategia pre-experimental) por medio de una prueba estandarizada para su medición (Test PC), se confirma que la experiencia formativa intensiva permite a todos/as los/as futuros/as maestros/as alcanzar un nivel suficiente de PC, independientemente de su experiencia previa en programación y de su nivel inicial de PC (todos acaban aprendiendo, sea aumentando su nivel de PC, sea mejorando su eficiencia). Por otro lado, medidos los resultados de aprendizaje en el proyecto de Scratch, vemos una relación clara entre un nivel alto de PC resultante (POST) y un buen desempeño en la tarea de aprendizaje de programación por bloques, lo que evidencia que el proyecto de Scratch ayuda a desarrollar el PC de los/as futuros/as maestros/as.

Palabras clave: pensamiento computacional; lenguaje de programación; formación de profesores; evaluación.

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INTRODUCTION

There is no doubt about the popularity that the concept of Computational Thinking (CT) has acquired in the field of education in recent years. In light of this, it is necessary to conduct a thorough analysis of the concept of CT itself and its educational practice from a research perspective.

When talking about CT, we should certainly pay attention to the work of Seymour Papert (1980), who, at the end of his classic *Mindstorms*, mentions computational thinking, and refers to learning environments in which the computer is "an object to think with" (p. 182). Traditionally, however, the concept itself is considered to be born with Wing's (2006) seminal definition, a quarter of a century later. Although this is only a conceptual approximation, there is no doubt that it has largely functioned as a definition that points to important elements of CT: "Computational thinking involves solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science." (Wing, 2006, p. 33). However, it is in Wing (2014) where we find a complete definition: "Computational thinking is the thought processes involved in formulating a problem and expressing its solution(s) in such a way that a computer -human or machine- can effectively carry out". This is a definition with very important key ideas: a mental process, the formulation of a problem, the expression of its solution(s), the need for a computer (human or machine); to which are added interesting reflections on abstraction or the importance of CT beyond the concrete contexts of computer science.

On this basis, many authors consider CT to be a core competence for the 21st century (Angeli et al., 2016; European Commission/EACEA/Eurydice, 2012; Fluck et al., 2016). It enables us to develop an effective problem-solving and problem-posing procedure (Fluck et al., 2016) in any dimension of the world we live in, and consequently helps us to understand and live in it (Furber, 2012). In that sense, Grover and Pea (2013) emphasize that computing is a human activity; abstraction helps to focus on the essential and neglect the superfluous; and, consequently, CT promotes the creation of knowledge, creativity and innovation, in all senses and at all levels. Attitudinal elements such as confidence, perseverance or collaboration are also pointed out (Bocconi et al, 2016b). For these reasons, many education systems have decided to include it in the curriculum: Canada, the United Kingdom, Finland, and Australia are examples (Acevedo Borrega, 2016; Bocconi et al., 2016a).

However, what interests us now is to focus on the teachers who must accompany this learning process. In this sense, it is generally accepted that teachers need to be trained specifically in CT; and, because of this common assumption, for more than a decade now, the focus has been on both teacher training itself and the pedagogical models associated with CT (Morreale et al., 2012).

According to Butler and Leahy (2021), the lack of research on the CT training processes of future teachers justifies that this should become a focal point as a matter of priority in order to improve the training of trainers and, consequently, the training of children. To this end, a first part dedicated to CT development is essential before addressing didactic issues; and, based on what we already know, few efforts in this direction yield many results: both in the improvement of CT and in the improvement of attitudes towards it (Bustillo & Garaizar, 2015; González-Martínez et al., 2018; Peracaula-Bosch et al., 2020). There is evidence of a lack of a conceptual basis on CT in teachers (Acevedo-Borrega et al., 2022; Morze et al., 2022), as well as the need to focus, both in initial and in-service training, on specific technical and conceptual skills (Rich, Mason & O'Leary, 2021) to improve teachers' own performance in formal educational contexts (Collado-Sánchez et al., 2021). Research, in fact, tells us that the improvement in specific training not only improves self-perception, but that this generates a perfect spiral: the improvement of their own CT allows teachers to feel more confident, both in their CT practice and in their teaching practice; and this confidence effectively improves their actual competence (Rich, Larsen & Mason, 2021), even in short training experiences (Pala & Türker, 2021), which must focus, to be effective, on elements such as age or the correct design of the activities (Li, 2021). This is supported by the TPACK model (Mishra & Koehler, 2006), which is based on the need for trainers to have a combination of three types of knowledge: content, pedagogical, and technological. In this case, the adequate level and development of CT would correspond to *content knowledge* and a lack of it would represent a barrier in the teaching process deployed by the teacher. In the literature review conducted by Mason and Rich (2019), 21 studies are analyzed (12 on pre-service teachers and 9 on in-service teachers, with a total of 802 participants) in which the results indicate that factors such as teachers' perceived CT self-efficacy increase with training that promotes its development, and this has an impact on their understanding of the concept and their ability to design and evaluate CT learning experiences. These results are further corroborated in Rich, Mason and O'Leary (2021) in a study of 127 teachers, which is consistent with Lamprou and Repenning's (2018) study of 471 pre-service teachers. In this study, CT training, focusing, for example, on the concepts of abstraction, analysis, and automation, drastically increases teachers' confidence in their ability to teach CT. Thus, the perception of self-efficacy in CT also leads to self-efficacy in the ability to teach CT. Finally, it is noteworthy to pay attention to a recent study with 245 teachers from 47 schools in Hong Kong (Kong et al., 2023) who were trained in CT development during one school year and were followed up in their classroom implementation, offering a direct analysis of the relationship between teachers' training, teaching performance and student learning. The study corroborates the need for teacher training in CT and its development, validating training programmes based on block and mixed programming environments and recommending continuous support during teaching through platforms, mentoring and repositories of materials. In this regard, we take up a vision that seems to us to be very appropriate, proposed by Estebanell et al. (2018), in which they point out that, before facing the issue of CT didactics, trainee teachers must consolidate themselves as CT users and as reflective users (i.e. develop their own CT in a reflective way) before going on to develop their dimension as CT teachers or reflective CT teachers, which would be the last stage. We also know that providing clear models that provoke reflection can be helpful as a strategy to compensate for the lack of specific training (Dobgenski & Garcia Silva, 2022). However, the solution is not simple, and there are many issues that still need to be clarified. On the one hand, as in any disciplinary didactics subject, it is important not to stop at the development of disciplinary knowledge, but to jump to didactic issues; therefore, the time devoted to disciplinary knowledge must be very limited and targeted. On the other hand, precisely for this reason, it seems sensible to think that, in terms of efficiency, the effort we devote to the development of CT should allow us to learn the use of tools that we can then also use in the didactic approach and for the conceptualization of reflective processes (Pérez-Marín et al., 2020).

Nevertheless, dedicating an intensive first part of a course or subject to CT development in teacher training is not easy, nor can its results be taken for granted (the conceptualization of CT is complex, and its development is not immediate). It is in this context that this research proposal was born; in it, we set out, as a general objective, to analyze the development of CT through an intensive block programming activity in the university training of student teachers, prior to training in the didactics of CT (which is, in fact, the final objective in teacher training).

So, at the end of this reflection, we come to our research question: is it possible to develop the CT of future teachers through training in Scratch, at the beginning of a course, before moving on to didactic aspects?

To this general question, we can add the following questions, which will help us to go deeper into our object of study:

- How do the different starting points of learners in CT development influence the results?
- Is it possible to relate the CT results to some of the competences and skills required for the development of a programming project with Scratch?
- The CT test we will use measures understanding of languages and computational logic from less to more complex configuration challenges. From this, does having created a complex program, with ingenious and optimized solutions that works, relate to the CT results?

METHODS AND INSTRUMENTS

To conduct this research, we decided to work with two study groups composed of second-year students of the degrees of Early Childhood Education (ECE) and Primary Education (PE) at the University of Girona (some of them from the double degree of ECE and PE). The study was carried out within the framework of the course Computational Thinking and Programming of the Information and Communication Technologies degree minor taught during the second semester of the 2020/21 and 2021/22 academic years. The total number of participants was 71, of whom 36 took the subject in the first cohort and 35 in the second.

As for their prior knowledge of programming and robotics, the students have received an introduction to CT related activities with some practical exercises (demonstrations of educational robotics and an introduction to programming with Scratch) during the first year of their studies as part of a compulsory course. In addition, the test asks students whether they have previous experience in programming activities, referring to any possible training they may have received in the stages prior to entering university, both in formal academic contexts and outside it.

In relation to the research design and its fit with the learning experience (aimed at developing CT), a pre-experimental design was proposed in terms of the application of one of the instruments (the CT Test, which we will detail below) and an ex post facto collection of information in terms of the analysis of part of the evaluation activities handed in by the participants at the end of the experience (programming project with the Scratch visual block language, https://scratch.mit.edu/). As for the pre-experimental strategy, the CT Test was applied at the beginning of the course and at the end of the first part (February to April), dedicated to the implementation of different activities to develop the students' CT, before tackling the second part of the semester, dedicated to the development of didactic competences to teach CT to kindergarten and primary school children. In a summarized version, this training and research strategy considered the following sequence:

- Weeks 1 to 4: CT Introduction activities
  - Unplugged CT activity
  - CT Test (PRE)
  - Theoretical analysis and reflection
  - Block programming workshop (TurtleStitch, https://www.turtlestitch.org/) in 2021 and MicroBlocks (https://microblocks.fun/) in 2022
- Weeks 5 to 9: Tutorials and Scratch exercises starting from a basic level (programming the movement of an element or character) and gradually increasing in complexity: interaction with and between characters, sensors, variable conditionals, operators, functions and modularization, and use of the graphic editor for the creation and modification of characters and scenarios.
- Weeks 5 to 10: Development in individual and autonomous work of a Scratch project that simulates a scientific phenomenon of free choice (examples include: water cycle, phases of the moon, development of a plant, fall of a meteorite in the presence of unsuspecting dinosaurs, etc.). The aim is not only to learn how to program but also to emphasize that the fact of having to narrate visually in a precise language is conducive to a deep understanding of the phenomenon to be explained. In terms of programming, students are told that the use of various programmed elements (characters), scenario transitions, and elements characteristic of computer languages, such as conditionals, iteration in loops, operators, variables, and some interactivity with the user, will be valued. During the development of the project, students receive the tutorials indicated in the previous point, tutoring with trainers, and can consult and participate in a forum of doubts, answers, and discoveries for communication and for the exchange of the whole group and the teaching staff.
- Week 11: CT Test (POST)
- Weeks 11 to 14: Design phase: The course continues for a few weeks focusing on the didactics of CT (design and implementation of activities that allow its development), the analysis of which is beyond the scope of this reflection.

As for the instruments, as we said, first, we decided to use an existing instrument, the Computational Thinking Test (CTt, hereafter) validated by Román-González (2016) and Román-González et al. (2018). For this study we have used the adaptation of the original test CTt-RA+B, specifically designed for participants over 14 years of age (Moreno-Leon et al., 2022). The CTt measures, according to its creators, CT understood as follows: "CT involves the ability to formulate and solve problems by relying on the fundamental concepts of computing, and using logic-syntax of programming languages: basic sequences, loops, iteration, conditionals, functions and variables" (Román-González et al., 2017, p. 681). Consequently, it measures the understanding of computational languages and computational logic in configurations from less to more complex. During its resolution, students do not develop their own algorithms or programs, but rather decipher proposed algorithms, generally by answering which of several options solves the challenge of the question. The algorithms are presented in different languages and symbology.

Secondly, the tasks given for the assessment of learning at the end of the first part of this subject were analyzed. A large part of the students' training is devoted to learning visual programming by blocks through different activities and tutorials, among which, due to the complexity and time spent, the creation of a Scratch project that simulates a natural or scientific phenomenon plays a major role.

In order to analyze these tasks, and in relation to the specific research questions of this topic, from the Scratch project that each student developed during the training and the report she or he made on it we extracted the factors that can be related to their CT level according to the parameters measured by the CTt mentioned above, so that we classified them in the categories shown in Table 1. In each of these categories a maximum score of 4 points could be obtained considering the assessment items; therefore, a maximum total score of 12 points could be obtained.

Table 1

Elements assessed in Scratch projects

Categories	Elements of evaluation	Maximum score
How the program works and at what level the student understands it	Correct functioning of the program	4
	Use of initial conditions	
	Annotated parts of the algorithm reflecting the understanding of actions	
	Description of the problems encountered and understanding of the solutions found	
Complexity	Various programmed characters/scenarios	4
	Changes in appearance	
	Transitions	
	Interactivity	
Optimization and ingenuity	Variety of computer language elements that help and simplify programming: loops, conditionals, sensors, variables, operators.	4
	Elegant and ingenious solutions.	

RESULTS

In this section we will present and analyze the results obtained in two blocks: the first one will focus on the results of the CTt, while the second one will analyze the results obtained in the CTt (pre and post) and their relationship with those obtained in the Scratch project.

Comparative analysis of pre- and post-training CTt scores

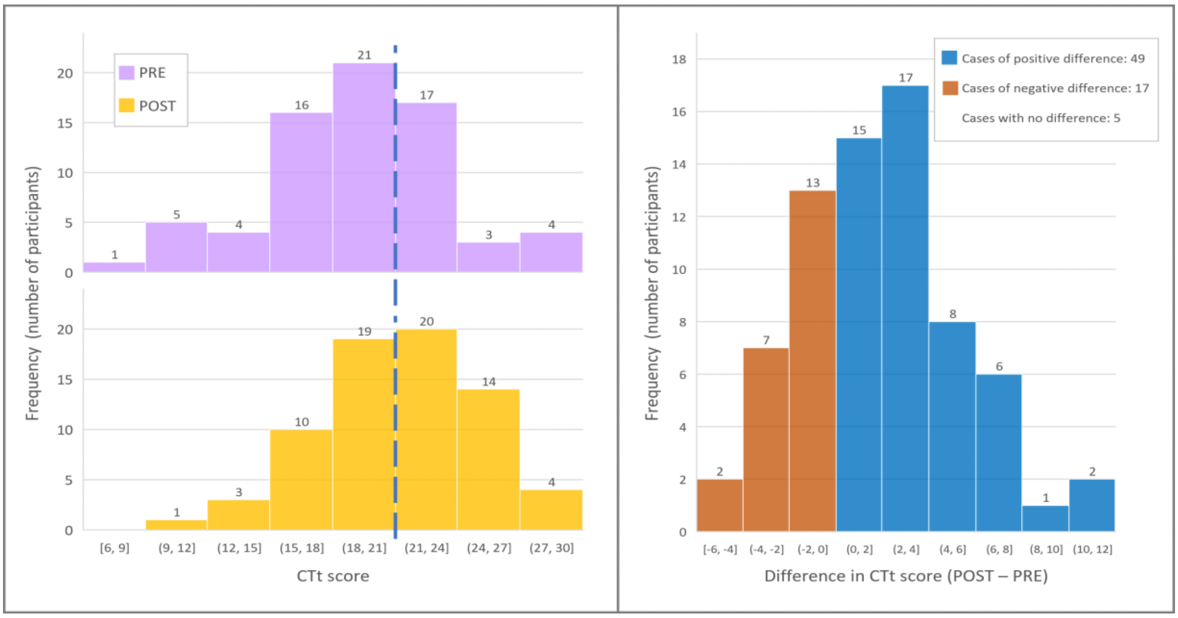
Table 2 gives details of the reliability coefficients, which are considered acceptable for the ranges commonly accepted in the educational field.

Table 2
Reliability levels

Scale	Cronbach's Alpha
Pre-test	0.781
Post-test	0.835

Figure 1a represents, on the same scale, the histograms or frequency plots of the participants' scores on the CT pre- and post-training tests. The Kolmogorov-Smirnov normality test for a sample confirms that both follow a normal or Gaussian distribution, which will allow us to use the means and standard errors as a valid description of the data and to use parametric statistics to perform comparison tests (Rubio Hurtado and Berlanga Silvente, 2012; Simpson, 2015). We can observe that in the distribution of the POST test there is a general displacement of the scores towards higher values than those of the PRE test, so that if we focus on score 21 (which lies between the intervals containing the PRE and POST mean, marked by the blue dashed line), we can see that before the training we have 47 values below or equal to it and 24 above it, and after the training these values become 33 and 38 respectively. Figure 1b shows the distribution of each participant's score difference between the POST and PRE tests. In addition to the fact that 49 of the differences are positive, 17 negative and in 5 cases there is no score difference, it is worth noting the asymmetry with respect to the 0 difference across the distribution, which denotes that the positive differences are significantly larger. An example of this is the fact that the maximum negative difference is 5 points while the maximum positive difference is 12 points. Thus, the graphs in Figure 1 show that between the PRE and POST tests there has been, on average, a development of CT according to the parameters measured by the CTt.

Figure 1
a) Frequency histogram of the scores obtained by the participants in the pre-training test (top) and in the post-training test (bottom) b) Frequency histogram of the difference in scores between the two tests obtained by each participant

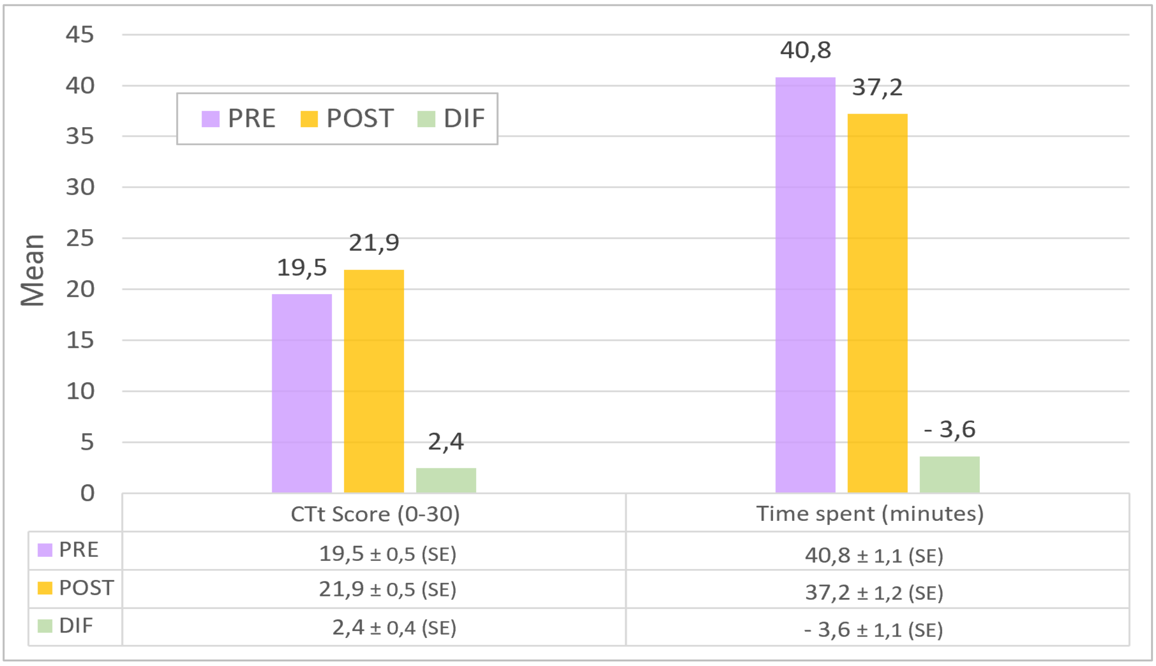


González-Martínez, J., Peracaula-Bosch, M., & Meyerhofer-Parra, R. (2024). Impact of intensive programming training on the development of Computational Thinking in prospective teachers. [Impacto de una formación intensiva en programación en el desarrollo del Pensamiento Computacional en futuros/as maestros/as]. *RIED-Revista Iberoamericana de Educación a Distancia, 27*(1), 187-208. https://doi.org/10.5944/ried.27.1.37672

This development of the CT is shown quantified in Figure 2, where the means of the CTt score and the time students needed to complete it in the PRE and POST tests are indicated with their standard errors (SE) or standard error of the mean. As we can see, the mean CTt score has increased from 19.5 to 21.9 on a 30-point scale and there has been a decrease in the time taken to complete the test from 40.8 to 37.2 minutes. The differences in both cases are statistically significant with a p-value<0.001, i.e., we can state that the probability that the difference is not due to chance is greater than 99.9%. The practical significance measured by the sample size effect of Cohen's d is 0.6 in the case of differences in score and 0.4 in the case of differences in time.

Figure 2

Mean values of the CTt result and the time needed to solve it in the total population (71 participants between 2021 and 2022) applied pre-training (PRE) and post-training (POST) and their comparison (DIF). Their standard errors (SE) are also indicated



Next, we analyzed the data by grouping the participants according to whether they had previous experience in programming or robotics activities prior to entering university, at any stage of education in both formal and informal settings. Of the 71 participants, 33 reported no previous experience and 38 reported having some experience. Table 3 shows, for each of these two groups, the mean scores obtained in the CTt (PRE and POST) and the time taken to solve them. The differences obtained by comparing the results of the two CTt (PRE and POST) in the same group and by comparing the results of a single CTt (PRE or POST) between groups are also shown. To test the statistical significance of these differences we used, in the first case, the non-parametric test for paired samples Wilcoxon Signed Rank, and, in the second case, the non-parametric test for independent samples Mann-Whitney U. We considered the differences to be significant (not due to chance) for p-values<0.05.

Table 3

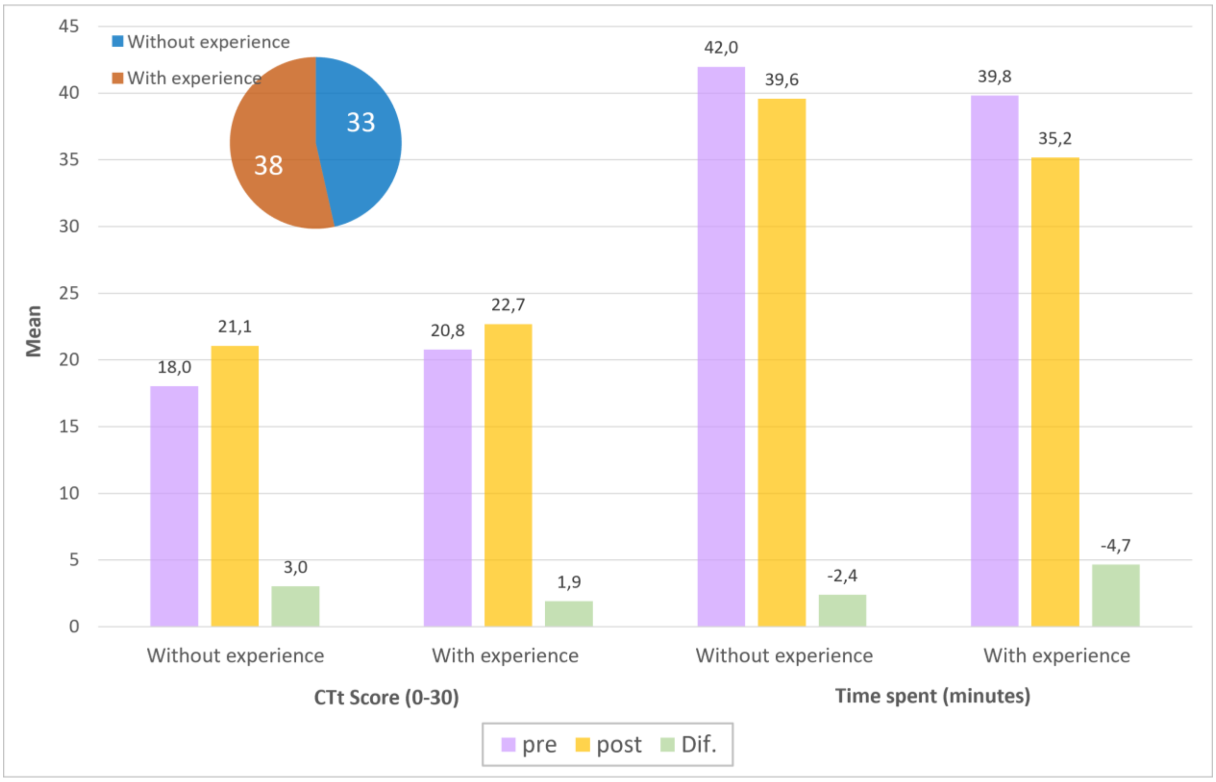
Mean values of the CTt result (PRE and POST) and the time needed to solve it according to previous experience with their standard errors (SE). Differences between tests of the same group and between groups of the same test, their statistical significance (p) and their practical significance according to the sample size (Cohen's d) are also shown

	Average CTt score			**Average time spent (minutes)**		
	PRE	**POST**	**DIF (POST-PRE)**	**PRE**	**POST**	**DIF (POST-PRE)**
With experience (33 participants)	18.0±0.8 (SE)	21.1±0.6 (SE)	3.1±0.6(SE) p<0.001, d=0.8	42.0±1.6 (SE)	39.6±1.8 (SE)	-2.4±1.8(SE) p=0.1, d=0.2
Without experience (38 participants)	20.8±0.6 (SE)	22.7±0.7 (SE)	1.9±0.5(SE) p<0.001, d=0.6	39.8±1.5 (SE)	35.2±1.6 (SE)	-4.6±1.5(SE) p=0.001, d=0.5
Difference (with exp. - without exp.)	2.8±1.0 (SE) p=0.02, d=0.6	1.6±1.0 (SE) p=0.08, d=0.4		-2.2±2 (SE) p=0.3, d=0.2	-4.4±1.5 (SE) p=0.04, d=0.4	

If we focus on the mean score of the CTt, and compare between the two groups, we can see that prior to the training the students with previous experience obtain a score of 20.8 points and this is 2.8 points higher than the mean score of the students with no experience. This difference is significant, with p=0.02. After the training, the difference in the mean CTt score decreases and cannot be considered significant (p=0.08). When we compare the PRE and POST results of each group we can see (Figure 3) that both groups have increased the mean score of the CTt, and this increase is more relevant in the group that had no previous experience. Therefore, insofar as there has been a development of the CTt in both groups, although unequal, the training has been able to partly compensate for the lack of previous experience.

It is worth noting that part of the ability in solving the CTt is also reflected in the time taken to solve it, and in the case of students with previous experience the decrease in time is relevant (4.6 minutes, p=0.001). Therefore, while for inexperienced students the increase in CT development is more evident in the CTt results (which increase more), students with previous experience show it in the time taken to complete it (which decreases more). This may indicate that, depending on the stage of CT development, the impossibility of passing certain test scores, which were already initially high, is reflected in the time spent.

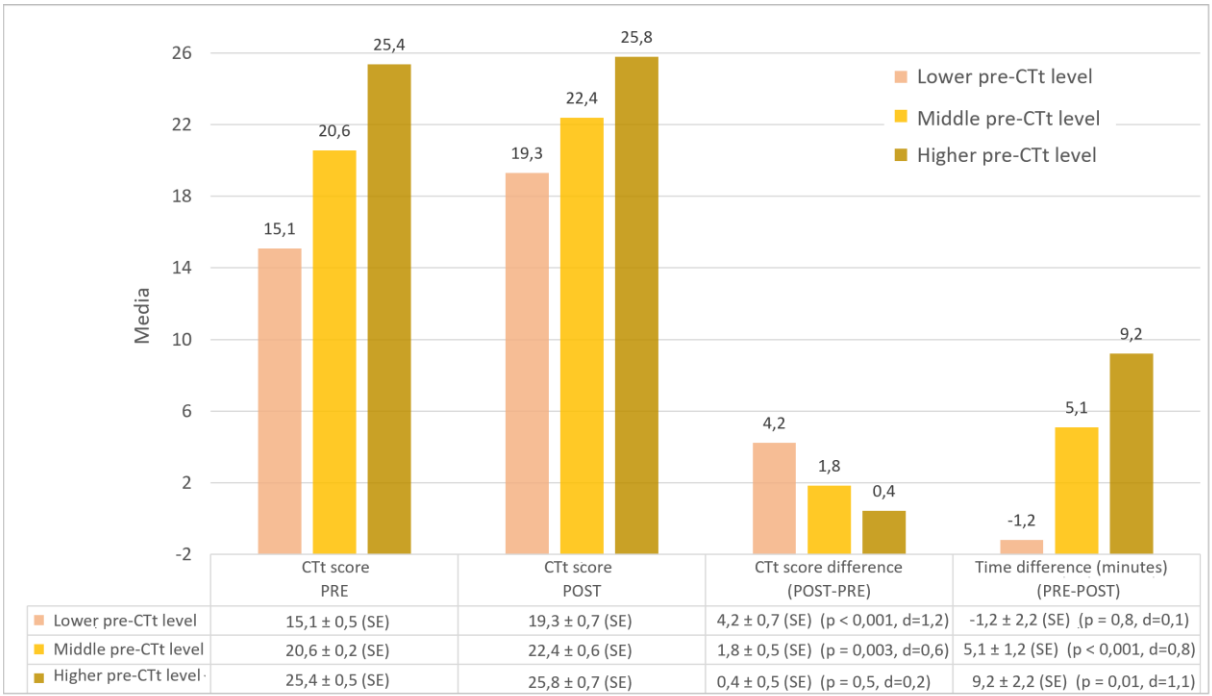
Figure 3
Mean values of the CTt result and the time needed to solve it according to previous experience applied before the training (PRE) and after the training (POST) and their comparison (DIF)



To further analyze this aspect, we grouped the variables of the entire population into three samples, taking as a reference the score obtained in the pre-training CTt. Thus, from the terciles calculated in the distribution of the PRE score, we grouped the participants into the levels "lower pre-CT" (26 participants with an average score of 15.1), "middle pre-CT" (31 participants with an average score of 20.6) and "higher pre-CT" (14 participants with an average score of 25.4) and calculated for each of them the results obtained in the post-training CTt. In Figure 4 we can see, for each group, the mean scores, the differences in mean score between the POST and PRE test and the differences in mean time taken to perform the test.

Figure 4

Mean values of the CTt result and the time needed to solve it (PRE and POST) grouping the population according to initial result



We observe that, in the lower level group, there has been a significant increase in the CTt score (4.2 points; p=0.001); in the medium level group there has also been a significant increase, although it has been lower (1.8 points; p=0.003); and in the higher level group the increase in the CTt score is not significant. However, if we focus on the average time needed to solve the test, the effect is different: in the lower level it has remained without significant changes and in the medium and higher levels it has decreased significantly, so that the group with medium level has needed an average of 5.1 minutes less than in the PRE test to solve the POST test and the group with higher level has done it in an average time of 9.2 minutes less. Therefore, the results show that the training has helped the three groups in the development of CT and has had a certain equalizing effect (the group with the lowest initial score has shown a greater increase), and has improved the agility in its use in those students who already started from a high level, who have needed less time to do it. In the analysis of the correlation between the PRE and POST CTt scores of the whole sample, a positive, moderately high and statistically significant correlation was obtained, with a value of r=0.67. This can be interpreted in terms of test reliability and stability. The fact that total convergence is not reached can be explained by the difference in the increase in learning according to the starting level found in the analysis of the samples by levels.

Relationship between programming with Scratch and the results of the CTt

We would now like to analyze whether there is a relationship between the results of Scratch Programming according to the categories shown in Table 1 and the results of the CTt, focusing on two main areas of interest: firstly, how the starting point of the CTt influences the results of Scratch Programming; secondly, how the level of development of Scratch Programming is reflected in the final CTt.

As a frame of reference, regarding the total score in Scratch Programming according to the categories in Table 1 obtained by the 71 participants, the minimum score is 4 points and the maximum is 12, the mean value is 9.3±0.2(SE) points, the median is 10 points, and the mode is 11. The evaluation was carried out by a single researcher expert in Scratch programming, in a double cycle (weighting and review), in order to guarantee the homogeneity of the criteria applied.

In order to analyze whether the starting point indicated by the pre-training CTt can be related to the outcome of the Scratch project, we calculated the mean values of the score by grouping the population according to the 3 samples "Lower pre-CTt level", "Middle pre-Ctt level" and "Higher pre-CTt level" that had been used in the comparison between the PRE and POST CTt, and we obtained the results shown in Table 4. As we can see, there is no significant variation in the results related to CT in the Scratch project between the participants who started at the medium level and those who started at the lower level. There is, however, a certain difference with respect to the other levels in the results obtained by those participants who started from a higher level, who also obtained better results in programming. This result may support, on the one hand, the compensatory aspect of the training with respect to the CT level according to the parameters of the CTt, especially between the lower and middle pre-CT level groups; and, on the other hand, the fact that the programming elements identified as characteristic of the parameters measured by the CTt are applied to their Scratch projects by the students who started from a higher level.

Table 4

Relationship between the values of the CTt (pre) and the Scratch project

PRE-CTt level	Lower pre-CTt	Middle pre-CTt	Higher pre-CTt
CT Scoring in Scratch Programming	8.8±0.4(SE)	9.1±0.4(SE)	10.9±0.2(SE)
Differences	Lower-Middle: 0.3±0.5(SE) p=0.8	Higher-Middle: 1.8±0.6(SE) p=0.02	Higher-Lower: 2.1±0.6(SE) p=0.006

At this point, we can ask ourselves whether having created a complex program (using a computer language, using ingenuity and optimization that works) is related to the results of the CTt. To analyze this relationship between the results of Scratch programming and the results of the CTt after the creation of the project, we have grouped the participants according to the levels of lower programming, medium programming, and higher programming, taking as a reference the terciles of the programming score distribution. Thus, in the Lower programming level group (score range 4 to 8 points) there are 20 participants; in the Middle programming level (score range 9 and 10 points) there are 25 participants; and in the Higher programming level (score range 11 and 12 points) there are 26 participants. Table 5 shows the average total programming score for each of these groups and their scores on the CTt. Differences in CTt scores between the three levels are also shown with their statistical significance.

Table 5

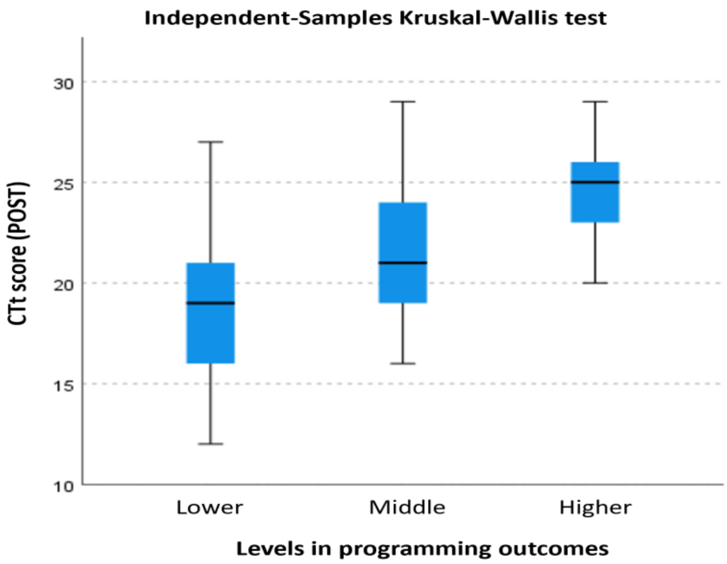
Relationship between Scratch project values and CTt(post)

Programming level	Lower [4,8] 20 participants	Middle [9,10] 25 participants	Higher [11,12] 26 participants
Total programming	6.6±0.3(SE)	9.6±0.1(SE)	11.27±0.09(SE)
POST CTt Score	18.9±0.8(SE)	21.6±0.7(SE)	24.6±0.6(SE)
Differences	Lower-Middle: 2.7±1.0(SE) p=0.03	Higher-Middle: 3.1±0.9(SE) p=0.007	Higher-Lower: 5.7±1.0(SE) p<0.001

We can observe that there is a gradation in the CTt score that also corresponds to the gradation of the three programming levels, so that the students belonging to the Lower programming level group obtain an average score in the POST CTt of 18.9 and this is surpassed by 2.7 points by the students of the Middle programming level and by 5.7 points by the students of the Higher programming level. In order to check the statistical significance of the differences between the groups, the non-parametric Kruskal-Wallis test was used to compare more than 2 groups and it was considered that these differences were not due to chance for $p<0.05$. As can also be seen in Table 5, the differences in the POST CTt results are significant in the pairwise comparisons of the 3 groups. Figure 5 shows the POST CTt score gradation according to the programming level groups.

Figure 5

Distribution of the results of the CTt (post) according to the results of the Scratch project



The result reflects that work in Scratch that involves care and dedication can help in the development of the CT regardless of the level of CT development from which it was started. Therefore, getting a good result programming Scratch does not depend so much on the initial CT level (as its creators say, Scratch has a low floor from which you can evolve to a ceiling as high as you want (Resnick, 2018)); on the contrary, having done a planned and conscious (not incidental) work in Scratch exploring and using its different possibilities and dimensions has an impact on the development of the subsequent CT level.

To complete the analysis of the relationship between the results of Scratch Programming and the results of the CTt, we present the results of the correlations between the two tests, as they can be interpreted in terms of predictive validity of the CTt (in the case of the correlation "CTt-pre * Scratch projects" and in terms of concurrent/convergent validity of the test, in the case of the correlation "CTt-post * Scratch projects" in an approach similar to Román-González et al. (2019). The value of the correlation "CTt * Scratch projects" is r=0.40 and is statistically significant. The convergence is partial, and agrees with the results obtained in the analysis by terciles according to starting level in the CTt score, which indicate that the participants who started from the lowest and middle levels have obtained similar results in programming, significantly surpassed by the participants from the highest level (Table 4), so that the Scratch training has had the compensatory effect that is observed throughout the analysis. The value of the correlation "CTt * Scratch projects" is r=0.59. This value, which is higher than in the case of the PRE CTt agrees with the results of the analysis by terciles according to the results of the programming (Table 5), which confirms that the concepts and skills acquired during the Scratch training and the effort in carrying out the project do not depend so much on the initial CT level, but do imply a development in this as is reflected in the final CT level according to the CTt.

DISCUSSION AND CONCLUSIONS

Based on everything we have been referring to in the results section, it is now time to try to synthesize the main findings and interpret them in the light of what we already know from previous literature. For the sake of clarity of discourse, we will try to organize this reflection into two main parts: the first part focuses on the validation of the training itself (to what extent an intensive training experience such as the one we present allows CT to be developed, in the style of what we saw in Pala and Türker (2021), for example). Secondly, we will focus on the relationship between this CT development and the creation of a Scratch project.

In relation to the first block, we note the following three important ideas. (1) There is a generalized development of CT according to the parameters measured by the CTt, which shows that the training proposal allows all students to achieve their learning objectives. (2) The participants with no previous experience start from a lower CT level than the experienced participants, in effect; but the former experience a higher average increase in the CTt score than the latter. However, in the more experienced group, after the training, the time needed to take the test decreases. And (3) the analysis of the population analyzed in three initial levels according to the PRE-CTt score and the analysis of the POST-CTt results for each of these groups shows that students starting from lower levels experience a higher average increase in the CTt score than students starting from higher levels. In the higher levels the development of CT is shown in the decrease of the time needed in the resolution.

From these three points we conclude that the training fulfils the objective of developing CT according to the parameters measured by the CTt, as already documented, with a single cohort, in Peracaula-Bosch and González-Martínez (2022); but not only that, it also has an equalizing effect on the ability to solve the problems posed by the test and speeds up their resolution in those students who already started from such a high level that it was difficult to improve their scores. To an extent, this is in line with what Wong (2023) points out with the school population: "The results of the study show that children, regardless of their prior problem-solving skills, significantly improve their understanding of basic CT through programming, particularly for low-performing students" (p. 17). In its simplicity and economy, the training strategy is therefore effective in general, and especially for those with less advantageous starting points (Morze et al., 2022). And it is especially important if we bear in mind the need to guarantee a sufficient set of technical user skills to tackle the second part of the course, which is dedicated to CT didactics (and therefore it is proposed for this second part that students not only develop their own CT, but also know enough about Scratch to be able to transfer it to their didactic planning), in line with what Rich, Larsen and Mason (2021) and Collado-Sánchez et al. (2021) point out.

In relation to the second block, dedicated to analyzing the relationship between the level of programming and the results of the CTt, we have broken down the study into two steps. We found that, on the one hand, the results of the CTt prior to training are related to the competences and skills demonstrated by the students in the development of a complex programming project with Scratch in the case of subjects who started with a high score in the CTt. For the students who scored at the lower and intermediate levels, this relationship is not significant, so that the learning outcomes are more important. On the other hand, the score in competences and skills shown in the use of programming elements and concepts in the Scratch project does show a significant relationship with the results of the POST CTt, which indicates that the training carried out through this resource and with the design used has had an impact on the development of the CTt (Pala & Türker, 2021; Rich, Mason & O'Leary, 2021), despite the short time available for this, which requires an intensive approach (Ung et al. 2022).

Finally, despite these good results (both for the confirmation of previous experiences and for the deepening of the specific analysis of the Scratch project), we must recognize limitations in the research that, at the same time, become possible future lines of investigation. The final evaluation of the students' work also took into account other factors such as creativity, the use of artistic elements, and the quality of the writing of the final document in which they explained the process, the learning obtained and the transfer and its didactic use at school. However, for our study we limit ourselves to the analysis of the elements that are directly related to the development of CT according to the parameters measured by the CTt. There is no doubt that the complexity of CT itself (Wing, 2014) should lead us to consider further analyses. As Acevedo-Borrega et al. (2022) and Morze et al. (2022) point out, we must go deeper into the conceptualization of CT in the field of education, on a two-way path between research and practice.

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Techniques and applications of Machine Learning and Artificial Intelligence in education: a systematic review

Técnicas y aplicaciones del Machine Learning e Inteligencia Artificial en educación: una revisión sistemática

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ABSTRACT

Machine learning is a field of artificial intelligence that is impacting lately in all areas of knowledge. The areas of social sciences, especially education, are no stranger to it, so, a systematic review of the literature on the techniques and applications of machine learning and artificial intelligence in Education is performed. The lack of knowledge and skills of educators in machine learning and artificial intelligence limits the optimal implementation of these technologies in education. The objective of this research is to identify opportunities for improving teaching-learning processes and educational management at all levels of the educational context through the application of machine learning and artificial intelligence. The databases used for the bibliographic search were Web of Science and Scopus and the methodology applied is based on the PRISMA statement for obtaining and analyzing 55 articles published in high impact journals between the years 2021-2023. The results showed that the studies addressed a total of 33 machine learning and artificial intelligence techniques and multiple applications that were implemented in educational contexts at primary, secondary and higher education levels in 38 countries. The conclusions showed the strong impact of the use of machine learning and artificial intelligence. This impact is reflected in the use of different intelligent techniques in educational contexts and the increase of research in secondary schools on artificial intelligence.

Keywords: machine learning; artificial intelligence; educational innovation; emerging technology; educational revolution.

RESUMEN

El *Machine Learning* es un campo de la inteligencia artificial que está impactando últimamente en todas las áreas del conocimiento. Las áreas de las ciencias sociales, en especial la educación, no es ajena a ella, por tanto, se realiza una revisión sistemática de la literatura sobre aquellas técnicas y aplicaciones del *Machine Learning* e inteligencia artificial en Educación. La falta de conocimientos y habilidades de los educadores en *Machine Learning* e inteligencia artificial limita la implementación óptima de estas tecnologías en la educación. El objetivo de este trabajo es identificar las oportunidades de mejora de los procesos de enseñanza-aprendizaje y la gestión educativa en todos los niveles del contexto educativo a través de la aplicación de *Machine Learning* e inteligencia artificial. Las bases de datos utilizadas para la búsqueda bibliográfica fueron *Web of Science* y Scopus, la metodología aplicada se basó en la declaración PRISMA para la obtención y análisis de 55 artículos publicados en revistas de alto impacto entre los años 2021 y 2023. Los resultados mostraron que los estudios trataron un total de 33 técnicas de *Machine Learning* e inteligencia artificial y múltiples aplicaciones que fueron implementadas en contextos educativos en niveles de educación primaria, secundaria y superior en 38 países. Las conclusiones mostraron el fuerte impacto que tiene el uso de *Machine Learning* e inteligencia artificial. Este impacto se ve reflejado en el uso de diferentes técnicas inteligentes en contextos educativos y el aumento de investigaciones en escuelas de secundaria sobre inteligencia artificial.

Palabras clave: machine learning; inteligencia artificial; innovación educativa; tecnología emergente; revolución educativa.

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INTRODUCTION

Machine Learning (ML) is a branch of artificial intelligence (AI) that has seen an exponential increase in recent years. The scientific community is paying increasing attention to educational tools enriched with smart technology, as they have the potential to revolutionize teaching-learning processes.

At present, ML research applied to education in areas such as teacher perception (Salas Rueda et al., 2022), student perception (Demir & Güraksın, 2022), academic performance (Ahajjam et al., 2022), school dropout (Alvarado Uribe et al., 2022) and computational thinking (Almeida Pereira Abar et al., 2021), among others, show in their results, the implication of the use of intelligent techniques in the solution of complex problems in the education sector.

Different types of research have been compiled in systematic reviews on AI (Zawacki-Richter et al., 2019; Zhai et al., 2021; Salas-Pilco & Yang, 2022; Su et al., 2022) and systematic reviews on ML (Sasmita & Mulyanti, 2020; Luan & Tsai, 2021; Mittal et al., 2022). Reviews on AI have mainly focused on the university sector, with the exception of Su et al. (2022) which studies the primary school and high school levels. ML reviews have identified common keywords in research, such as prediction, identification, performance, and recommendation, and have described the type of intelligent algorithms or techniques used. Although these systematic reviews were conducted during or after the pandemic, only the study by Mittal et al. (2022) addressed COVID-19.

In education, the difference between ML and AI is not always clear, even though both fields focus on applying the concept of prediction. ML is focused on systems learning from data (Luan & Tsai, 2021), while AI allows systems to perform tasks autonomously (Zhai et al., 2021). However, our systematic review departs from analyzing studies of both AI and ML applied to the education sector for the following reasons: AI and ML aim to create systems that can execute tasks that are normally considered human-like, both fields use mathematical and statistical techniques to analyze and process data, they have great potential to revolutionize the way we interact with the world, and finally, the period from 2021 to February 2023 has experienced an exponential growth in research related to this topic.

In recent years, ML has provided different techniques or algorithms to predict situations according to large amounts of information that, through good data processing and filtering, can generate very effective predictions. Different authors have developed ML algorithms to help educators (Duzhin & Gustafsson, 2018; Yu et al., 2022). This has allowed these intelligent techniques to be applied to the education sector and to help combat the dynamic problems that afflict all types of contexts.

AI in schools offers multiple possibilities for school administrators, teachers, and students. One example is ChatGPT, the latest version, GPT-4, is integrated into software such as Microsoft Office, Edge, and Bing, optimizing educational tasks. AI and ML have been oriented towards educational tasks (Zafari et al., 2021), which highlights the need to strengthen Teachers' Digital Competence (TDC).

Continually, research in the education sector seeks to close educational gaps, and ML and AI emerge as an alternative means to achieve optimal results. A study of robotics with intelligent techniques aims to close the gap between educational and professional robotics by introducing ML techniques where differences in access, trajectory, progress and educational outcomes are best for students (Dietz et al., 2022). In addition to research in education, technological advancement is an important factor

Forero-Corba, W., & Negre Bennasar, F. (2024). Techniques and applications of Machine Learning and Artificial Intelligence in education: a systematic review. [Técnicas y aplicaciones del Machine Learning e Inteligencia Artificial en educación: una revisión sistemática]. *RIED-Revista Iberoamericana de Educación a Distancia, 27*(1), 209-253. https://doi.org/10.5944/ried.27.1.37491

for the education gap. Technological development has opened the gap to challenges in understanding the use, application, and inner workings of technologies, especially emerging technologies such as AI and ML (Temitayo et al., 2022). This indicates its importance as an emerging technology based on its correct use and application for the benefit of quality and dignified education.

The current curricula are constantly updated and with that in mind, curriculum development, which must provide answers to the demands imposed by the knowledge society, must include topics and activities based on ML and AI at all school levels, allowing to dynamize the teaching-learning processes. However, the complexity and dynamics of AI teaching highlight the need for a detailed examination of the curriculum development process in a given context (Dai et al., 2022), showing the relevance of curriculum assessment in all instructional areas and how to approach them according to the context.

Educational processes along with these intelligent techniques and tools applied in and out of the classroom have led to their implementation being treated with restraint due to the ethical considerations involved (Bogina et al., 2022). So much so, that teachers need to be trained and updated to cope with the teaching processes, improving their competences in communication, research, pedagogy, technology, and management, among others. As referred to by UNESCO (2019) in the Beijing Council on AI and education, education sectors must address the integration of the TDC on AI in ICT competency frameworks, to support the teachers training in educational environments with a strong presence of AI.

The inclusion of ML in education has made digital transformation of great benefit to all educational actors, making the education system more convenient for both teachers and students (Nafea, 2018). However, it would also be of great benefit to school administrators and families, who are an important reference point in any educational community and are closely involved in the benefits that these new technologies can generate.

The training of teachers in AI and ML is a challenge for educational institutions. For digital transformation in the classroom to become a reality, teachers must be prepared to adapt technology to their teaching practices (Almeida Pereira Abar et al., 2021), which requires solid knowledge in these areas. Lack of such knowledge limits the optimal implementation of AI and ML technologies in education. As such, school administrators need to take on the challenge of leading the training of the TDC.

The aim of this research is to identify opportunities for improving teaching-learning processes and educational management at all levels of the educational context through the application of machine learning and artificial intelligence.

On this basis, this paper answers the following research questions (RQ):

RQ1: What levels of education have ML or AI studies been conducted in education?
RQ2: In which countries has ML or AI research in Education been conducted and which country has the most influence?
RQ3: What are the key issues and the most frequent words used in the studies?
RQ4: What ML techniques have been used in research?
RQ5: What were the results of implementing ML or AI as an emerging technology in education?

METHODOLOGY

The methodology considered appropriate for ascertaining the current status of all types of research is the systematic review (Marín, 2022), following the PRISMA 2020 protocol (Yepes-Nuñez et al., 2021). The search equation (Table 1) was applied to obtain the studies in the Web of Science (WoS) and Scopus databases. From the inclusion and exclusion criteria for the filtering and narrowing of studies applied (Table 2), a group of 55 articles could be systematically obtained (Table 3).

Table 1 shows the search equation according to subject, educational approach, context, and level. For the document search in both databases, this equation is applied to the title, abstract and keywords. In WoS, "TS" is applied to the equivalent formula (title, abstract, and keywords) and in Scopus, the equivalent of "TITLE-ABS- KEY". The design of the search terms as well as the inclusion and exclusion criteria (Figure 1) are based on the recommendations by Zawacki-Richter et al. (2020), for systematic reviews focused on educational research, as well as the indications from Marín (2022) for educational technology research.

The search formula was as follows:

Table 1
Search equation

Topic	Search terms
Subject	*(“machine learning”) OR (“artificial intelligence”)*
Educational approach	*(“education”) OR (“teach*”) OR (“tutor*”) OR (“educational*”) OR (“pedagog*”)*
Context	*(“school*”) OR (“universit*”)*
Level	*(“kindergarten”) OR (“elementary school*”) OR (“primary school*”) OR (“middle school*”) OR (“secundary school*”) OR (“Bachelor*”) OR (“high* school*”) OR (“master*”) OR (“doctora*”)*

Source: own elaboration.

The inclusion and exclusion criteria are as follows:

Table 2
Inclusion and exclusion criteria

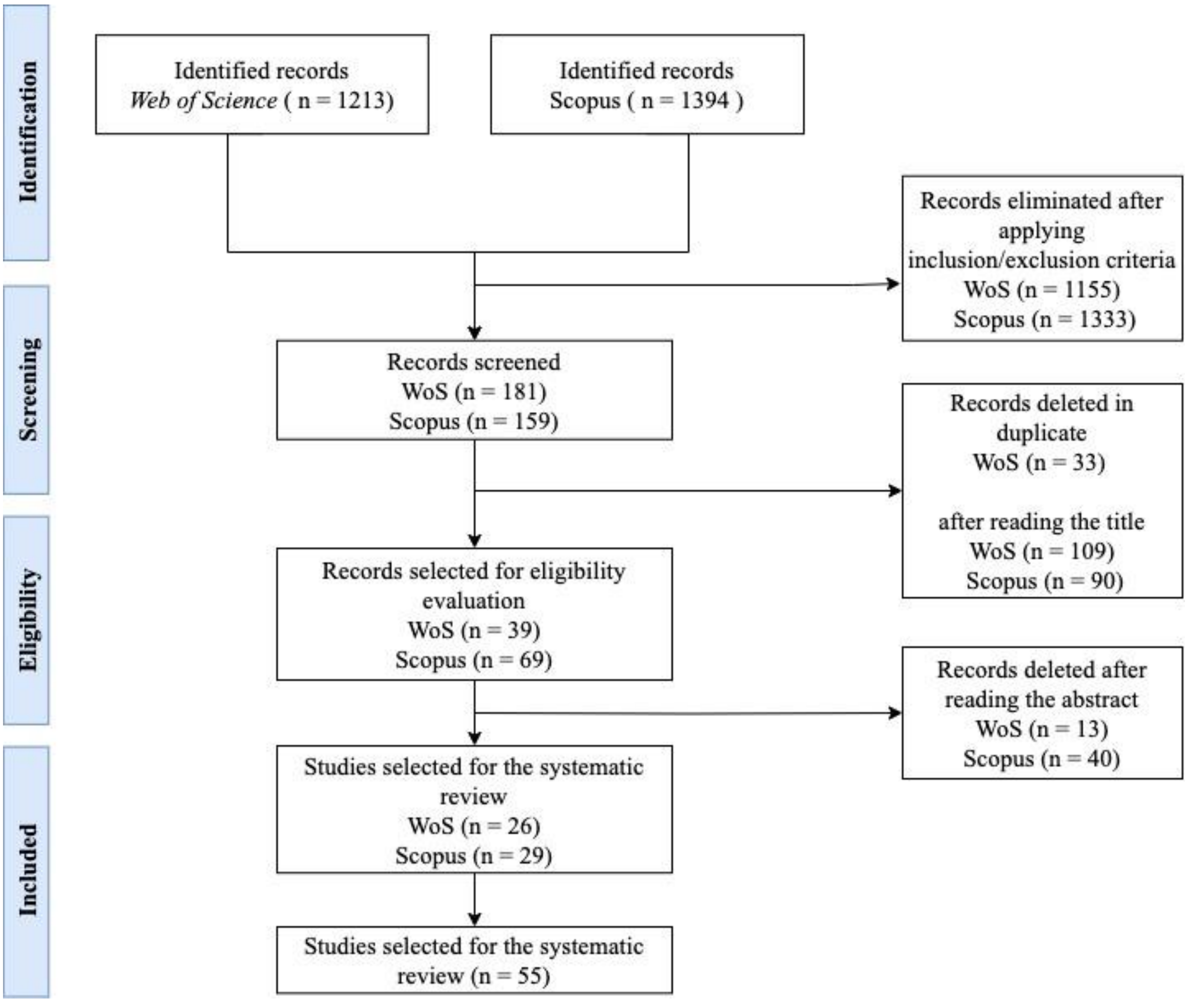
Inclusion criteria	Exclusion criteria
Published between 2021 to February 2023	Published before 2021
English	Not in English
Indexed in Web of Science or Scopus	Not indexed in Web of Science or Scopus
Publications related to education	Non-education publications
No systematic reviews	Systematic reviews
Open access	Not open access

Source: own elaboration.

Considering Table 2, the studies were taken between 2021 and 2023 to reflect the latest advances in scientific knowledge. This research was done during and after the pandemic. In previous systematic reviews (Sasmita & Mulyanti, 2020; Su et al., 2022), the selection of studies was limited to the English language. This is because most high-impact journals publish their articles in English, which is why we selected studies in English for our review. This allowed us to obtain studies relevant to our research. Databases are limited to WoS and Scopus as they are valued as the two most relevant bibliometric tools, being considered the two leading databases of academic articles in the world ranking (Zhu & Liu, 2020), allowing the identification of quality studies. To identify the latest research in the area, follow trends and research relevance, the WoS *Core Collection* database was used.

Figure 1 shows the entire procedure with all inclusion and exclusion criteria.

Figure 1
PRISMA Flowchart of the study



Source: own elaboration.

The two researchers were involved in the screening, jointly reviewing the studies up to the results. For the systematic review, the *Rayyan* tool was used, which allowed coding data on the year of publication, journal name, countries of authorship, sample, methodology and results. The socialization of the sample, methodology and results of each study was necessary to unify criteria and guarantee the quality of the research.

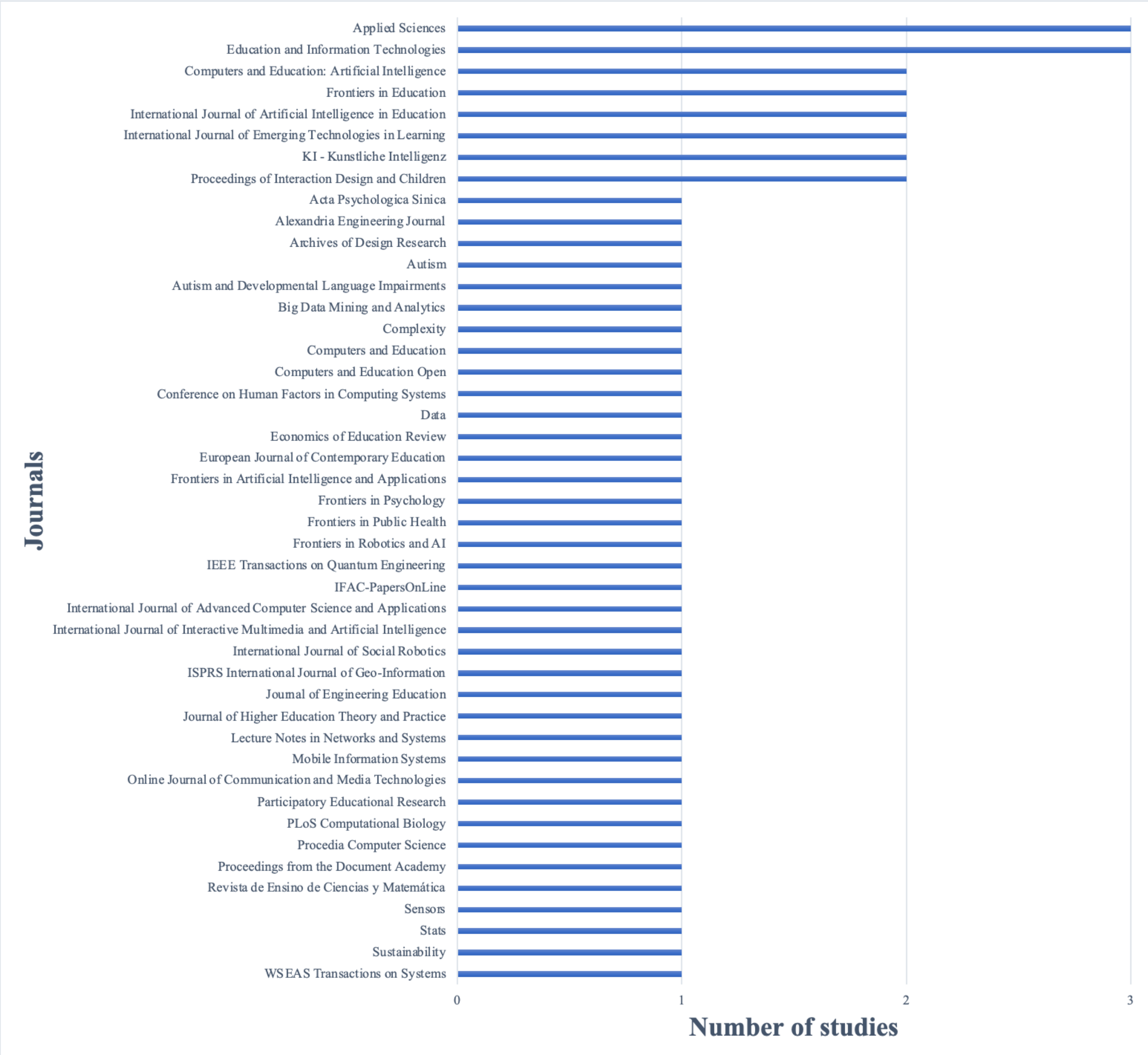
The documentary analysis was carried out using descriptive statistics and systematic content analysis. *Orange Data Mining 3.35.0* software was used to perform the geographical location of the studies, the word cloud was used to analyze the top 20 most frequent words in the selected full papers. In addition, *VOSviewer 1.6.19* was used for the network map, *Microsoft Excel* for the statistical graphs and *app.diagrams.net* for the classification of ML techniques.

RESULTS

The results of the 55 articles below were drawn from 45 high-impact journals, as shown in Figure 2. The number of journals analyzed is an indicator that the study was comprehensive, covering a wide range of perspectives, trends, and patterns.

Figure 2

Journals vs Number of studies/journal



Source: own elaboration.

The journals with the highest number of studies in the review were Applied Sciences and Education and Information Technologies with 3 articles each. The significance of having 45 different journals out of 55 in the review increases the likelihood that a wider range of studies will be included and therefore be more representative of the available evidence.

Table 3 presents the studies selected in this review, specifying the title, central subject, context of application, country, or countries in which the research was implemented, whether it covered the COVID-19 topic, educational level, or levels at which the study was applied and the year of publication. (P: Primary), 2. (P, S: Primary, Secondary), 3. (S: Secondary), 4. (S, U: Secondary, University) 5. (U: University).

Table 3
Selected studies

Nº	Title	Central subject	Country	COVID 19	Educational level	Year
1	Automatic Detection of Gaze and Body Orientation in Elementary School Classrooms	Orientation of teachers and students in the classroom	Chile	NO	P	2021
2	Collaborative construction of artificial intelligence curriculum in primary schools	AI Curriculum	China	YES	P	2022
3	Computational Thinking in Elementary School in the Age of Artificial Intelligence: Where is the Teacher?	Computational thinking	Brazil, Portugal, Cape Verde, and Angola	NO	P	2021
4	Identifying Functions and Behaviours of Social Robots for In-Class Learning Activities: Teachers' Perspective	Social robotics	Canada	NO	P	2022
5	Shyness prediction and language style model construction of elementary school students	Predicting shyness	China	NO	P	2021
6	A machine learning approximation of the 2015 Portuguese high school student grades: A hybrid approach	Academic performance	Portugal	NO	P, S	2021
7	Sentiment analysis of Arabic tweets regarding distance learning in Saudi Arabia during the covid-19 pandemic	Distance learning	Saudi Arabia	YES	P, S	2021
8	"Alexa, Can I Program You?": Student Perceptions of Conversational Artificial Intelligence Before and After Programming Alexa	Student perception	United States	NO	S	2021

Nº	Title	Central subject	Country	COVID 19	Educational level	Year
9	A Practical Model for the Evaluation of High School Student Performance Based on Machine Learning	Academic performance	Iran	NO	S	2021
10	AI Curriculum for European High Schools: An Embedded Intelligence Approach	AI Curriculum	Lithuania, Finlandia, Slovenia, Italy, and Spain	NO	S	2022
11	An Education Tool at Supports Junior Learners in Studying Machine Learning	Teaching AI	Japan	NO	S	2022
12	An Effective Decision-Making Support for Student Academic Path Selection using Machine Learning	Academic guidance	Benin	NO	S	2022
13	Artificial Intelligence and Machine Learning to Predict Student Performance during the COVID-19	Academic performance	Morocco	YES	S	2021
14	ARtonomous: Introducing Middle School Students to Reinforcement Learning Through Virtual Robotics	Virtual robotics	United States	YES	S	2022
15	Children as creators, thinkers and citizens in an AI-driven future	Generative models	United States	NO	P, S	2021
16	Computer or teacher: Who predicts dropout best?	School dropout	Netherland s	NO	S	2022
17	Contextualizing AI Education for K-12 Students to Enhance Their Learning of AI Literacy Through Culturally Responsive Approaches	AI Curriculum	Japan	YES	P, S	2021
18	Determining middle school students' perceptions of the concept of artificial intelligence: A metaphor analysis	Perception AI	Turkey	NO	S	2022
19	Early Introduction of AI in Spanish Middle Schools. A Motivational Study	AI Curriculum	Spin	NO	S	2021
20	Exploring generative models with middle school students	Generative models	United States	NO	S	2021
21	Exploring teachers' preconceptions of teaching machine learning in high school: A preliminary insight from Africa	Teaching ML	Nigeria, Ghana, Tanzania, Kenya, South Africa, and Namibia	NO	S	2022

Nº	Title	Central subject	Country	COVID 19	Educational level	Year
22	Formation of the Optimal Load of High School Students Using a Genetic Algorithm and a Neural Network	School efficiency	Russia	NO	S	2021
23	From high school to postsecondary education, training, and employment: Predicting outcomes for young adults with autism spectrum disorder	ASD in Education with ML	United States	NO	S	2022
24	Graph Neural Network for Senior High Student's Grade Prediction	Academic performance	China	NO	S	2022
25	Identifying supportive student factors for mindset interventions: A two-model machine learning approach	Mindset intervention	United States	NO	S	2021
26	Improvement and Optimization of Feature Selection Algorithm in Swarm Intelligence Algorithm Based on Complexity	Teaching AI	China	NO	S	2021
27	Interdisciplinary K-12 Control Education in Biomedical and Public Health Applications	Virtual Reality in Health	United States	YES	P, S	2022
28	Learning Time Acceleration in Support Vector Regression: A Case Study in Educational Data Mining	Computational efficiency	Brazil	NO	S	2021
29	Modeling English teachers' behavioral intention to use artificial intelligence in middle schools	Teaching AI	China	NO	S	2022
30	Nurturing diversity and inclusion in AI in Biomedicine through a virtual summer program for high school students	Teaching AI	United States	YES	S	2022
31	Predicting Students' Final Performance Using Artificial Neural Networks	Academic performance	Morocco	NO	S	2022
32	Prediction of differential performance between advanced placement exam scores and class grades using machine learning	Academic performance	United States	NO	S	2022
33	Situation and Proposals for Implementing Artificial Intelligence-based Instructional Technology in Vietnamese Secondary Schools	Teaching AI	Vietnam	NO	S	2022

Nº	Title	Central subject	Country	COVID 19	Educational level	Year
34	Stem education-career pathway for emerging forensic analytics: Innovative professional development in multimodal environments	STEM for forensic analysis	United States	YES	S	2021
35	Teachers' readiness and intention to teach artificial intelligence in schools	Teaching AI	Nigeria	NO	S	2022
36	Teaching Quantum Computing to High-School-Aged Youth: A Hands-On Approach	Teaching quantum computing	Canada and United States	NO	S	2022
37	The application of artificial intelligence assistant to deep learning in teachers' teaching and students' learning processes	Learning processes	China	NO	S	2022
38	The Effect of Design Classes Using Artificial Intelligence in the Era of COVID-19 on Social Responsibility of High School Students	Social responsibility	South Korea	YES	S	2022
39	Understanding the response to financial and non-financial incentives in education: Field experimental evidence using high-stakes assessments	Economy	England	NO	S	2021
40	Urban-Rural Gradients Predict Educational Gaps: Evidence from a Machine Learning Approach Involving Academic Performance and Impervious Surfaces in Ecuador	Academic performance	Ecuador	NO	S	2021
41	Wearable Artificial Intelligence for Assessing Physical Activity in High School Children	Physical activity	Qatar	NO	S	2023
42	AI-Based Metaverse Technologies Advancement Impact on Higher education Learners	Metaverse	India	NO	S, U	2022
43	Erwhi Hedgehog: A New Learning Platform for Mobile Robotics	Robotics	Italy	NO	S, U	2021
44	Digital Transformation of Legal education: Problems, Risks and Prospects	Legal framework in Digital Education	Russia	NO	U	2021
45	Educating Software and AI Stakeholders About Algorithmic Fairness, Accountability, Transparency and Ethics	FATE	Israel and Spain	NO	U	2022

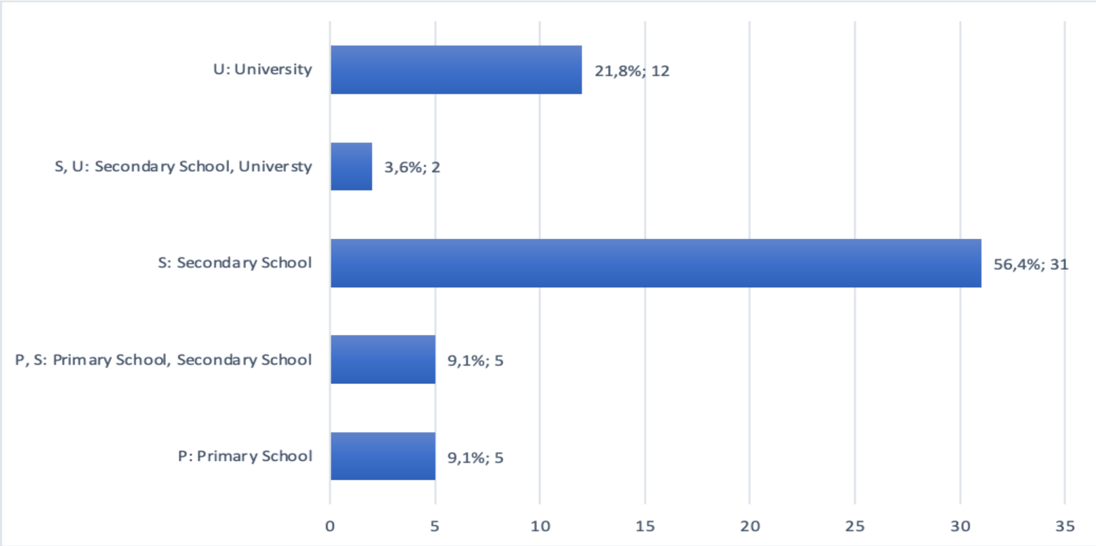
Nº	Title	Central subject	Country	COVID 19	Educational level	Year
46	Evaluating the user's experience, adaptivity and learning outcomes of a fuzzy-based intelligent tutoring system for computer programming for academic students in Greece	Intelligent tutor	Greece	NO	U	2022
47	Evaluation of postgraduate academic performance using artificial intelligence models	Academic performance	Malaysia	NO	U	2022
48	Machine Learning in Clinical Psychology and Psychotherapy Education: A Mixed Methods Pilot Survey of Postgraduate Students at a Swiss University	ML in clinical education	Switzerland	YES	U	2021
49	Modeling deception: A case study of email phishing	Phishing	United States	NO	U	2021
50	Online English Teaching Based on Artificial Intelligence Internet Technology Embedded System	Teaching AI	China	NO	U	2021
51	Predicting academic success of autistic students in higher education	School dropout ASD	Netherlands	NO	U	2023
52	Student Dataset from Tecnológico de Monterrey in Mexico to Predict Dropout in Higher Education	School dropout	Mexico	NO	U	2022
53	Teachers' Opinion About Collaborative Virtual Walls and Massive Open Online Course During the COVID-19 Pandemic	Teacher perception	Mexico	YES	U	2022
54	Towards the Grade's Prediction. A Study of Different Machine Learning Approaches to Predict Grades from Student Interaction Data	Academic performance	Spain	NO	U	2022
55	Using Recommender Systems for Matching Students with Suitable Specialization: An Exploratory Study at King Abdulaziz University	Recommendation of studies	Saudi Arabia	NO	U	2021

Note: P: Primary school, S: Secondary school, U: University, ASD: Autism Spectrum Disorder, FATE: fairness, accountability, transparency and ethics, STEM: Science, Technology, Engineering and Mathematics

To answer the first research question, based on Table 3, Figure 3 shows the level of education applied in the studies.

RQ1: What levels of education have ML or AI studies been conducted in education?

Figure 3
Educational level applied in studies

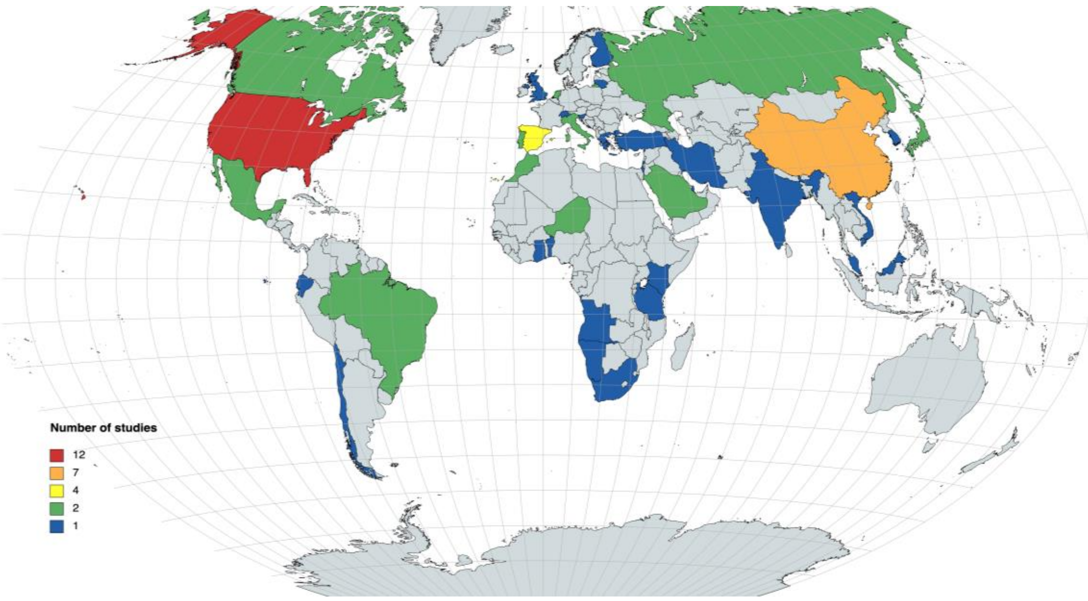


Source: own elaboration.

To answer the second research question, it is noted that studies in English often do not reflect the diversity of global research. Therefore, the choice was made to select research papers in English and to analyze how non-English speaking countries can base their studies in English to have a wider research reach. Figure 4 shows the geographical location (countries) in which the research was conducted and/or applied.

RQ2: In which countries has ML or AI research in Education been conducted and which country has the most influence?

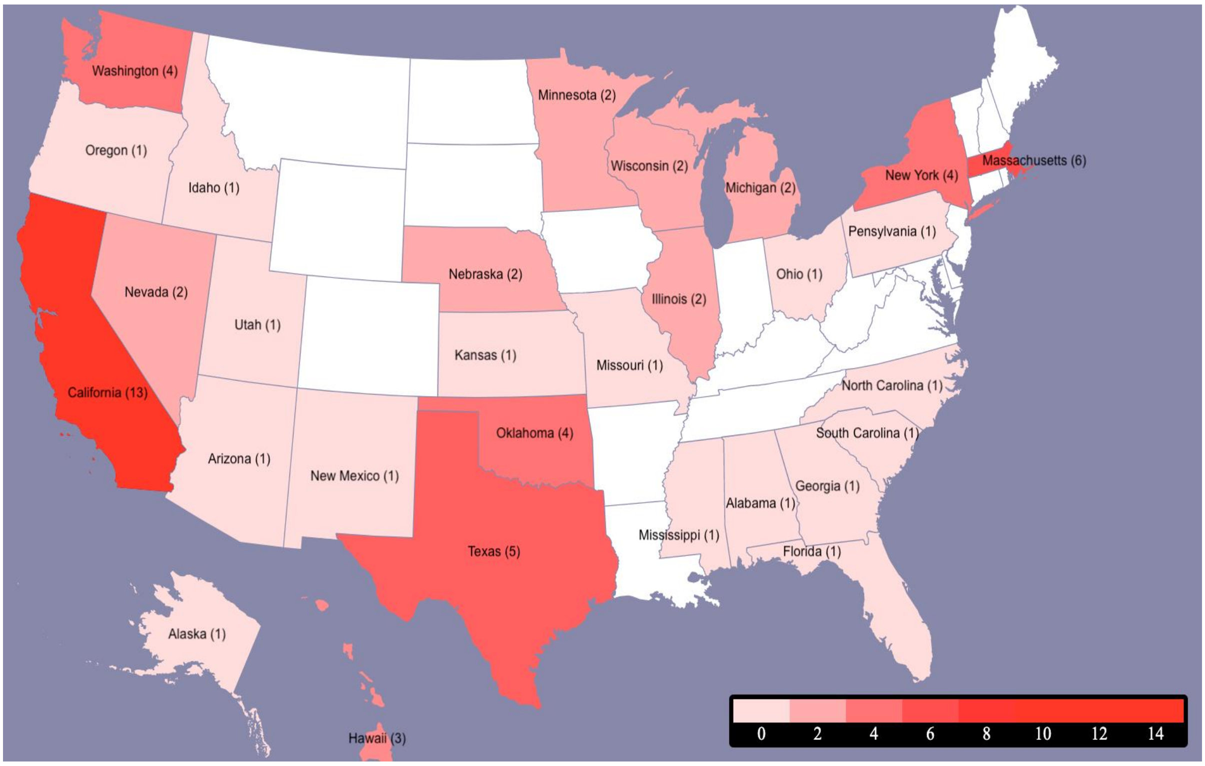
Figure 4
Geographical location of the studies



Source: own elaboration.

Figure 4 shows that the United States (USA) has the largest number of studies. Therefore, Figure 5 estimates the states with the highest research influence in the articles.

Figure 5
Influence of articles on USA



Source: own elaboration.

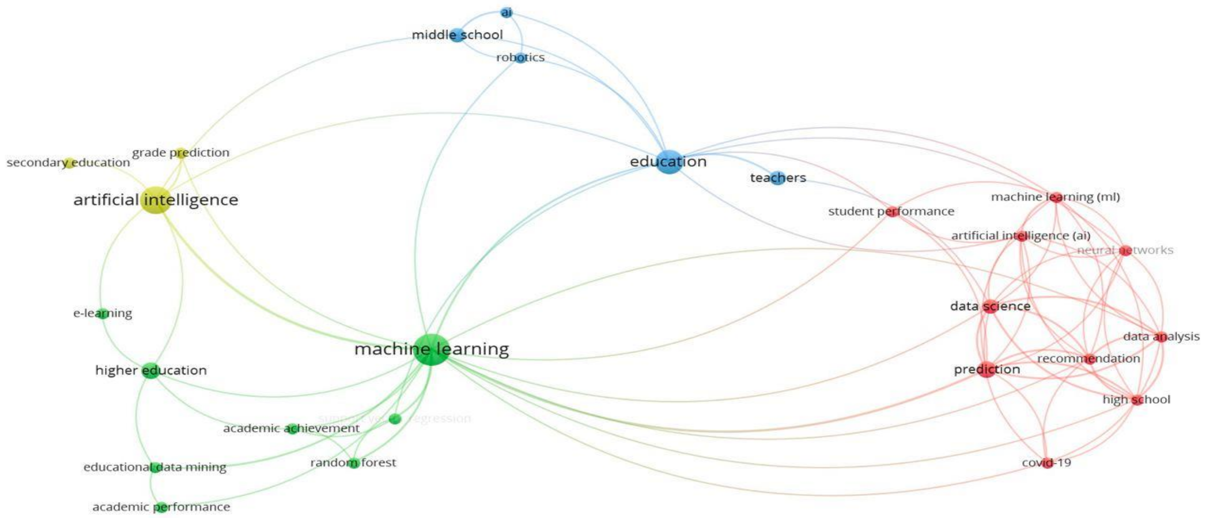
To answer the third research question, Figure 6 shows a network map depicting the relationships between the key subjects of the selected studies, and Figure 7 shows a word cloudhighlighting the 90 most frequent and relevant words in these studies.

RQ3: What are the key issues and the most frequent words used in the studies?

Figure 6 shows a network map representing the key subjects from the titles and abstracts of the 55 research papers. The network map shows four subclusters of interrelated key subjects, identified by colors: green for machine learning (ML), yellow for artificial intelligence (AI), blue for education and red for prediction.

Figure 6

Network map of the 55 research projects on ML and AI in Education



Source: own elaboration.

The green ML sub-cluster is connected to the yellow sub-cluster representing the AI theme because it is a key piece of technology for creating intelligent tools from data recognition and learning. On the other hand, the red sub-cluster representing the key subject of prediction is connected to the ML sub-cluster because ML techniques or algorithms are based on predictionfor decision making. Finally, both the ML and AI sub-cluster are connected to the blue sub-cluster representing the education subject, because it has the potential to improve the teaching-learning process in several ways, such as focusing on improving teacher skills, predicting, and identifying students' strengths and weaknesses to estimate their academic progress, supportingfields such as educational robotics and augmented reality, among others.

Figure 7

Word cloud representing the most frequent words

Source: own elaboration.

To quantitatively establish the *ranking of the* word cloud, Table 4 shows the 20 most frequent words in our word cloud. According to the *ranking*, the words "*students*", "*learning*" and "*ai*" (abbreviation for artificial intelligence) are the three most frequent words, indicating that the selected studies have a high ratio of application of smart tools in education.

Table 4
Most frequent words in studies

Ranking	Word	Frequency
1	*students*	3628
2	*learning*	2380
3	*ai*	2034
4	*education*	1870
5	*data*	1631
6	*school*	1600
7	*teachers*	1184
8	*student*	1175
9	*high*	1088
10	*model*	1012
11	*research*	958
12	*machine*	910
13	*study*	878
14	*teaching*	825
15	*educational*	694
16	*intelligence*	689
17	*performance*	657
18	*information*	639
19	*models*	619
20	*technology*	601

Source: own elaboration.

RQ4: What ML techniques have been used in research?

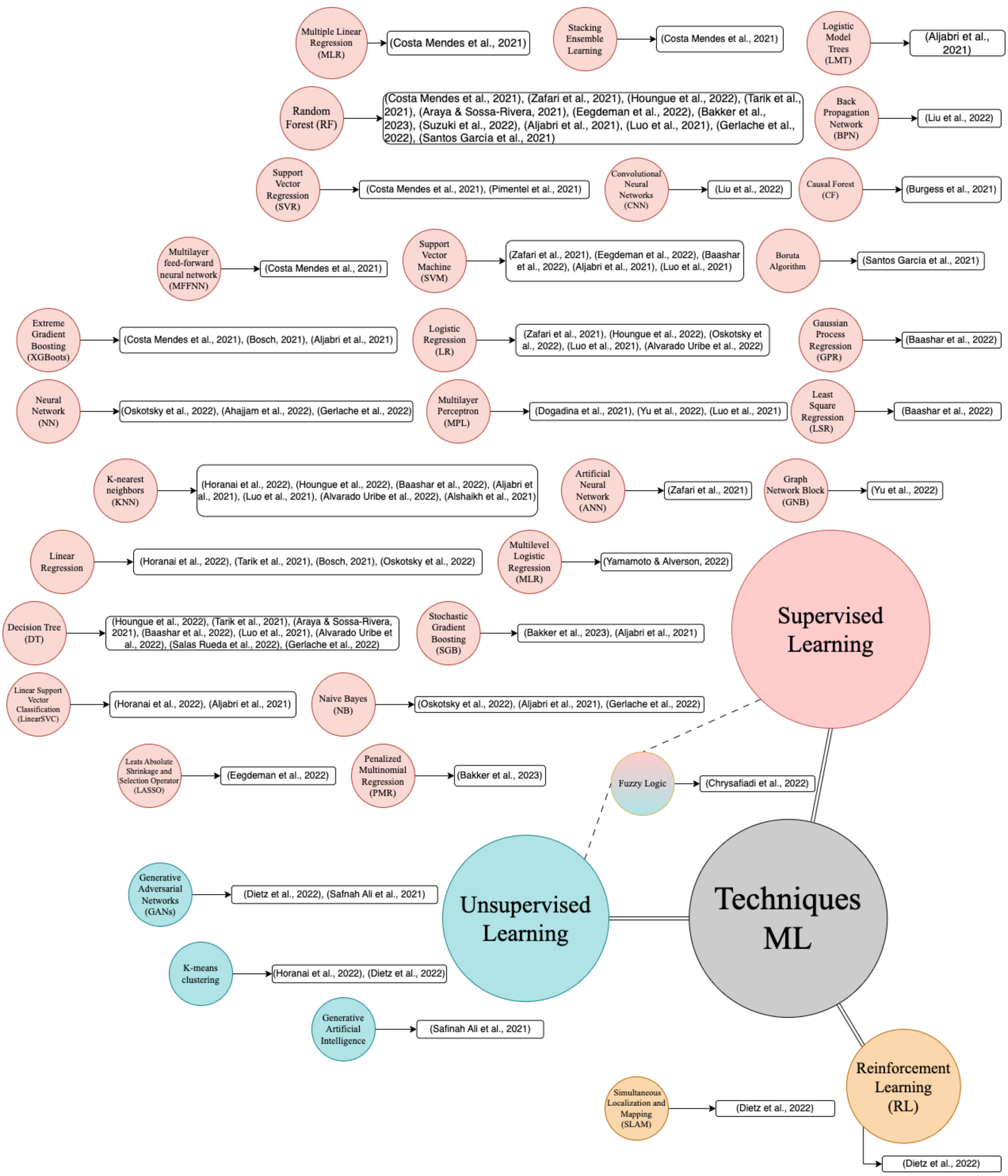
Figures 7 and 8 provide information in response to the fourth question.
ML techniques are classified according to the type of learning:

- **Supervised learning:** Learning from labelled data (Segura et al., 2022).
- **Unsupervised learning:** Learning from unlabelled data (Taha et al., 2018).
- **Semi-supervised learning:** Learning from labelled and unlabelled data (Chrysafiadi et al., 2022).
- **Reinforcement learning:** Learning from interactions with their environment (Dietz et al., 2022).

Figure 8 classifies the techniques according to the type of learning: supervised, unsupervised and reinforcement learning. The names of the techniques in English and their initials are maintained in relation to other scientific papers.

Figure 8

ML techniques found in ML studies (Supervised learning, Unsupervised learning, Semi-supervised learning, Reinforcement learning)

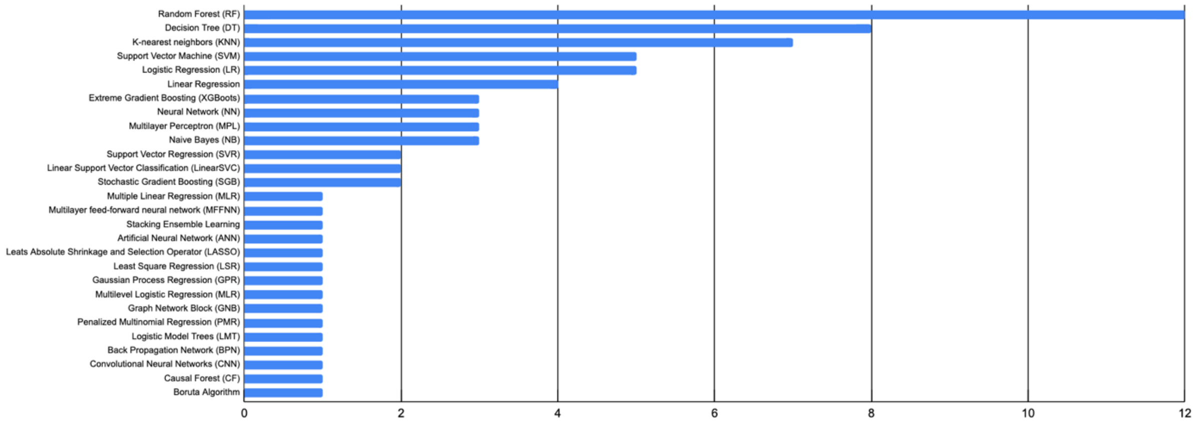


Source: own elaboration.

Figure 9 represents the frequency of supervised learning techniques found in the studies. The most commonly used techniques in the studies are as follows *Random Forest* (RF), *Decision Tree* (DT) *and K-nearest neighbors* (KNN), being the least used *Boruta Algoritm, Causal Forest* (CF), *Convolution Neural Networks* (CNN), *Back Propagation Network* (BPN), *Logistic Model Trees* (LMT), *Penalized Multinomial Regression* (PMR), *Graph Network Block* (GNB), *Multilayer Logistic regression* (MLR), *Gaussian Process Regression* (GPR), *Least Square Regression* (LSR), *Leasts Absolute Shrinkage and Selection Operator* (LASSO), *Artificial Neural Network* (ANN), *Stacking Emsemble Learning, Multilayer feed-fodward neural network* (MFFNN), *and Multilayer Linear Regression* (MLR).

Figure 9

Supervised learning techniques in studies



Source: own elaboration.

RQ5: What were the results of implementing ML or AI as an emerging technology in education?

In response to the fifth research question, Table 5 can be found in the main section of the **Annex**. This table presents the research study, the sample, methodology and results. The order is established according to the order criteria in Table 3.

According to the results in Table 5, the opportunities for improvement in teaching-learning processes and educational management can be grouped into the following categories: prediction of academic performance and school dropout, analysis of student and teacher perception, development of virtual robotics, learning on generative models, implementation of AI and ML, insertion of computational thinking at all levels, strengthening the legal framework in education, efficiency of school management, social robotics intervention, computer security training, incorporation of AI in clinical education, STEM for forensic analysis and AI support in students with special educational needs (SEN), among others. These enhancement opportunities can help improve student academic performance, reduce dropout rates, strengthen educational equity, and improve the overall quality of education.

The studies highlight predictions at the institutional level; however, classroom-level predictions are also recommended because they are more accurate and are based on more specific data on individual students. Nevertheless, institution-level predictions can provide a more general view of academic performance since they are based on institution-wide data, such as grade point averages, attendance rates, graduation rates, dropout rates, etc.

The methodologies used in the studies were defined at two levels: research and teaching.At the research level, the aim was to find new knowledge and test hypotheses using quantitative,qualitative, or mixed methods. At the teaching level, the aim is to strengthen the TDC necessaryfor personal and professional development for student learning.

DISCUSSION AND CONCLUSIONS

This systematic literature review analyzed 55 references on the use of ML and AI in education conducted in 38 countries, with the United States leading the way, from primary school through university levels. The results show that the 33 intelligent techniques extracted from the studies can be applied in the education sector to:

- Detect students' academic performance early.
- Improve the educational skills of teachers.
- Facilitate the learning of students with autism spectrum disorders (ASD).
- Predict school dropout and make decisions about it.
- Improve and generate educational content.
- Close educational gaps.
- Implement AI teaching at all educational levels.
- Strengthen the information security of the educational community.
- Motivate learning through mobile devices.
- Strengthen the field of robotics.
- Improve academic and career guidance for students.
- Prevent the spread of fake news on social networks.
- Understand and reflect on the relationship between humans and machines.
- Develop critical thinking based on computational thinking.

The distribution of studies on the application of intelligent techniques in education is analyzed. The studies analyzed focused on the use of AI and ML techniques. The results show that the application of intelligent techniques in education is gaining ground at all educational levels. In the past, most of this research focused on the university sector (Forero & Negre Bennasar, 2022), but 74.6% of the analyzed studies were applied at the primary school and secondary school level. Our review is more comprehensive than other systematic reviews, as it analyzes studies at all primary, secondary and university levels.

Table 3 shows that 20% of the selected studies addressed COVID-19 in some way. This significant increase compared to other systematic reviews is since the studies were conducted between 2021 and February 2023, when much of this research was still ongoing during the pandemic. The COVID-19 pandemic has been a major global event that has had a significant impact on all aspects of life. Consequently, it is not surprising that many scientific studies have focused their attention on this issue. From our review it can be inferred that one in five studies focused on the COVID-19 disease and its consequences.

In recent years, there has been an increase in the publication of research from non-English-speaking countries in high-impact English-language scientific journals. This is due to the growing importance of science and technology in the globalized world, increased investment in research and development in emerging countries, and the need to share knowledge and results with a wider scope. In Latin America, Brazil, Mexico, Chile, and Ecuador are the countries that have experienced the greatest growth because they have a strongscience and technology base and are increasingly investing in research. In Europe, Spain, the Netherlands, Portugal, Italy, Greece, Switzerland, Lithuania, Finland, Slovenia, Russia, and Turkey are some of the countries leading the growth as they have a long scientific tradition andare committed to international research. In Africa, Benin, Cape Verde, Angola, Morocco, Nigeria, Ghana, Tanzania, Kenya, South Africa, and Namibia have experienced significant growth because they are increasingly investing in research to address the development challenges they face. In Asia, Japan, China, Saudi Arabia, Iran, Vietnam, South Korea, Qatar,India, Israel, and Malaysia are always stepping up as they have strong economies and are increasingly investing in research to drive economic growth. This increase is a positive trend that is contributing to the globalization of science.

Figure 5 shows that California, Massachusetts, and Texas are the states with the highestconcentration of ML and AI research in education. This is because institutions such as the University of Southern California, the Massachusetts Institute of Technology and the University of North Texas are putting a lot of effort into this field. The authors of this researchare mainly engineers, which highlights the need to involve education professionals in the research process.

As can be seen in Figure 8, this study found 33 different ML techniques, which are classified into the four main categories of learning: supervised (28), semi-supervised (1), unsupervised (3) and reinforcement learning (1), some techniques are subgroups of others, such as Artificial Neural Network ANN (Zafari et al., 2021) and Neural Network NN (Oskotsky et al., 2022), but are not grouped together as a single technique, to respect the full name that appears in the research. This indicates that experts are increasingly convinced that ML techniques are appropriate and very important for educational research as they are recognizing the potential to improve educational understanding and practice through new models and methods of teaching-learning.

In line with the above, institutions can use smart techniques and tools to help their students. Grade prediction is a high-impact tool that can considerably benefit both students andinstitutions (Gerlache et al., 2022), for example, they can provide students with insight into theircurrent performance and potential for success, helping students to identify areas or subjects in which they need to improve and to take steps to improve their results. In addition, grade predictors can help students make decisions about their future careers, knowing how they will do in a particular career, students can make more robust decisions about what to study andwhere they want to work in the future.

The most frequent applications using ML techniques focus on the prediction of academic performance, in particular, the *Random Forest* algorithm is the most frequently usedin these investigations, which is a supervised learning technique with high prediction probability. An example of the effectiveness of *Random Forest* for academic performance prediction is a study by Houngue et al. (2022) where it achieved 99% prediction accuracy. However, where there are other techniques with good probability, the choice will depend on the type of data available and the specific objective of the study. In general, ML algorithms have achieved a higher predictive level compared to classical models (Costa Mendes et al., 2021), this is because ML algorithms can learn complex patterns in the data, which allows them to generate more accurate predictions.

The research sample handles a large amount of information, since, for ML techniques to be effective in their predictive capacity, it is necessary for the data to be correctly labelled. Therefore, Big Data comes to play an important role, where the role of the data must maintain those aspects of ethical and moral integrity regarding the information of both the participants (Blease et al., 2021) as well as the curriculum (Eguchi et al., 2021). Both studies agree that thedata used for ML must be ethical and moral, as biases in the data can negatively affect the accuracy of the models.

ML studies are developing new techniques that can improve the prediction system in the education sector. For example, the study by Suzuki et al. (2022) used an ML model to predict the academic performance of primary school students in Japan with an error of 10%. The study by Tarik et al. (2021) used an ML model to predict class attendance of university students in Malaysia with an error of 5%. Thus, being able to effectively predict educational management by minimizing errors at the technical level and at the institutional level enables problem solving in dynamic educational contexts.

The TDC is indispensable for teachers, as it assesses their skills in the knowledge and use of digital technologies. Therefore, identifying these opportunities for improvement in teaching-learning processes helps to mainstream ML and AI concepts in all subject areas and levels of knowledge. The teachers from different subject areas and with different levels of computer science training may have different conceptions of how to integrate ML concepts in schools (Temitayo et al., 2022). Therefore, this paper also seeks to raise awareness about the importance of teachers, regardless of their background, having the necessary skills and competences to apply ML and AI in the classroom. The integration of smart technologies is a crucial educational innovation across all subject areas and educational levels, as it has the potential to bridge the digital and school divide that has become a challenge for education experts.

LIMITATIONS AND FUTURE WORK

This review, due to its current subject matter, broad scope and to limit the proposed methodology, only studies in English have been analyzed. However, it is possible that there is research in ML and AI applied to education in other languages that have not been considered and that could be of interest.

Although the WoS and Scopus databases have been used to narrow down the study, the research could be extended by consulting other databases, as they could yield interesting resultson ML and AI.

It is necessary to strengthen education systems in Latin America, Africa, and Oceania with the implementation of AI and ML experiences and research, improving the provision of human and physical resources and quality teacher training, especially in the TDC.

The equation used allows the implicit integration of certain studies with the keyword "K-12" (Ali, DiPaola, Lee, Sindato et al., 2021; An et al., 2022; Duncan et al., 2022; Eguchi et al., 2021; Sanusi et al., 2022). However, it does not include references to the keywords "high* education*", "ungraduate*", "vocational training*", "vocational education", "adult education" or "corporate training*". This could be of interest for future work, as these keywords could broaden the scope of the research.

The curricula of subjects must incorporate the concepts of new intelligent technologiesin a cross-cutting manner. To this end, it is necessary for educational and institutional management to strengthen the competences of teachers and students in these new educational fields.

Despite the scarcity of research related to diversity, learners with special educational needs, disability and illness, there is a need to deepen and strengthen these fields to close gaps and have a positive impact on education and society.

Finally, it is hoped that this research will contribute to the knowledge and understanding of educational practices with ML and AI and how these can be implemented to strengthen teaching-learning and educational management processes in all types of contexts.

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APPENDIX

Table 5
Characteristics of the reviewed studies

Nº	Study	Sample	Methodology	Results
1	(Araya & Sossa-Rivera, 2021)	4 teachers and first grade students	Basic heuristics	It is possible to estimate the direction of the teacher and the orientation of the head and body of students with ML.
2	(Dai et al., 2022)	23 primary school computer science teachers	Triangulation between ethnographic observation, interviews, and artefacts with teachers.	Influences for curricular incorporation of AI faculty at a partner university
3	(Almeida Pereira Abar et al., 2021)	11 teachers	Qualitative and action-research	Computational thinking in basic education helps children in solving all kinds of problems.
4	(Ceha et al., 2022)	5 primary school and secondary school teachers	Participatory design, qualitative method, Engeström's Activity System Model	The teachers answered positively to the idea of introducing a social robot as a technological tool for learning activities.
5	(Luo et al., 2021)	1,306 primary school students on an online learning platform	Application of ML algorithms	Students with shy behavior, cognitive and emotional problems have unique characteristics in language style.
6	(Costa Mendes et al., 2021)	362,261 scores of pre-schools, primary and secondary school student	Mixed (Quantitative and Qualitative)	Socio-economic indices have inherently limited predictive power.
7	(Aljabri et al., 2021)	3,200 tweets in Arabic	Analysis of people's tweets about distance learning in Saudi Arabia	This result can be used by the Ministry of Education to further improve the distance learning education system.
8	(Van Brummelen et al., 2021)	47 students	Student perception workshops	The students felt that Alexa was very intelligent and they felt closer to her.
9	(Zafari et al., 2021)	246 secondary school students in open-ended physics questions.	Correlation Coefficient for Feature Selection and Application of ML Algorithms	ML models are influential in assessing students and improving the educational factor.
10	(Bellas et al., 2022)	30 students from 6 schools	Proactive learning (Learning by doing)	Fully practical curriculum based on the concept of the intelligent agent.

Nº	Study	Sample	Methodology	Results
11	(Horanai et al., 2022)	An educational tool with AI	Software development with ML	Students have a better understanding of the fundamentals of AI and ML, increasing their interest in the future development of AI applications.
12	(Houngue et al., 2022)	325 grades grade 6 to grade 9	Application of ML algorithms	The performance of five ML algorithms in predicting students' scientific or literary ability was compared.
13	(Tarik et al., 2021)	72,010 students between 2,000 and 2015	Application of ML algorithms	The best model for predicting high school Grade Point Average GPA using an RF regression algorithm.
14	(Dietz et al., 2022)	15 students with learning difficulties or low resources between 11-14 years old	Mixed Research (qualitative and quantitative)	Educational robotics tools, training and programming of simulated robots is attractive and educational for the participants.
15	(Ali, DiPaola, Lee, Sindato et al., 2021)	38 secondary school students aged 10 to 15 years, 18 females and 20 males	5-day virtual workshop to teach about generative ML.	Students demonstrated an understanding that deep-fakes can contribute to the spread of misinformation.
16	(Eegdeman et al., 2022)	9 teachers and 95 students	Teacher survey and use of ML algorithms	ML could help advance the use of evidence to make decisions and predictions in the education sector.
17	(Eguchi et al., 2021)	Teachers and curricula	K-12 student learning experiences.	70% of teachers felt insecure about implementing AI in their classrooms.
18	(Demir & Güraksın, 2022)	339 seventh and eighth grade students from 4 middle schools	Qualitative method analyzing metaphors	Most participants associated IA with humans, technology, and the brain.
19	(Fernández-Martínez et al., 2021)	84 students	Application of didactic unit with IA	It is necessary to rethink the planning for the introduction of AI in the curriculum.
20	(Ali, DiPaola, Lee, Hong y Breazeal, 2021)	72 students (grades 5-9)	Four online workshops	We found that the workshops enabled the children to understand what generative models are.
21	(Temitayo et al., 2022)	12 secondary school computer science teachers	Semi-structured interview	The need to train teachers to use introduce ML in their classes.
22	(Dogadina et al., 2021)	Course contents and 250 assignments	Pareto set and Application of ML algorithms	Minimizes student effort while maximizing the effectiveness of the educational process.
23	(Yamamoto & Alverson, 2022)	393 in 2017 and 387 in 2018 students with ASD	Two methods of predictive analytics (PA): Multilevel logistic regression and ML	The ML model with the best MLR performance in PSO prediction.

Nº	Study	Sample	Methodology	Results
24	(Yu et al., 2022)	Grades de 100 students	Application of ML algorithms	The proposed method works well in predicting the grades of high school students.
25	(Bosch, 2021)	16,310 students from 76 schools in grade 9	Implementation of 2 ML models	The intervention was most effective for students with low academic achievement.
26	(Chen et al., 2021)	68 students	Six classes at school No. 1 in the city	Students and teachers are very satisfied with the algorithm-based teaching
27	(Duncan et al., 2022)	3000 participants	Conferences and Workshops (Webinars)	Students from the beginning of their education should have knowledge and skills in ML and AI related topics.
28	(Pimentel et al., 2021)	5,095,270 students	Massive data set analysis	Using seven input variables, it is possible to accurately predict a student's average grade.
29	(An et al., 2022)	470 English teachers	Survey	Provide educators with policies to encourage AI teaching.
30	(Oskotsky et al., 2022)	18 in 2019, 29 in 2020, 27 in 2021 students admitted to the program UCSF AI4ALL	Evaluation of student transcripts, letters of recommendation and short essay responses.	More students were familiar with working with data and evaluating and applying ML algorithms.
31	(Ahajjam et al., 2022)	72,010 students enrolled between 2,000 and 2,015	Rating prediction using ML and data mining techniques.	The best results for good academic and career guidance were with the neural network algorithm which provided good scores and predictions.
32	(Suzuki et al., 2022)	381 students from 6 secondary schools	Application of ML algorithms	Early detection and intervention allow for the improvement of students' academic performance.
33	(Giam et al., 2022)	119 teachers from middle schools belonging to some cities in Vietnam	Likert-type survey, Quantitative analysis	Secondary teachers are aware of the need for AI implementation in secondary education.
34	(Cheng et al., 2021)	30 teachers	Integrated Model for Convergent Careers, Mixed Method	STEM CareerBuilder program had a positive impact on teachers and students.
35	(Ayanwale et al., 2022)	368 primary and secondary school teachers	Quantitative Structural Equation Modeling	Confidence and relevance in teaching AI predicts intention and readiness to teach AI in institutions.
36	(Angara et al., 2022)	Grade 9 - 12 students in Victoria and Broomfield	Unplugged activities designed to teach basic concepts of quantum computing.	Quantum computing, through its various avenues, is also accessible to people beyond high school.

Nº	Study	Sample	Methodology	Results
37	(Liu et al., 2022)	80 students	Comparative analysis of pre-test and post-tests, action research.	AI technology can act as a learning companion, indicating the problems faced by teachers during the teaching process.
38	(Byun & Kim, 2022)	96 secondary students	Art subject design based on trends, policies, and cases of AI education due to COVID-19.	Educational activities using AI had a positive impact on student participation and interest in class.
39	(Burgess et al., 2021)	10,649 students from 63 schools	Random selection of groups for financial incentives and non-financial incentives (travel).	Incentives in schools predicted to help close gaps.
40	(Santos García et al., 2021)	248,252 student records	Application of ML algorithms	High academic achievement was mainly related to responses related to academic environment and cognitive skills.
41	(Ahmed et al., 2023)	29 secondary school children (12 boys and 17 girls) from 13 to 17 years of age	Cross-sectional observational study to assess physical activity at various times of the day.	Need to design effective programs and strategies to improve physical activity in students.
42	(Bhavana & Vijayalakshmi, 2022)	597 secondary and higher education students	ARCS (attention, relevance, confidence, and satisfaction) model for analyzing Augmented Reality Education	The use and application of reality for smartphones would help students to learn and be more motivated.
43	(Bruno, 2021)	Robot Erwhi Hedgehog	Computer vision and ML	Accelerate and simplify the development of robotics for researchers, educators, students, and professionals.
44	(Demchenko et al., 2021)	129,666 students and 17,923 teachers in higher education	The chi-square test was used to test statistical hypotheses.	It is recommended to introduce tools to improve the digital skills of law students in the curricula.
45	(Bogina et al., 2022)	20 primary and secondary school teachers	Description and evaluation of some educational activities	Educational needs of professionals who produce algorithmic systems, should cover FATE aspects.
46	(Chrysafiadi et al., 2022)	140 undergraduate students	Quasi-experimental research	The intelligent tutor significantly improves student performance and achieves learning goals.
47	(Baashar et al., 2022)	635 master's degree students	Regression algorithms using MATLAB, model performance and predictive decision making.	Variables such as research, marital status and living conditions would have improved the accuracy of ML models.

Nº	Study	Sample	Methodology	Results
48	(Blease et al., 2021)	120 clinical psychology students in the master's program.	Mixed (Quantitative and Qualitative)	Formal education is limited on how AI/ML tools might affect psychotherapy.
49	(Almoqbil et al., 2021)	251,000 accounts of students, faculty, staff, alumni, and retirees, all over 18 years of age.	Information from phishing emails to the network administrator.	Phishing increased in the summer and vacation season, staff and students were the main target audience.
50	(Ban & Ning, 2021)	Primary school students	3 months of teaching in 6 classes.	The unique data of the educational system includes not only the conversation data generated by teacher-student interaction, but also educational management data.
51	(Bakker et al., 2023)	101 students with ASD at the Vrije Universiteit Amsterdam	Application of ML algorithms	Institutions can reduce the risk of dropout and increase school completion for autistic students.
52	(Alvarado Uribe et al., 2022)	121,584 secondary school and undergraduate students	Data life cycle	An appropriate model would benefit students with timely and personalized strategies to support their career retention.
53	(Salas Rueda et al., 2022)	54 teachers from the National Autonomous University of Mexico	Quantitative research	CVWs and MOOCs positively influence student learning and engagement.
54	(Gerlache et al., 2022)	4,522 records with data from master's degree students	Application of ML algorithms	AI can predict educational situations with an accuracy of over 96%.
55	(Alshaikh et al., 2021)	960 student registrations in science, medicine, computer science and engineering	Collaborative filtering technique was used to build the recommender system.	The specialization to be studied for each student was predicted with good accuracy.

Note: ASD: Autism Spectrum Disorder, RF: Random Forest, FATE: fairness, accountability, transparency, and ethics, MLR: multilevel logistic regression, PSO: post-high school outcomes, CVWs: Collaborative Virtual Walls (CVWs), MOOCs: Massive Open Online Courses.
Source: own elaboration.

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Implementation and training of primary school teachers in computational thinking: a systematic review

Implementación y formación del profesorado de educación primaria en pensamiento computacional: una revisión sistemática

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ABSTRACT

Computational thinking encompasses mental processes that facilitate automated solutions to specific problems. Its integration into primary education is grounded in enhancing problem-solving skills and adapting to the digital environment. However, exactly what constitutes effective teacher training and classroom implementation strategies remains ambiguous. These concerns are addressed in this systematic review, highlighting the influence of school practices on shaping educational curricula. This research examines the implementation of computational thinking and teacher training at the primary education level. Initially, 428 studies were identified in Scopus and Web of Science, and these were then narrowed down to 24 empirical studies published between 2006 and 2023 after applying eligibility criteria and quality assessment. The findings indicate that many educators strive to incorporate computational thinking without adequate training. Robot programming prevails as the primary strategy, and there is high demand for training on the subject, but the use of "unplugged" activities is limited. Nevertheless, before computational thinking in primary education is advocated for, further research is warranted, particularly in the early grades. Educational institutions are encouraged to take the lead in designing and evaluating teacher training programs according to a set of guidelines provided. The successful integration of computational thinking into primary education necessitates more robust pedagogical approaches supported by appropriate teacher training.

Keywords: computational thinking; primary education; teacher training; initial teacher training; in-service teacher training.

RESUMEN

El pensamiento computacional engloba procesos mentales que propician soluciones automatizadas a problemas específicos. Su integración en la educación primaria se sustenta en la mejora de habilidades resolutivas y adaptación al entorno digital. No obstante, la formación del profesorado y las estrategias eficaces para su implementación en aulas son aún ambiguas. Estas inquietudes se abordan en esta revisión sistemática, destacando la influencia de la práctica escolar en la configuración de planes de estudio de educación. Esta investigación examina la implementación del pensamiento computacional y la formación del profesorado en la etapa de educación primaria. Inicialmente, se identificaron 428 estudios en Scopus y Web Of Science, reduciéndose a 24 estudios empíricos publicados entre 2006 y 2023 tras aplicar los criterios de elegibilidad y la evaluación de calidad. Los resultados indican que muchos docentes intentan incorporar el pensamiento computacional sin suficiente formación. La programación de robots prevalece como estrategia principal y es la más demandada en la formación, mientras que el empleo de actividades desconectadas es limitado. No obstante, antes de promover el pensamiento computacional en primaria, se requiere mayor investigación, especialmente en los primeros cursos. Se insta a las Facultades de Educación a liderar el diseño y evaluación de programas de formación del profesorado, ofreciéndose pautas al respecto. La integración exitosa del pensamiento computacional en educación primaria demanda enfoques pedagógicos más sólidos respaldados por una formación docente adecuada.

Palabras clave: pensamiento computacional; educación primaria; formación de profesores; formación inicial del profesorado; formación permanente del profesorado.

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INTRODUCTION

Computational thinking (CT) is increasingly present in various educational systems. The more intuitive technological developments and the supposed benefits of its development make it an essential competence (González et al., 2018). Wing (2006) defined CT as a thinking process based on computational concepts that enables problem solving and system design. Following Wing's publication, research in this area experienced a growing increase. However, studies addressing teacher training and pedagogical approaches to CT teaching and learning remain scarce. Most focus on measuring CT (Haseski & Ilic, 2019) and reflect the lack of consensus on its definition and components (Bocconi et al., 2016; Hsu et al., 2019; Moreno-León et al., 2019; Román-González et al., 2017; Segredo et al., 2017; Shute et al., 2017).

Aware of the need for agreement on these aspects, Angeli et al. (2016, p.49) attempted to unify existing definitions. The authors define CT as "a thinking process that uses the elements of abstraction, generalisation, decomposition, algorithmic thinking and debugging (error detection and correction)". There is also a lack of consensus on other issues, such as its scope or nature (González et al., 2018; Rich & Langton, 2016). This continues to highlight the need to further delimit the term (Bocconi et al., 2016) in order for it to be fully and effectively included in education.

In most countries, the integration of CT takes place mainly at the secondary education stage (Haseski & Ilic, 2019). However, it is necessary to include it from elementary education levels in the same way as other basic skills such as numeracy or reading (Zapata-Ros, 2015). CT can enable the development of skills such as creativity, problem solving or collaborative skills (Arranz & Pérez, 2017). Including it in primary school would also help to alleviate gender differences in CT development (Ketelhut et al., 2019; Shute et al., 2017). However, for this inclusion to be truly effective, a number of methodological and pedagogical criteria must be established. There is a clear need for further studies in this direction, as they are still scarce (Haseski & Ilic, 2019).

Another aspect that also requires further study is the evaluation of CT (Bocconi et al., 2016; Cutumisu et al., 2019, Lockwood & Mooney, 2017; Román-González et al., 2017). Existing tools and methods cover only certain aspects, focusing more on computational concepts than on practices or perspectives. The existence of multiple definitions of CT has generated a wide variety of assessment methods that lack sufficient validation (Cutumisu et al., 2019; Shute et al., 2017).

Teachers play a key role in the inclusion of CT in schools (Yadav et al., 2017). Teacher qualifications are considered a major factor for educational quality and an essential driver for effectively addressing educational change. The introduction of CT to education policy is creating a strong demand for teacher training, as most teachers do not learn about CT in their initial training (Bocconi et al., 2016; Bustillo, 2015; Ling et al., 2018; Yadav et al., 2017). Given the shortage of teachers qualified to teach this type of thinking and effectively use tools to foster its development (Ling et al., 2018), more studies focusing on this group (Haseski & Ilic, 2019) are needed to design evidence-based training plans.

Several researchers have addressed some of these issues in systematic reviews or literature reviews conducted more frequently since 2014. Works such as Kalelioğlu et al. (2016) and Cometa et al. (2021) provide an overview of the status of CT. Shute et al. (2017) analyse different aspects related to this thinking (characteristics and components, interventions to develop it, evaluation and existing theoretical frameworks and models). Others focus on specific dimensions. Pollak and Ebner

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(2019) investigate the integration of CT, and Palts and Pedaste (2020) discuss the dimensions of CT thinking skills and how they can be combined in a new model to develop CT thinking. Cutumisu et al. (2019), Alves et al. (2019) and Tang et al. (2020) discuss, from different perspectives, the assessment of CT. Ioannou and Makridou (2018), Uslu et al. (2022) and Xia and Zhong (2018) focus on robotics, while Lye and Koh (2014), Popat and Starkey (2018) and Zhang and Nouri (2019) analyse different aspects related to coding. Other studies, such as García-Tudela and Marín-Marín (2023), are more specific and analyse the uses and achievements of Arduino. Barcelos et al. (2019) and Chan et al. (2023) address the development of mathematical learning through CT activities. Menon et al. (2019) investigate the use of escape board games to develop and assess CT.

Although the authors of the aforementioned systematic reviews address some of the issues surrounding CT, it remains unclear whether there are methods, specific strategies or tools that can be used to successfully incorporate it from the primary education stage onwards. The search for these answers, which is the subject of this new systematic review, contributes to the subsequent identification of the keys to defining what initial teacher education in universities should be like. We believe that school practice influences and provides valuable information for the design of curricula in faculties of education.

In this context, this systematic review seeks answers to the following research questions:

What are the main learning strategies, inclusion principles and tools used in the implementation of CT at the primary education stage (6-12 years old)?

What are the main characteristics of the design of initial and in-service training experiences for primary school teachers in CT?

METHOD

In this study, evidence is gathered on the current situation regarding teacher training and the implementation of CT in primary education. The general objective is to draw conclusions about the teaching-learning process of CT in primary education that can be considered in university teacher training.

The research design follows the process established by Kitchenham and Charters (2007) for conducting systematic reviews and the recommendations offered by Sánchez-Meca (2022). The guidance and checklist of the PRISMA 2020 Declaration (Page et al., 2021) are also accounted for. Annex I shows which suggestions from this checklist have been met, which have not been met, and which are not appropriate to check, as this is not a meta-analysis.

Selection criteria

The selection of studies was based on the criteria set out in Table 1.

In 2006, Wing published his article titled Computational Thinking, which, together with international education policies and the impetus of the technology industry, led to an increase in the popularity of the term and interest in its study and inclusion in the classroom. This milestone justifies the criterion that eligible studies were published between 2006 and 14 March 2023, the day in which the search was conducted.

Table 1
Inclusion criteria

Inclusion criteria	Description
Type of study	Empirical studies
Place of publication	Peer-reviewed journals in any field of knowledge
Language	Spanish or English
Date of publication	Between 2006 and 14 March 2023
Content	Related to the objective and research questions

Source: own elaboration.

Search strategies

The Scopus and Web of Science (WOS) databases were used to search for articles, following the unregistered protocol set out in Table 2.

Table 2
Search protocol

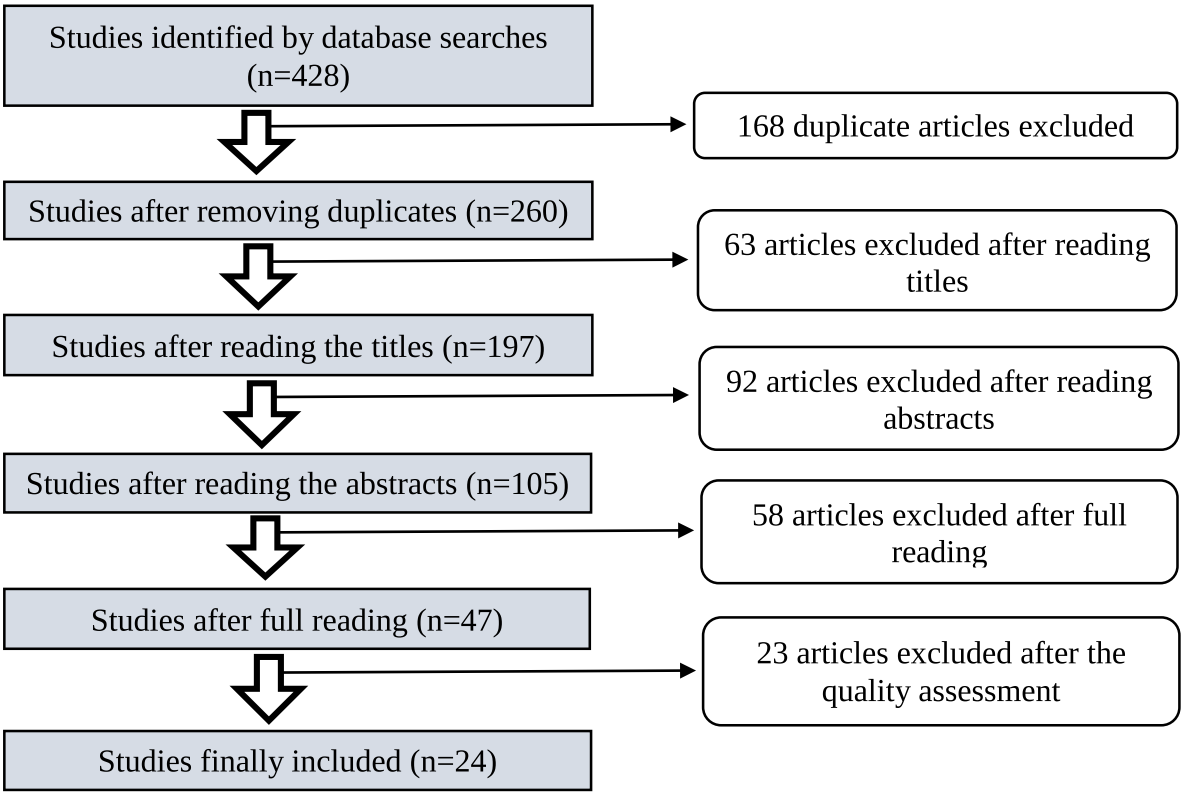
Database	Search protocol
Scopus	Search string (article title): "Computational thinking" AND "Elementary" OR "Primary" OR "K-12" OR "Teacher training" OR "education*". Limited year of publication: from 2006 to 14 March 2023 Limited language: English or Spanish. Limited document type: articles. Limited resource type: magazine. Search conducted on 14 March 2023.
Web Of Science: Science Citation Index Expanded (SCI-EXPANDED), Social Sciences Citation Index (SSCI), Arts and Humanities Citation Index (AyHCI), Emerging Sources Citation Index (ESCI)	Search string: (TI=("computational thinking")) AND TI=("elementary" OR "K-12" OR "primary" OR "teacher training" OR "education*"). Limited year of publication: from 2006 until 14 March 2023 Limited language: English or Spanish. Limited document type: articles. Search conducted on 14 March 2023.

Source: own elaboration.

Procedure for the selection of studies

After an initial search in Scopus and WOS, 231 and 197 articles were obtained, respectively. A total of 168 duplicate articles were eliminated. Subsequently, the titles were read, and 63 articles were eliminated because they were not clearly related to the research objectives. Next, the abstracts were read, and 92 articles were eliminated. After a thorough reading, the selection was reduced to 47 studies. Finally, the quality of these articles was assessed (the procedure is detailed in the following section), and 24 articles were selected, as shown in Figure 1. This whole process was carried out by the researcher who is the first author of this article.

Figure 1
Procedure for article selection



Assessment of the quality of studies

The Critical Appraisal Skill Programme (CASP) checklist[1] was used to assess the quality of the articles. This tool, developed by the Oxford Centre for Triple Value Healthcare, allows the critical appraisal of the reliability and relevance of the results obtained in the different studies, regardless of the area of knowledge from which they originate. It provides ten questions that are accompanied by a series of indications for answering them correctly. With the application of the CASP checklist, the aim is to eliminate the risk of bias to guarantee the credibility and generalizability of the results obtained.

To assess the different types of studies, an adaptation of the CASP checklist including nine questions was created. The quality of the studies was assessed independently by two investigators, as shown in Annex II. Papers were labelled high quality (≥70%), moderate quality (69-40%) or low quality (<40%). Only articles of high and moderate quality (n=24) were included. Excluded articles are shown in Annex III.

RESULTS

Following the procedure developed in the previous section, a total of 24 articles were selected. Analysing their general characteristics revealed that most of the articles were published from 2019 onwards, with a concentration in 2021. Most of the studies took place in China, followed by the United States and Spain. The continents of Asia

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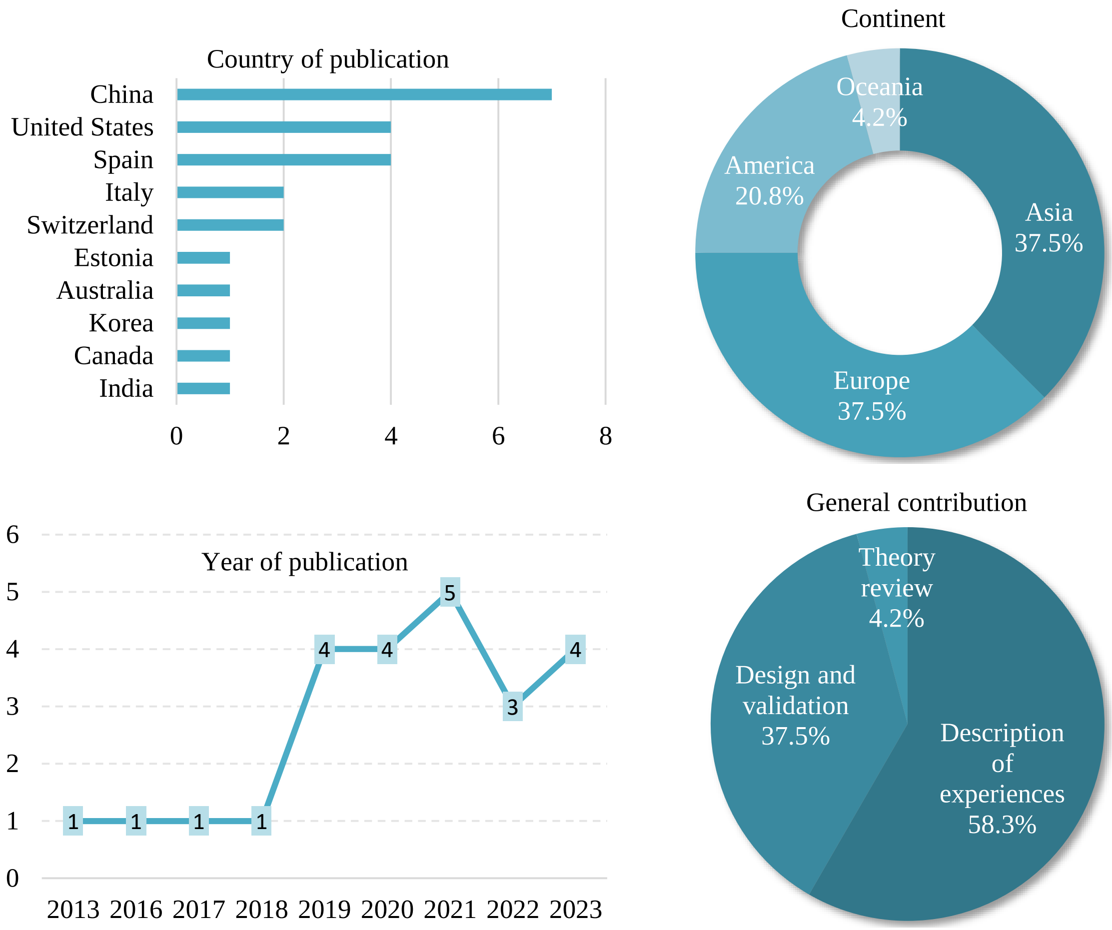
and Europe accounted for most of the selected articles. Analysing the general contributions of the research, 58.3% were based on the description of CT experiences with students or teachers and future primary school teachers, and 37.5% were based on the design and validation of CT models, programmes, resources or evaluation instruments. In terms of research design, most of the studies used quantitative or mixed methods. Experiments with an experimental and control group and the use of pretest and posttest predominated.

Figure 2

Distribution of studies by country, continent, year of publication and overall contributions



In relation to the research questions and the objectives of the review, most of the articles were related to the implementation and evaluation of experiences with CT among primary school students. Only 6 of the 24 articles dealt with the training of in-service or future teachers. The most relevant results are developed below:

Implementing computational thinking in primary education

Most studies focused on students in the third to sixth grades of primary school (Basu et al., 2021; Chevalier et al., 2020; Chiazzese et al., 2019; El-Hamamsy et al., 2022; Freina et al, 2019; Hooshyar et al., 2021; Huang et al.,2023; Jiang & Li, 2021; Liu et al., 2023; Noh & Lee, 2019; Sáez & Cózar, 2017; Sengupta et al., 2013; Shen et al., 2020; Tran, 2019; Wei et al., 2021). Only four studies (Caballero-González & García-Valcárcel, 2020; Del Olmo et al., 2020; El-Hamamsy et al., 2022; Yadav & Chakraborty, 2023) addressed initial levels.

Regarding the tools used, most studies employed robotics (Caballero-González & García-Valcárcel, 2020; Chevalier et al., 2020; Chiazzese et al., 2019; Liu et al, 2023; Noh & Lee, 2019; Shen et al., 2020) and/or computer programming (Basu et al., 2021; Freina et al., 2019; Jiang & Li, 2021; Sáez & Cózar, 2017; Sengupta et al., 2013; Tran, 2019; Wei et al., 2021). Most did so through visual programming environments, such as Scratch (Basu et al., 2021; Chevalier et al., 2020; Freina et al., 2019; Jiang & Li, 2021; Sáez & Cózar, 2017; Sengupta et al., 2013; Wei et al., 2021), App Inventor (Basu et al., 2021) or Blockly (Tran, 2019).

Only two papers (Basu et al., 2021; Del Olmo et al., 2020) addressed CT without using technological devices. Other studies made use of computer games (Hooshyar et al., 2021) or board games enriched with augmented reality (Huang et al., 2023). Finally, apps were also used, such as Lightbot, Code Hour, Q Space App, Preschool and kindergarten app and Luca's educational patterns game app (Yadav & Chakraborty, 2023).

With regard to the learning strategies followed to develop CT in primary school, learning by doing stands out (Chiazzese et al., 2019; Freina et al., 2019; Hooshyar et al., 2021; Jiang & Li, 2021; Liu et al., 2023; Sáez & Cózar, 2017; Shen et al, 2020; Yadav & Chakraborty, 2023), followed by collaborative work (Caballero-González & García-Valcárcel, 2020; Chevalier et al., 2020; Chiazzese et al., 2019; Freina et al., 2019; Jaipal-Jamani & Angeli, 2016; Jiang & Li, 2021; Liu et al, 2023; Noh & Lee, 2019; Tran, 2019; Wei et al., 2021), scaffolding (Chevalier et al., 2020; Freina et al., 2019; Jaipal-Jamani & Angeli, 2016; Sengupta et al., 2013; Yadav & Chakraborty, 2023), and solving problems or challenges (Basu et al., 2021; Caballero-González & García-Valcárcel, 2020; Chevalier et al., 2020; Chiazzese et al., 2019; Freina et al., 2019; Jiang & Li, 2021; Liu et al., 2023; Shen et al., 2020; Yadav & Chakraborty, 2023).

Other studies revealed some principles to consider for CT inclusion to be truly effective: taking students' prior skills into account (Chiazzese et al., 2019; Huang et al.,2023; Liu et al., 2023; Noh & Lee, 2019; Sengupta et al, 2013); using varied environments, tools and activities to respond to the diversity of learners (Sengupta et al., 2013; Tran, 2019); and developing CT from the lowest levels (Caballero-González & García-Valcárcel, 2020; El-Hamamsy et al., 2022; Del Olmo et al., 2020; Tran, 2019; Yadav & Chakraborty, 2023). Given the near nonexistence of methodological and pedagogical principles for teaching CT in primary school, some authors designed their own models and approaches (Chevalier et al., 2020; Liu et al., 2023; Sengupta et al., 2013).

Several studies presented examples of the inclusion of CT in curricular areas, especially in STEM areas such as computer science, science and mathematics (Chiazzese et al., 2019; Sengupta et al., 2013; Tran, 2019; Yadav & Chakraborty, 2023) but also others discussed this in areas such as art education (Sáez & Cózar, 2017). The remaining studies created unique programmes without integrating them into specific curricular areas.

The most commonly used assessment instrument was the selection and adaptation of Bebras tests (Chiazzese et al., 2019; Del Olmo et al., 2020; Huang et al., 2023; Noh & Lee, 2019; Yadav & Chakraborty, 2023). Some authors (Hooshyar et al., 2021; Jiang

& Li, 2021; Liu et al., 2023) used or adapted validated instruments, such as the CT test (CCT) by Román-González et al. (2015), the CT scale (CTS) by Korkmaz et al. (2017) or Dr. Scratch by Moreno-León et al. (2015). Other authors created their own assessment instruments developed specifically for the experience conducted (Basu et al., 2021; El-Hamamsy et al., 2022; Shen et al., 2020; Tran, 2019). Authors such as El-Hamamsy et al. (2022) highlighted the importance of combining several CT tests to adequately assess students' computational competences.

Teacher training in computational thinking

Effective inclusion of CT in primary classrooms requires teachers to possess a range of pedagogical skills and knowledge. However, the reality is that most teachers have no prior CT training or have misconceptions about CT (Chalmers, 2018; Freina et al., 2019; Jaipal-Jamani & Angeli, 2016). However, we found studies showing that teachers experience an increase in their computer skills and confidence in including CT in the classroom after participating in training experiences (Chalmers, 2018; Jaipal-Jamani & Angeli, 2016; Kong & Lai, 2022; Molina-Ayuso et al., 2022; Rich et al., 2021).

Most of the teacher education experiences reviewed were aimed at in-service teachers (Chalmers, 2018; Kong et al., 2023; Kong & Lai, 2022; Rich et al., 2021). Only two studies (Jaipal-Jamani & Angeli, 2016; Molina-Ayuso et al., 2022) targeted prospective primary school teachers. The duration of these training experiences was quite variable, with some experiences lasting less than three months (Chalmers, 2018; Jaipal-Jamani & Angeli, 2016) and others lasting more than eight months (Kong et al., 2023; Kong & Lai, 2022; Rich et al., 2021).

Regarding the content of these learning experiences, some papers addressed computer programming (Kong et al., 2023; Kong & Lai, 2022; Molina-Ayuso et al., 2022; Rich et al., 2021) or robotics (Chalmers, 2018; Jaipal-Jamani & Angeli, 2016). Only the study by Kong and Lai (2022) considered the use of disconnected activities. Among the works which addressed computer programming, those describing the use of Scratch or Scratch Jr (Kong et al., 2023; Kong & Lai, 2022; Molina-Ayuso et al., 2022; Rich et al., 2021) stand out, although other resources, such as App Inventor (Kong et al., 2023; Kong & Lai, 2022) are also used. Robotics is addressed with Lego WeDo kits (Chalmers, 2018; Jaipal-Jamani & Angeli, 2016).

Analysing the structure of the courses reveals that most of them opt for an initial instruction phase and a practice or knowledge implementation phase (Jaipal-Jamani & Angeli, 2016; Kong et al., 2023; Kong & Lai, 2022; Molina-Ayuso et al., 2022; Rich et al., 2021). The most commonly employed strategies are collaborative work (Jaipal-Jamani & Angeli, 2016; Kong et al., 2023), modelling (Kong & Lai, 2022; Rich et al., 2021) and scaffolding (Jaipal-Jamani & Angeli, 2016; Kong et al., 2023).

Finally, the evaluation of training experiences was very diverse and was carried out using a variety of tests created specifically for the experience or adapted from existing ones. All studies assessed both teachers' knowledge acquisition and their reflections on the experience. Studies such as Chalmers (2018) and Kong and Lai (2022) are relevant because they provided information on the challenges teachers face.

Tables 3 and 4 show a synthesis of the above results.

Table 3
Synthesis of results. Implementation of computational thinking in primary education

Authors	Year	Country	Course	Area	Teaching strategies	Resources	Data collection instruments
Sengupta et al	2013	United States	6th	Science	Constructivism Scaffolding Modelling	NetLogo	CT-specific tests
Sáez y Cózar	2017	Spain	6th	Arts education	Play-based learning	Scratch Picoboard Raspberry Pi	Specific CT questionnaire Interview
Chiazzese et al.	2019	Italy	3rd and 4th	Computing	Instruction and learning by doing (projects) Collaborative learning	Lego WeDo 2.0	Tests Adapted Bebras Opinion questionnaire
Freina et al	2019	Italy	5th	Integrated into the school curriculum	Instruction and learning by doing (projects) Collaborative learning Scaffolding	Scratch	Interview Remarks Student diaries Opinion questionnaire Scratch Test Sociogram
Noh and Lee	2019	Korea	5th and 6th	Specific course	Specific instructional design Creative problem-solving model Collaborative learning	Entry Robot hamster	Tests Adapted Bebras Creative thinking test
Tran	2019	United States	3th	Specific programme integrated into the school curriculum	Constructivism Collaborative learning	Code.org Cs unplugged	Specific CT test Interview
Caballero-González and García-Valcárcel	2020	Spain	1st	Integrated into the school curriculum	Collaborative learning Learning by doing (challenges)	Beebot	Adapted rubric

Authors	Year	Country	Course	Area	Teaching strategies	Resources	Data collection instruments
Chevalier et al	2020	Switzerland	4th	Not specified	Creative problem-solving model Collaborative learning	Thymio Robot	Remarks
Del Olmo et al.	2020	Spain	2nd	Not specified	Mixed approach (CT unplugged and CT plugged in)	Unplugged tasks Code.org	Tests Adapted Bebras Adapted motivation test
Shen et al.	2020	United States	5th	Specific curriculum	Instruction and learning by doing (projects)	NAO humanoid robot	Specific CT test
Basu et al.	2021	China	4th, 5th and 6th	Troubleshooting	Troubleshooting	Scratch App inventor	Specific CT test Interview
Hooshyar et al.	2021	Estonia	5th	Not specified	Learning by doing	Autothinking	Adapted CT test Adapted attitude questionnaire
Jiang and Li	2021	China	5th	Specific compulsory course	Instruction and learning by doing (projects) Collaborative learning	Scratch	CT Test
Wei et al	2021	China	4th	Specific course	Collaborative learning	Scratch	Survey Interview Dr. Scratch
El-Hammamsy et al	2022	Switzerland	3rd and 4th	Not specified	Not applicable (validation of an assessment tool)	CT disconnected	Specific CT test
Huang et al	2023	China	3rd	Not specified	Play-based learning	Scratch block-based board game Augmented Reality	Specific CT test
Liu et al.	2023	China	5th	Not specified	Reverse engineering pedagogy Instruction and learning by doing (projects) Collaborative learning	UKit Explore Robotics	Adapted CT test

Authors	Year	Country	Course	Area	Teaching strategies	Resources	Data collection instruments
Yadav and Chakraborty	2023	India	2nd	Integrated into the school curriculum	Instruction and learning by doing Scaffolding	Apps: The Lightbot: Code Hour; Kid's Educational Games: Preschool and Kindergarten; Lucas' Educative Patterns Game; Q space	Tests Adapted Bebras

Source: Own elaboration.

Table 4
Synthesis of results. Teacher training in computational thinking

Authors	Year	Country	Type of training	Experience	Duration	Teaching strategies	Resources	Data collection instruments
Jaipal-Jamani and Angeli	2016	Canada	Initial	Scientific methods course	12 weeks	Instruction and learning by doing (homework) Collaborative learning Scaffolding	Lego WeDo	Tailored interest questionnaire Adapted self-efficacy questionnaire CT Questionnaire Tasks
Chalmers	2018	Australia	Permanent	Experience of integrating CT in classrooms	6 weeks	Learning by doing	Lego WeDo 2.0	Opinion questionnaire Semistructured interviews Reflection journal
Rich et al	2021	United States	Permanent	Specific programme to train teachers in CT	1 year	Learning by doing (challenges) Modelling Sharing experiences and projects Debates	Scratch Scratch Jr	CT Survey Opinion polls
Kong and Lai	2022	China	Permanent	Specific curriculum	48 hours of training	Instruction and learning by doing	Scratch App inventor	Opinion poll

Authors	Year	Country	Type of training	Experience	Duration	Teaching strategies	Resources	Data collection instruments
Molina-Ayuso et al	2022	Spain	Initial	Didactics of numerical operations and measurement	5 days	Instruction and learning by doing (challenges)	Scratch	Tests of adapted Bebras Adapted CT test Opinion poll
Kong et al	2023	China	Permanent	Scalable teacher development programme	1 school year	Collaborative work Learning by doing Mentoring	Scratch App Inventor	PC-specific test Transcripts of meetings Opinion poll

Source: own elaboration.

DISCUSSION

In this section, we present a general interpretation of the results in the context of other studies and discuss their implications for educational practice and future research. In addition, we show in the final part of this section the most substantial limitations we identified from this systematic review.

First, we contrasted our results with those obtained in other research on the implementation of CT in primary education (first research question).

Although education systems in many countries have modified their curricula to respond to the need for the efficient inclusion of CT in primary classrooms, we have found that there are very few studies that focus on the first two years of primary school, which undermines the desirability of starting CT development early. This also makes it difficult to recommend a gradual shift from offline to technology-based activities (Brackmann et al., 2017; Serrano & Ortuño, 2021).

Visual block programming and robotics were the most commonly used strategies or tools in the reviewed studies, coinciding with the conclusions obtained in two meta-analyses (Merino-Armero et al., 2021; Sun et al., 2021), which indicated that robot programming is the most efficient strategy for CT development in primary education.

The use of disconnected activities was fairly limited in the selected studies. This contrasts with the advantages, especially in primary school (Serrano & Ortuño, 2021), that this strategy has according to several previous studies (Huang & Looi, 2020; Weigend et al., 2019). In one meta-analysis (Li et al., 2022), the authors also concluded that both unplugged activities and scheduling exercises are useful for CT development among students. According to this study, the effects of programming are somewhat better than those provided by disconnected activities and are enhanced when working in an interdisciplinary way and not only within specific subjects, which is far from the results of our research.

In relation to the teaching strategies employed, we concluded that there are a number of strategies that are suitable for use, including instructional and learning-by-doing strategies, scaffolding, collaborative work and problem or challenge solving, thus largely agreeing with previous work (Park & Park, 2018; Kale et al., 2018; Voogt et al., 2015). However, game-based learning was reported in some previous studies (Kaleliöğlu et al., 2016) as one of the most commonly used strategies in CT development experiences, a conclusion that does not coincide with the results obtained in our review.

Some authors analysed how to assess CT development, showing that there is a great gap in terms of valid assessment tools and strategies (Alves et al., 2019). Although there are instruments for assessing CT development in primary education (Bebras, CCT Test, CTS Scale, Opinion polls, Dr. Scratch, etc.), we find that they are not useful for verifying the real and complete development of CT, as they focus more on programming skills than on analysing the development of CT components. In the absence of effective approaches to assess CT in primary school, we propose the combination of multiple assessments to cover all dimensions of CT. This issue requires further research, as already noted in previous studies (Cutumisu et al., 2019; Lockwood & Mooney, 2017; Román-González et al., 2017).

Second, we discuss the characteristics of CT teacher education at the primary school level (second research question).

According to the results obtained, we note the scarcity of studies that rigorously evaluate training experiences, especially in initial teacher training, coinciding with the results of other research (Bocconi et al., 2016; Bustillo, 2015; Ling et al., 2018; Yadav et al., 2017). This is most likely because there is still no proliferation of teacher training plans for CTdevelopment, which is still a pending goal, as pointed out by Haseski and Ilic (2019). Educational institutions should take the lead in teacher training, as they are the best places for teachers to reflect on their previous beliefs about CT, to learn about key concepts and, most importantly, to adopt the most appropriate pedagogical approaches (González et al., 2018; Yadav et al., 2017).

Introducing CT concepts in the initial training of teachers is a key strategy for achieving this goal since it is at that time that they are generally most willing to understand the relevance of CT within their own discipline (Butler & Leahy, 2021; Yadav et al., 2014). In any case, beyond specific training actions, the implementation and evaluation—in different contexts—of training proposals is needed, and fortunately, such efforts are beginning to emerge and can be consulted in different works (Esteve-Mon et al., 2019; Kotsopoulos et al., 2017; Serrano & Ortuño, 2021; Tsai et al., 2021; Voon et al., 2023).

In addition to the need to design training models that operationalize CT development with specific strategies, importantly, there are generic pedagogical models that can be the basis for designing specific models. Some authors (Kale et al., 2018; Yadav et al., 2017) consider the TPACK (technology, pedagogy, and content knowledge) model, promoted by Mishra and Koehler (2006), to be useful for teaching CT in initial teacher education. This model includes preservice teachers learning about the effective integration of technology within the context of subject matter and pedagogy; similarly, teachers need to develop CT knowledge within the context of their content knowledge and pedagogical knowledge.

The study by Kong et al. (2020) presented a (primary) teacher development programme to develop CT competences in relation to programming and the TPACK model. The researchers identified concerns among teachers about programming due to the lack of efficient and pedagogically rich training support. The authors proposed a pedagogy for playing, thinking and coding for the development of computer skills with programming in primary schools.

Despite the emphasis on CT as a mental tool that extends beyond computer-based environments, most current teacher professional development efforts have focused on exposing teachers to programming environments, consistent with the findings of our review. Thus, teachers should be engaged to think about how CT can be integrated into authentic learning situations in other content areas. The training programme developed by Yadav et al. (2018) highlights this idea.

The pedagogical knowledge training of primary school teachers is, in general, solid. However, this needs to be complemented by CT-specific pedagogical practices and content, such as modelling a problem, thinking about or solving a problem iteratively and incrementally, or explaining a solution to a problem in a series of steps (Carlborg et al., 2019).

Furthermore, we found that in-service teachers carry out training that varies in duration and is very focused on technical aspects such as computer programming and robotics, leaving in the background the use of unplugged activities and issues related to didactic strategies, precisely those aspects that have a high impact on learning in promoting CT among future students, as mentioned above.

In summary, we conclude that – most likely – many teachers are trying to integrate CT into their classrooms without having the necessary competences, especially those that should be developed during initial teacher training. Such training should be based on the principles of educational technology, involve teachers in the task of determining how to integrate CT into learning situations in an interdisciplinary way, be complemented by pedagogical practices and CT content, go beyond teaching programming, and incorporate offline activities as a preliminary step in robot programming. The effectiveness of these training programmes requires improved approaches to CT development assessment beforehand.

Third, we refer to the main limitations of the research. The remaining limitations, which we consider minor, can be found in the PRISMA 2020 checklist (Annex I).

This systematic review analyses the studies collected by Scopus and WOS. With this inclusion criterion, we deliberately discarded other types of publications that could be equally valuable. This decision was made because previous systematic reviews did account for studies published in journals indexed in databases such as ERIH Plus. It would be valuable to consider unpublished "grey literature" on the topic to counteract the problem of publication bias. However, we argue that this limitation does not detract from the validity of the conclusions obtained. Selecting studies published in high-impact journals is a useful, necessary and accepted filter among the scientific community.

Although in the first task of article selection (reading article titles) we discarded those studies that were clearly not related to the research, we consider that in order to avoid bias and errors, it would be more convenient to analyse the abstracts as well. Another aspect to improve in this part in future studies is that the selection of studies should be done by more than one reviewer and in an independent manner. This recommendation was partially followed during the assessment of the quality of the papers with the CASP checklist, in which the two researchers who signed this article participated. In relation to this instrument, we consider that its utility is questionable for two reasons: because it does not distinguish studies according to the type of research design of each study and because of its limited application in studies in the social sciences. We recommend exploring and selecting other checklists or scales available on the Equator Network website[2].

NOTES

[1.] Web de CASP: https://casp-uk.net/

[2.] Sitio web Equator Network: https://www.equator-network.org/

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Conflict of interest

The authors declare that there are no relationships or activities that may have influenced the conduct of this systematic review.

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ANNEX I. Prism checklist

Supplementary material to this article can be found in its electronic version at: https://joseluisserrano.net/annex-I-PRISMA-RIED-EN.pdf

ANNEX II. Results obtained in the evaluation of the quality of the articles

To assess the quality of the studies, an adaptation of the CASP checklist has been used. The questions, as numbered in the table, are as follows:

1. Is the focus of the research topic clearly defined?
2. Is the information sought out by the authors adequate?
3. Have the authors identified all the important confounding factors?
4. Was the follow-up of the topics comprehensive enough?
5. Are the results linked to the objectives?
6. Are the results accurate?
7. Are the results applicable to other types of populations?
8. Are the results of this study consistent with other available evidence?
9. Are the implications of this study valid for practice?

Each question was scored with "Yes = 1", "No = 0" and "UN = Unclear". High (≥70%) and moderate (69-40%) quality studies included in this review are highlighted in Table 5.

Table 5
Results obtained in the quality assessment of the articles

Study	Researcher	1	2	3	4	5	6	7	8	9	%	Average %
Ángel-Díaz et al. (2020)	A	1	UN	UN	UN	1	0	0	0	UN	22.2	27.8
	B	1	1	0	UN	1	0	0	UN	UN	33.3	
Basu et al. (2021)	A	1	1	1	1	1	1	UN	0	UN	66.7	66.7
	B	1	1	1	1	1	1	0	0	UN	66.7	
Caballero-González & García-Valcárcel (2020)	A	1	1	0	UN	1	1	0	1	1	66.7	55.6
	B	1	UN	0	0	1	1	0	1	UN	44.4	
Chalmers (2018)	A	1	UN	0	0	0	1	0	1	1	44.4	50.0
	B	1	1	UN	0	0	1	0	1	1	55.6	
Chen et al. (2017)	A	1	UN	0	UN	1	1	UN	UN	UN	33.3	33.3
	B	1	0	0	UN	1	1	UN	0	UN	33.3	
Chevalier et al. (2020)	A	1	1	0	0	1	1	0	1	1	66.7	55.6
	B	1	1	0	0	1	UN	0	1	UN	44.4	
Chevalier et al. (2022)	A	1	UN	0	UN	1	1	0	UN	UN	33.3	27.8
	B	1	0	0	0	1	UN	0	0	UN	22.2	
Chiazzese et al. (2018)	A	1	UN	0	0	1	UN	0	UN	0	22.2	27.8
	B	1	1	0	0	1	0	0	0	0	33.3	
Chiazzese et al. (2019)	A	UN	1	0	1	1	1	1	UN	1	66.7	66.7
	B	1	1	0	1	1	1	UN	UN	1	66.7	
Connolly et al. (2021)	A	1	0	0	0	1	UN	0	UN	UN	22.2	22.2
	B	1	UN	0	0	1	UN	0	0	0	22.2	
Del Olmo-Muñoz et al. (2020)	A	1	1	0	UN	1	1	1	1	1	77.8	77.8
	B	1	1	0	0	1	1	1	1	1	77.8	
El-Hamamsy et al. (2021)	A	1	UN	0	0	UN	1	UN	UN	UN	22.2	22.2
	B	1	0	0	0	UN	1	0	0	UN	22.2	
El-Hamamsy et al. (2022)	A	1	1	UN	1	1	1	UN	1	1	77.8	72.3
	B	1	1	1	1	UN	UN	0	1	1	66.7	

Study	Researcher	1	2	3	4	5	6	7	8	9	%	Average %
Freaina et al. (2019)	A	1	1	0	0	1	1	0	0	1	55.6	50.0
	B	1	1	0	0	UN	1	0	0	1	44.4	
Gamito et al. (2022)	A	1	UN	0	UN	1	0	0	1	UN	33.3	33.3
	B	1	UN	0	0	1	0	0	1	UN	33.3	
Gane et al. (2021)	A	1	1	0	0	1	UN	0	UN	UN	33.3	27.8
	B	1	UN	0	0	1	0	0	0	UN	22.2	
Gao & Hew (2022)	A	1	1	UN	UN	1	UN	0	0	UN	33.3	33.3
	B	1	1	UN	0	1	UN	0	0	0	33.3	
Hooshyar et al. (2021)	A	1	1	1	UN	1	1	UN	1	1	77.8	77.8
	B	1	1	UN	UN	1	1	1	1	1	77.8	
Hsu et al. (2022)	A	1	UN	0	UN	1	1	0	UN	UN	33.3	33.3
	B	1	0	0	0	1	1	0	0	UN	33.3	
Huang et al. (2023)	A	1	1	0	0	1	1	0	1	UN	55.6	50.0
	B	1	1	0	0	UN	1	0	1	UN	44.4	
Jaipal-Jamani & Angeli (2017)	A	1	UN	0	UN	1	1	0	1	1	55.6	50.0
	B	1	1	0	UN	UN	1	0	1	UN	44.4	
Jiang & Li (2021)	A	1	UN	0	UN	1	1	0	1	UN	55.6	61.2
	B	1	1	0	UN	1	1	0	1	1	66.7	
Kastner-Hauler et al. (2022)	A	1	UN	0	UN	1	UN	UN	0	UN	22.2	22.2
	B	UN	1	0	UN	1	0	UN	0	UN	22.2	
Kim & Kim (2016)	A	1	UN	0	0	1	UN	0	0	UN	22.2	22.2
	B	1	UN	0	0	1	0	0	0	UN	22.2	
Kong et al. (2023)	A	1	1	0	UN	1	1	0	1	UN	55.6	55.6
	B	1	1	0	UN	1	1	0	1	UN	55.6	
Kong & Lai (2021)	A	1	UN	0	UN	1	1	UN	UN	UN	33.3	33.3
	B	1	UN	0	0	1	1	0	UN	UN	33.3	
Kong & Lai (2022)	A	1	1	0	1	1	1	0	UN	1	66.7	55.6
	B	1	UN	0	1	1	UN	0	0	1	44.4	

Study	Researcher	1	2	3	4	5	6	7	8	9	%	Average %
Li et al. (2021)	A	1	1	0	0	1	UN	0	0	UN	33.3	33.3
	B	1	1	0	0	1	UN	0	0	UN	33.3	
Liu et al. (2023)	A	1	UN	1	UN	1	1	0	1	UN	55.6	61.2
	B	1	1	1	0	1	1	0	1	UN	66.7	
Matere et al. (2021)	A	1	UN	0	UN	1	1	0	UN	UN	33.3	38.9
	B	1	0	0	1	1	1	0	0	UN	44.4	
Molina-Ayuso et al. (2022)	A	1	1	1	1	1	1	UN	1	1	88.9	83.4
	B	1	UN	1	1	1	UN	1	1	1	77.8	
Noh & Lee (2020)	A	1	1	0	1	1	1	1	1	1	88.9	88.9
	B	1	1	0	1	1	1	1	1	1	88.9	
Pewkam & Chamrat (2022)	A	1	UN	0	UN	1	UN	0	1	UN	33.3	27.8
	B	1	0	0	0	UN	UN	0	1	UN	22.2	
Rich et al. (2020)	A	1	1	0	1	UN	0	UN	0	UN	33.3	22.2
	B	1	UN	0	UN	0	0	UN	0	UN	11.1	
Rich et al. (2021)	A	1	1	0	UN	1	1	0	1	UN	55.6	50.0
	B	1	UN	0	0	1	1	0	1	UN	44.4	
Rijke et al. (2018)	A	1	0	0	UN	1	UN	UN	1	UN	33.3	27.8
	B	UN	0	0	UN	1	0	0	1	UN	22.2	
Sáez & Cózar (2017)	A	1	1	1	UN	1	UN	UN	1	1	66.7	66.7
	B	1	1	1	UN	1	UN	UN	1	1	66.7	
Sengupta et al. (2013)	A	1	1	0	UN	1	1	0	1	UN	55.6	66.7
	B	1	1	0	1	1	1	UN	1	1	77.8	
Seo & Kim (2016)	A	1	UN	0	0	1	1	0	UN	UN	33.3	33.3
	B	1	UN	0	0	1	1	0	0	0	33.3	
Shen et al. (2022)	A	1	UN	UN	UN	1	1	0	1	1	55.6	61.2
	B	1	1	UN	UN	1	1	UN	1	1	66.7	
Silva et al. (2021)	A	1	0	0	0	1	UN	0	0	UN	22.2	22.2
	B	1	UN	0	0	1	UN	0	0	UN	22.2	

Study	Researcher	1	2	3	4	5	6	7	8	9	%	Average %
Tran (2019)	A	1	1	0	1	1	1	0	1	1	77.8	72.3
	B	1	1	0	1	1	UN	0	1	1	66.7	
Wang et al. (2022)	A	1	UN	0	UN	UN	1	0	0	UN	22.2	22.2
	B	1	0	0	0	0	1	0	0	UN	22.2	
Waterman et al. (2020)	A	1	UN	0	UN	1	0	0	UN	UN	22.2	22.2
	B	1	UN	0	UN	1	0	0	0	UN	22.2	
Wei et al. (2021)	A	1	1	0	UN	1	1	UN	1	1	66.7	61.2
	B	1	UN	0	0	1	1	0	1	1	55.6	
Yadav et al. (2018)	A	1	UN	0	UN	1	UN	0	UN	UN	22.2	27.8
	B	1	1	0	UN	1	0	0	UN	UN	33.3	
Yadav & Chakraborty (2023)	A	1	1	UN	UN	1	1	0	1	1	66.7	66.7
	B	1	UN	1	UN	1	1	0	1	1	66.7	

Source: own elaboration.

ANNEX III. References not included in the review

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Developing the DALI Data Literacy Framework for critical citizenry

Desarrollando el marco DALI de alfabetización en datos para la ciudadanía

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ABSTRACT

In the current postdigital age, where data has become increasingly ubiquitous, the management of data has emerged as a vital aspect of digital literacies, particularly for active citizenry. This article introduces a Data Literacy framework that emphasizes the importance of an ideological emancipatory vision of data literacy for critical citizenry. The framework provides a comprehensive perspective on the key elements of data literacy and their interrelationships. Grounded Theory served as the foundation for conducting a three-and-a-half round Delphi study involving experts from diverse fields such as data, education, and literacy, across four countries. The outcome of this study is the DALI Data Literacy framework, which encompasses four primary elements. Three of these elements are interconnected and sometimes overlapping: (1) Understanding Data, (2) Acting on Data, and (3) Engaging Through Data. Additionally, there is a cross-cutting element, (4) Ethics & Privacy, which permeates the other three. The DALI framework is flexible and scalable, making it suitable for adaptation across various international, organizational, and educational contexts. Furthermore, the article's conclusions reflect on how the DALI framework can support pedagogical initiatives aimed at promoting data literacy among adults. Its adaptability and scalability make it well-suited for addressing the diverse needs and contexts found within different educational settings and organizations internationally. By incorporating the DALI framework, digital education can evolve to foster critical data literacy skills and empower individuals to navigate and participate meaningfully in the postdigital age.

Keywords: information and communication technologies; literacy; citizen participation; information processing; model.

RESUMEN

En la era postdigital actual, donde los datos son cada vez más omnipresentes, la gestión de datos se ha convertido en un aspecto crucial de la alfabetización digital para la ciudadanía activa. Este artículo presenta el proceso de elaboración de un marco de Alfabetización en Datos que se llevó a cabo utilizando la Teoría fundamentada como base metodológica, y el método Delphi como estrategia para conjugar la participación de expertos de diversos campos como la ciencia de datos, la educación y la alfabetización, provenientes de cuatro países, en tres rondas y media de trabajo. El resultado de este estudio es el marco DALI de alfabetización en datos para la ciudadanía, que abarca cuatro elementos principales. Tres de estos elementos están interconectados y a veces se superponen: (1) Comprender los datos, (2) Actuar a partir de los datos y (3) Comprometerse a través de los datos. Además, hay un elemento transversal, (4) Ética y Privacidad, que impregna los otros tres. El marco DALI es flexible y escalable, lo que permite su adaptación a diversos contextos internacionales, organizativos y educativos. Además, las conclusiones del artículo reflexionan sobre cómo el marco DALI puede respaldar iniciativas pedagógicas destinadas a promover la alfabetización en datos entre los adultos y cómo su adaptabilidad y escalabilidad lo hacen ideal para abordar las diversas necesidades y contextos encontrados en diferentes entornos educativos y organizaciones internacionales.

Palabras clave: tecnologías de la información y de la comunicación; alfabetización; participación del ciudadano; tratamiento de la información; modelo; formación del concepto.

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INTRODUCTION

Digital and networked technologies have become so deeply integrated into work, education, and everyday life that categorizing specific activities as "digital" has lost meaning. To address this evolving socio-technical landscape, the term "postdigital" has gained popularity, acknowledging the messy and unpredictable intersections between the digital and the analogue, the technological and the non-technological, the biological and the informational, and the old and the new (Jandrić et al., 2022; Taffel, 2016).

In this postdigital age, the generation, processing, circulation, and commodification of data resulting from our daily lives have become more pervasive than ever. Data, which can be defined as measurements or observations collected for information purposes (Australian Bureau of Statistics, 2022), is constantly being collected by our surroundings, the places we visit, the online services and devices we use, and is often used to make inferences about our behaviour through algorithms. Monetizing data extracted through various forms of surveillance and monitoring has become a central aspect of the current economy (Bloom, 2019; Zuboff, 2019) with data serving as the new oil and data refineries playing a crucial role in the production of economic value within the framework of informational capitalism (Cohen, 2019).

However, our relationship with data is not merely passive, as we also consume vast amounts of data that shape our worldview and influence our decisions. Therefore, there is a growing need to educate people about reading, understanding, and analyzing data (Raffaghelli & Stewart, 2020). Furthermore, individuals may also want to explore patterns within the data, bring about changes, and communicate ideas using data. Consequently, the ability to effectively and ethically handle data, as well as navigate data-driven realities, has become essential for work, education, and active citizenship in contemporary societies (Markham & Pereira, 2019; Nguyen, 2021). Moreover, data literacy is not only critical for personal and professional growth but also plays a crucial role in promoting social justice (Atenas et al., 2020; Louie et al., 2022). Empowering individuals with data literacy skills allows them to critically assess information, challenge biases, and identify inequities in data-driven decision-making processes (Markham, 2020). However, achieving data literacy as a fundamental part of digital education for citizens has proven to be a complex challenge (Marín & Castañeda, 2022; Pangrazio & Selwyn, 2019).

Against this backdrop, *Data Literacy for Citizenship* (DALI)[1] emerged as a European Erasmus+ project that aims to empower adults for responsible citizenship and civic engagement in a postdigital world, by supporting the development of key competencies related to the use of data and the understanding of the associated implications. The project targets three demographic groups (young adults, general adults, and seniors) across four countries (Germany, Norway, Spain, and the UK). In addition to the impact of data on adults' lives, they also bear responsibility for regulating how young people engage with data both at home and in educational settings, as adults are typically legally responsible for their children's data in most countries.

DALI focuses on co-creating, piloting, and evaluating pedagogical strategies, as well as developing games and playful learning resources for adult learners. It also involves engaging stakeholders in the field of adult education to facilitate implementation. The project adopts a playful approach to increase learning demand

and participation through effective outreach, guidance, and motivational strategies (Arnab et al., 2019; Whitton, 2018).

With this process in mind, DALI began its work by creating a framework that helps define the field and the boundaries of data literacy (from here on DL) as a way of empowering people in the digital world and strengthening their agency.

There have been many attempts to approach an ethical view of data through frameworks (a great analysis of them in Atenas et al., 2023), and some specific attempts have already been made to define DL previously. For example, DL has been incorporated into frameworks that outline essential areas of competence encompassing knowledge, skills, and attitudes necessary for Digital Literacy (Marín & Castañeda, 2022). The European Commission's Digital Competence Framework for Citizens (DigComp) includes Information and Data Literacy as one of its five competency areas (Carretero Gomez et al., 2017; Kluzer & Priego, 2018). However, in certain work contexts, such as teaching, only specific aspects of DL are covered in the European Commission's DigCompEdu, primarily related to "responsible use" (Caena & Redecker, 2019). Additionally, while DigComp offers a broader perspective on digital competencies, a dedicated Data Literacy framework is necessary to focus on specialized skills for data analysis, interpretation, and ethical engagement. This new framework would empower individuals for data-driven decision-making and foster social justice through equitable data practices.

Different data literacy frameworks exist, including Learn2Analyse, Open Data Institute, and Data Citizenship Framework (Yates et al., 2021). They vary in aspects like target audience and creation methodology (Table 1).

Table 1
Previous frameworks about DL

FRAMEWORK	AUTHORS	TARGET GROUP	METHOD	DESCRIPTION
EDUCATIONAL DATA LITERACY COMPETENCE FRAMEWORK	Learn2Analyze (EU project)	Educational designers and online trainers	Expert-based questionnaire	Six dimensions of skills. Ethics as a specific dimension.
DATA SKILLS FRAMEWORK	Open Data Institute (non-profit company)	Organizations	Not found	Five domains depending on the roles of an organization. "Working ethically" as a subdomain.
DATA CITIZENSHIP FRAMEWORK	Yates et al. (2021)	Citizens	Systematic analysis of literature	Three domains that sometimes overlap. Ethical use as a part of Data Thinking

Various frameworks incorporate ethics to some extent, primarily concerning the use of data in their respective professional contexts. While these frameworks offer valuable contents, their creation processes lack detailed explanations, except for the *Educational Data Literacy Competence Framework*, which is based on an expert-based survey method (Yates et al., 2021). Conversely, the Data Citizenship Framework's development is inadequately described, with authors primarily from the United Kingdom, except for one person affiliated with a Chinese university. The creation process of the Data Skills Framework remains unknown.

To address this gap and promote interdisciplinary and cross-cultural interpretations, the DALI project employed a co-creation process to develop its own framework. This approach allowed for collective reflection on DL while acknowledging the theoretical and ideological diversity of the project's professionals. The framework creation utilized a Delphi study, recognizing the complexity of the Data Literacy Phenomenon (Marín & Castañeda, 2022). Additionally, the DALI framework aligns with the European Union's 2018 definition of Digital Literacy (European Union, 2018).

In addition, the basic structure for the framework is derived from the DigComp structure. DigComp is structured into the following components: a) competence areas (elements); b) competences titles and descriptors (sub-element, sub-competence), c) proficiency levels and d) examples of use (Carretero Gomez et al., 2017). Like the DigComp structure, the resulting framework in this study will also include indicators for precisely three levels of development (proficiency levels) for each sub-competence in each element or competence area (levels A to C from basic to advanced proficiency).

This article presents the collective process we followed with the aim of defining the *DALI Data Literacy Framework* for critical citizenry that subsequently underpins the design of the game-based networked learning strategies and playful resources generated during the project.

METHOD

The study's main objective was to collaboratively develop a framework that would be the foundation for the rest of the DALI project, a framework that is developed and implemented with indicators of the desirable basic, intermediate, and advanced levels of performance for the target audience of the project (i.e. adults). The DALI Data Literacy Framework (from here on the DALI Framework) emerged from a collective expert construction, rather than from a literature review. Therefore, we followed the Delphi technique in order to identify the essential areas that should be included in our framework, and we used the technique itself for its development (Okoli & Pawlowski, 2004).

A Delphi Study

Several circumstances led us to use the Delphi method. First, it is useful for creating a participatory synthesis, or what is the same, collecting, analysing and building opinions from homogeneous or heterogeneous groups of researchers to “illuminate certain aspects of a phenomenon or build collective understanding regarding this” (Cohen et al., 2017, p. 463). In addition, it has been extensively adopted in different fields, such as social and environmental sciences, to engage experts in dialogue and interaction around an object of study (Bond et al., 2021; Fefer et al., 2016). Particularly, it has been important in the field of educational research (Guàrdia et al., 2022). The Delphi technique can be understood as “a group communication process as well as a method of achieving a consensus opinion” (Salkind, 2010, p. 343), in such a way that allows participants to effectively “deal with a complex problem”

(Linstone & Turoff, 1975, p. 3). It is worth noting that the Delphi technique is aligned with the co-creation and co-design approach under which the whole work development in the DALI project is carried out since they are also addressed to "enable organisations, groups and individuals to interact, collaborate and solve problems by jointly generating solutions and creating value" (El-Jarn & Southern, 2020, p. 192).

Considering the definition of the DALI Framework as the first task for the project, this Delphi aimed to extract the ideological statements related to DL from within the core group, as well as to structure a group communication process that would take advantage of the academic diversity of the group for achieving a broader perspective related to the study object, and has been considered reliable to develop frameworks (Chen, 2019; Fefer et al., 2016). Nevertheless, a Delphi study has five conditions (1) a consultation of a mature set of experts –probably the essential characteristic of the technique– (2) anonymous –none of them should know the specific inputs of the others– (3) multiple rounds –which should be configured as iterations of the process–, (4) with feedback of the results and (5) the opportunity for the participants to reconsider their position (Becuwe et al., 2017; Cabero, 2013).

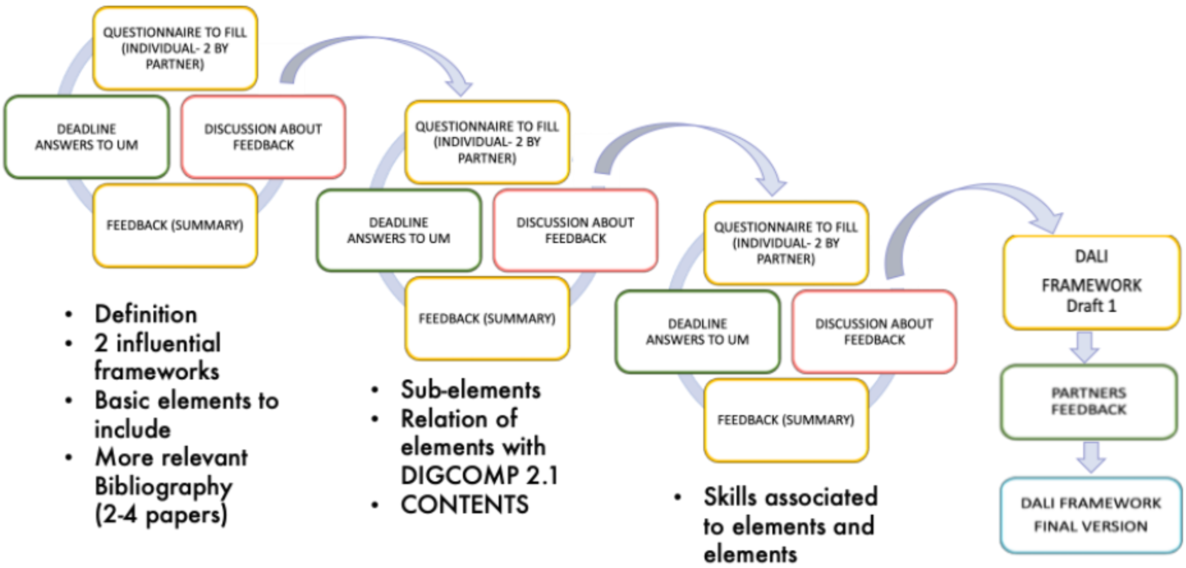
Panellists

The selection of experts is critical for the final validity of the results (Seo et al., 2020). In this case, the experts were chosen by the project partners. Each partner university chose two experts to take part in the Delphi panel, considering not just the role of the partner in the specialized consortium, but also the expertise of each participant. Ten experts in education, from five different institutions, in four other countries (Germany, Norway, Spain and the United Kingdom) and with diverse backgrounds and perspectives on the use and study of technology for education participated in the process. Nine of them held a PhD on topics relevant to education and technology.

The Delphi Structure

Taking advantage of the flexibility of the Delphi approach and the possibility of making some adaptations to it – including preliminary literature reviews which have been also recurrent in education studies (Seo et al., 2020) –, in this study, we decided to implement the Delphi panel following Bond et al.'s (2021) approach in a three and a half rounds' version (see Figure 1) which take 20 weeks in total.

Figure 1
DALI Framework Delphi Structure



The Delphi structure aimed to collaboratively shape the DALI Framework through iterative questionnaires and controlled opinion feedback (Dalkey & Helmer, 1963). Each iteration began with open-ended questions and an explanation phase (Chen, 2019; Fefer et al., 2016), where panellists individually addressed specific aspects of the framework. The moderator, representing the University of Murcia, collected, anonymized, and organized the responses for discussion in synchronous sessions. During these sessions, discussions occurred in small groups (2-3 people) followed by presentation and consensus-building in the larger group (Bond et al., 2021).

The work rounds served as phases for deepening the framework, with each round building upon the previous discussions. Consequently, the results of each round were directly integrated into the ongoing work. This approach effectively captured diverse perspectives from geographically dispersed panelists while ensuring anonymity to mitigate dominance or external social dynamics (Fake & Dabbagh, 2021; Fefer et al., 2016).

Data Collected

This section describes the data collected as part of the Delphi process in each one of the rounds depicted in Figure 1.

Round 1

As can be seen in Figure 1, the first round of the process focused on defining DL based on participants' backgrounds and the most relevant DL-related paper they could refer to. The panellists also identified key elements for the DALI Framework. During the online synchronous session, discussions centered on problematic terms and abilities in the DL definition. Additionally, priority order, relevance of terms and elements, and elimination of irrelevant information were discussed.

In this first round, panellists were asked about their preferred definition and elements for shaping DL. Results were organized in a definition and a list of elements. In addition, for representation purposes, the definitions were visualized using a word/tag cloud technique (McNaught & Lam, 2010) that highlighted the most repeated terms included in the definition (see Figure 2).

Figure 2
Word/tag cloud based on round 1 keywords

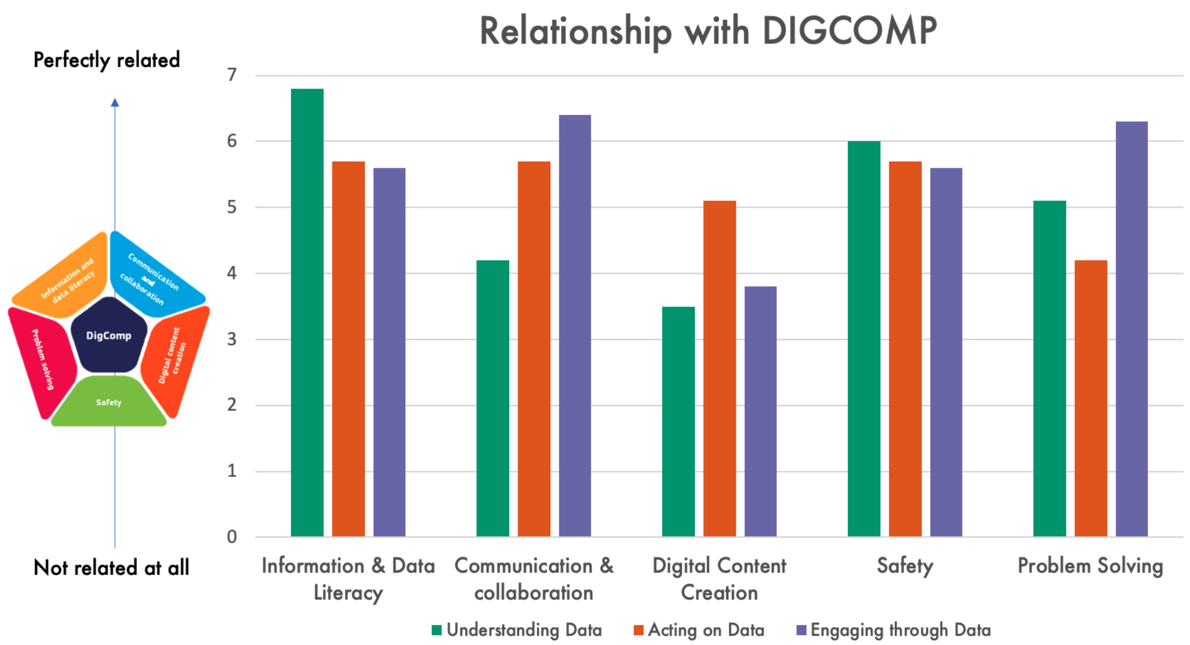
The definition of DL was based on nine scientific/academic articles highly relevant to the panellists. Three of these papers were used as references for defining the elements of DL. Additionally, the panellists were asked to include four essential references on DL, resulting in 19 papers included in Appendix 1.

From these data, it is evident which papers were particularly influential in the framework creation (Calzada-Prado & Marzal, 2013; Pangrazio & Selwyn, 2019; Raffaghelli, 2019). Moreover, it seems interesting that from the 39 different authors contributing to these papers, the work of Raffaghelli – which appears five times in three different papers – seems very influential in the development process. Also, the contribution of Carmi and Yates – which appears in two different papers in 2020 – is referenced twice by the panellists. Twelve authors were referenced by panellists at least twice: Cavero, Gooch, Kortuem, Lockley, Mandinach, Maybee, Montaner, Pawluczuk, Rashid, Schüller, Wolff, and Zilinski.

Round 2

The second round focused on the basic elements of DL and their relationship with DigComp elements. During the online synchronous discussion, the perceived connections between the defined DALI framework elements and DigComp elements (information and data literacy, communication and collaboration, digital content creation, safety, and problem-solving) were examined. The group also deliberated on better naming for each element and the inclusion of relevant skills. Part of the reflection involved rating the relationship between each framework element and DigComp elements on an 8-Likert scale, ranging from "Not related at all" (0) to "Perfectly related" (7). The results are depicted in Figure 3.

Figure 3
Relationship between DigComp and DALI Framework elements



The findings suggest that some elements from DigComp, such as “Safety” (e.g., sub-element "protecting personal data and privacy") and “Information & Data Literacy” (e.g. sub-element "managing data, information and digital content") are transversal to the three elements of DALI (understanding data, acting on data and engaging through data), whereas other elements, like “Communication & Collaboration” (e.g., sub-element "engaging in citizenship through digital technologies") or “Problem-Solving” (e.g., sub-element "creatively using digital technologies") are more present in some aspects of DL (e.g., engaging through data).

Round 3

In the third round, the focus was on defining the skills for each DL element and identifying them through indicators in three proficiency levels. Online synchronous discussions centred on validating the coherence of the skill levels. The process involved panellists filling a grid with sub-competences and elements, along with three columns (level A, B, and C) containing indicators. After anonymizing and compiling the responses, participants reviewed the components in groups and discussed the final wording of each indicator.

Final Round

A final half-round was used to discuss the final version of the DALI framework. The group coordinator made a first draft of the complete framework, based on the data collected during the previous rounds. This final half-round skipped the individual feedback -apart from typos and grammar precisions– and went directly to the group work discussion to elicit general impressions about the framework.

RESULTS: THE DALI FRAMEWORK

We now present the Delphi process's final product by describing the DALI Framework. Following an organizational structure like the EU DigComp framework, it includes a DL definition, the DL elements, the framework indicators, and levels of performance.

DL Definition

DL is about how people might understand, use, and engage with the data encountered in everyday life for the citizenry. It implies finding ways to make informed decisions – in everyday life and in various contexts according to personal or collective goals. To ask and answer questions from data sets through an inquiry process, considering ethical use of data.

DL includes an understanding of data, and awareness/attitudes toward non-neutrality/biased data (collection, etc.). It implies knowledge about collecting, selecting, storing, preserving, and managing data; analysing, evaluating, interpreting, critiquing, applying, using, and working with data; and representing, visualizing, and communicating stories from data.

DL also includes skills for making critical judgments and interrogating the claims accompanying data systems, including ethical and legal aspects that affect themselves and other people's rights. It also comprises abilities to use data as part of a design process as solving problems and making decisions for different purposes.

The DALI Framework reconciles all these considerations into four main elements. Three of them are mainly independent of each other, even though in some cases the boundaries between them overlap: (1) Understanding Data, (2) Acting on Data, and (3) Engaging Through Data. An extra element is considered transversal to the others: (4) Ethics & Privacy. While it is present in (1), (2) and (3) in terms of content and indicators, it is a fundamental element in all of them.

Some crucial points should be emphasized in the development of the definition and its components. In the process of defining the term, a significant discussion arose regarding citizenship versus citizenry, and we ultimately chose the latter term to be more inclusive, participatory, and justice-oriented (Westheimer & Kahne, 2004). This decision allows for a broader perspective, moving beyond the narrow confines of official citizenship status in local contexts. Also, concerning the DALI elements, the choice of names for each of them was not straightforward and without discussion. On the contrary, panellists started focusing on data for the components' titles. However, during the discussion sessions, an important point was made to give more importance to the people and the actions they develop with data. Therefore, the participants ended up entitling the DALI components from a participant's action perspective rather than from a data perspective.

DL Elements

The DALI Framework is represented in Figure 4 with its elements (mentioned before in the DL definition) and sub-elements.

All four elements are extensive and complex, so their definition is challenging. Nevertheless, for this project, we are defining the boundaries of them by the description of the contents that each one of them includes:

Understanding Data

Understanding data refers to cognitive operations, reflections, and processes that do not imply necessarily actions:

- Understanding data as a representation of reality, not the reality itself. What data is, what form it takes, and how it can be used in society (including personal data, institutional data, etc.).
- Understanding where data comes from, i.e., data origins (e.g., sensors, own apps, use of a tool, GPS on the own phone, etc.).
- Understanding different types (e.g., sensor data, audio data), and technical formats (e.g., MP4, JPG), as well as how these data can be collected from different environments.
- Understanding the complexity of data: big vs. small data, variations in complexity of data.
- Knowing about technical/technological pre-conditions for data creation and use (connecting devices, deciding on device settings…).
- Data processing and data manipulation (e.g., understanding that apps use data, algorithms use data).
- The potential and drawbacks of big data in different realms of society, such as health, education, economics, security, etc. (e.g., trade-offs of using social media, data surveillance).
- The human-data relationship: When to use automated processes vs human actions. Who makes the decision?
- Data as persistent and potentially stored: Data Security; data surveillance, opportunities with data (weather, maps, etc.); my data.
- The Data tools: how tools work not from the user perspective but the viewer perspective - Targeted advertisements. Identifying misrepresentation of data.
- How to identify, locate and use data sets, public data, databases, and APIs.
- Question data and use of data. How data is monetised, for which purposes it is being collected -- "data as the new oil."

Consequently, this element integrates three sub-elements: (1) Knowledge, (2) Awareness, and (3) Critical thinking.

Acting on Data

Acting on data explicitly refers to actions to be carried out on data, such as:

- Organising data.
    - Synthesizing, visualizing, and representing data in different formats. "Translate" data into language.
    - Clarifying: It should not be about doing one's own analyses but about transmitting information via data to others. It might be that oneself did not necessarily conduct such analyses.
    - Identifying misrepresentation of data.

- Using data to change one's own behaviour.
- Become aware of one's own role for acting on data from the different perspectives of a citizen (professional, familiar, etc.).
- Processing, protecting and storage (personal data management), how to move data from one application to another.
- Adapting to new scenarios by changing one's own choices and practices based on new situations (configuring privacy aspects, revoking access, requesting to have one's own data erased…).
- Putting data rights in practice.
- Making informed decisions when interacting with data-collecting actors (e.g., mobile apps, internet portals, employers…).
- Interacting with key stakeholders (e.g., data protection agencies) as needed for the resolution of certain situations.

Consequently, this element includes three sub-elements that help us to define it: (1) Collecting data, (2) Managing data, and (3) Sharing data artifacts.

Engaging Through Data

In this element, the ambition goes further to actions that affect individuals and the world. How do we engage through data? (Individual (I) & Collective (C))

- Self-regulate own data footprint (I)
- Taking own decisions based on critical consideration of data (personal, professional…) (I)
- Communicating data meaning to stakeholders or to other peers (C)
- Using data as a basis or activism for data engagement (C)
- Raising collective data awareness (C)
- Adapting data (I & C)
- Participating in data-based policy-making processes (C)

- Understanding balance between individual and social benefits and risks related to data literacy (I & C)

In consequence, this element is composed by four sub-elements: (1) Policy and regulation, (2) Taking decision, (3) Data activism, and (4) Data advocacy.

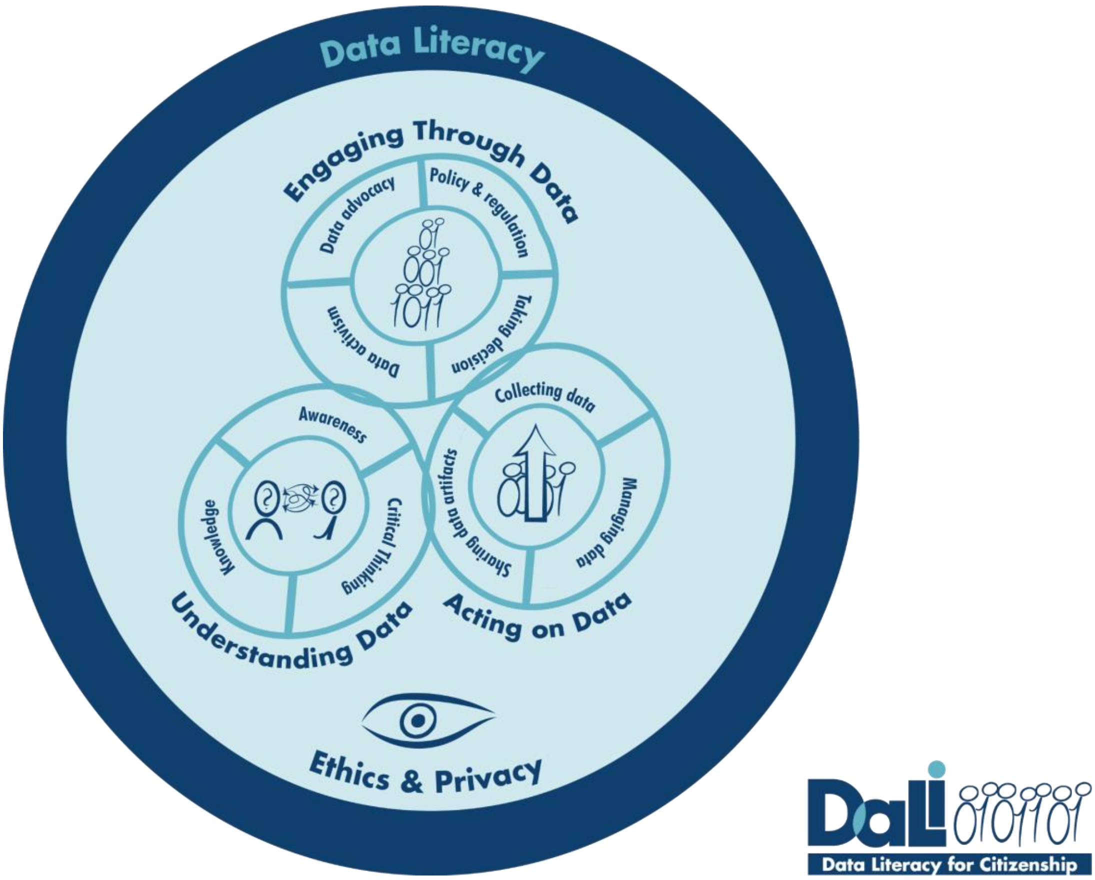
Ethics & Privacy

At this point, the fourth element, **Ethics & Privacy**, must be considered, as these concepts are omnipresent in the other three, as can be seen in Figure 4.

Ethics and Privacy are the base to build any component of this framework, and this ethical perspective must underlie all the skills and levels considered. Some key concepts of privacy include the relationship between personal information and data, the right for individuals to control their own data or cybersecurity concerns. In addition, key concepts of ethics include that some actions on data might be ethically questionable, despite being lawful, or algorithmic biases.

Therefore, Ethics and Privacy must be taken into account in a cross-cutting manner in the three main elements of the DALI Framework.

Figure 4
DALI Data Literacy framework



Framework Indicators and Levels

To make this framework operational, and to mirror other frameworks developed worldwide (e.g., DigComp), we have identified which indicators better shape the different elements and sub-elements in progressive levels of expertise, from level A (the most basic one) to level C (the advanced one).

In Table 2, we can see the correspondence between elements, sub-elements, and levels, with their descriptions.

Table 2

DALI Data Literacy framework's indicators and levels

Element	Sub-elements	Level A	Level B	Level C
Understanding Data	Knowledge	(Know) what is data and how it is created	(Know) where I can find data and in which formats	(Know) what I can do with data / (Know) how I can engage through data
	Awareness	Be aware / Know about the existence of data	Conceptualize & Describe what data represents	Understand the implications of data
	Critical thinking	Know that data have a value / Know data can be used for multiple purposes	Be conscious of the way and reasons why your data is being used	Know ways to influence the use of your data or using data / Know the way data can be used for collective purposes
Acting on Data	Collecting data	Use external devices/apps to collect data	Search & collect active data from repositories/apps and Internet portals	Create and store own data (e.g., based on external and own data) / Utilize specialized software for data collection and storage (databases)
	Managing data	Create, edit and store simple file formats like .txt or .xsl to manually insert the data	Manage data collected in apps and Internet portals	Manage data from diverse sources with specific software and be able to do complex operations with data (pivot tables, etc.)

Element	Sub-elements	Level A	Level B	Level C
	Sharing data artifacts	Share and communicating data sets that already exist under ethical considerations	Share data created by oneself in different formats (images, tables) using adequate repositories (open or ethically strong if it is needed)	Anonymise and/or combining data sets (external and own creation) and sharing them in an open repository
Engaging through Data	Policy and regulation	Understand how society shapes data use or influences policy making	Apply policies and regulations to own data activity	Have a say on policy
	Taking decision	Understand civil action / Understand individual potential to use data	Be involved in civil action / Use data for taking individual decisions	Take actual decisions / Lead civil action
	Data activism	Understand data activism movements and how these can change the use of that data that stakeholders do	Participate, sign, or approve data activism initiatives initiated by others	Impact on society / Take part, organize or lead data activism initiatives
	Data advocacy	Understand your influence on peers or stakeholders to help them understand the potential and applications of data	Raise collective awareness for using data	Actively advocate on peers and stakeholders enacting change in the use of data that they do

LIMITATIONS

There are two contextual limitations that must be acknowledged in this study. Firstly, the Delphi study participants were university staff from Europe, mainly representing WEIRD countries (Western, Educated, Industrialized, Rich, and Democratic) (Henrich et al., 2010). Although efforts were made to include diverse scholarly backgrounds, all the participants characteristics remained largely common to these global north contexts. Secondly, the framework's subject matter is closely tied to the current technological development in these countries.

References provided by the panellists during data collection exhibit a clear trend of citation in one language and publication type (Macgilchrist et al., 2022), with a notable absence of publications from literacy journals and publications in languages other than English, resulting in limited influence from less mainstream discourses.

These limitations underscore that the framework is not universally applicable. However, it is proposed as a starting point for adaptation and validation within the project and through external research endeavours. Validation should encompass diverse contexts to ensure effectiveness on fostering human agency, as defined by Jääskelä et al. (2017), and influenced by contextual singularities.

Rethinking and reformulating the framework in new contexts aims to enhance relevance and incorporate diverse academic perspectives. Furthermore, the framework is designed to align with ongoing technical, social, and organizational changes, requiring regular implementation. Its application contributes to continuous updates, akin to other international framework proposals (Kluzer & Priego, 2018). The DALI framework is conceived as a flexible and adaptable outcome, with the goal of long-term usefulness.

DISCUSSION AND CONCLUSIONS

Derived from the Delphi method applied in this work, we developed a framework for DL consistent with the target group of the DALI project (i.e., adults). Drawing on other recognised frameworks in the field of digital literacy as points of reference, we designed the DALI Data Literacy Framework to be in line with, and complement, already existing digital frameworks by extending the notion of data literacy – as a specific competence that must be included– and considering the needs of the adult citizenry in this respect. This is especially noted in work and results of the second round, where different DigComp areas were considered to integrate aspects of DL.

The DALI Data Literacy Framework includes both a definition and a description of four elements, from which three of them are structured into sub-elements with levels of performance, and the fourth has sub-elements embedded across the whole model. The DALI definition of data literacy is in line with early definitions collected by Wolff et al. (2016) in the sense that it aspires to help inform decisions and support problem-solving, and a granular approach by including the diverse subset of skills and abilities that are covered under the concept. Also, it is aligned with recent definitions, which integrate the idea of data literacy for social justice. This underpinning approach in the DALI definition is supported by the perspective of the global citizen included under the term "citizenry", which goes beyond the idea of the active citizen in local contexts and assumes global activism for the good (Chowdhury et al., 2019; Sutton, 2008).

Regarding the four elements there is a clear progressive relationship between the three main elements. The first element, *Understanding data*, covers the conceptual level of the framework and includes two declarative sub-elements mainly related to knowing about the definition and being aware of its existence and practical implications. The third sub-element emerges as the unique approach to DL for the citizenry. It addresses the critical approach through which data literate citizens can think critically about data implications for people. Many citizens might already be aware of some of the core concepts within this element, such as the existence and the value of data in the current economic market but it focuses on the requirements for them to develop new cognition regarding data thinking and to comprehend the role of data in the world. While this element is aligned with the 'Data Comprehension & Interpretation' one from the Learn2analyze's framework, in the DALI Framework, this element moves on to critical thinking. It is also noteworthy that within understanding data, there is the sub-element for data visualisation, which has been highlighted as troublesome at the compulsory educational level and, at the same time, an essential skill for informed citizens (Shreiner & Dykes, 2021).

The second element, *Acting on data*, involves higher-level actions on the data, such as collecting, managing, analysing, and sharing. It focuses on actions that citizens can perform on data and require different levels of competence, ranging from very simple skills, such as managing plain text or Excel files by manually inputting data, to complex data management processes utilising databases.

In this respect, Data from Eurostat on individuals' level of computer skills (2021) show that 57% of the EU citizens (27 countries) have copied or moved files between folders, devices or in the cloud, and 58% used word processing software in the last three months (other valuable data: the creation of files integrating different elements 38%; used spreadsheet software 38%; used advance features of spreadsheet software or organise, analyse and structure date 21%) (EU survey on the use of Information and Communication Technologies (ICT) in households and by individuals, annual survey)[2]. It means most European individuals have basic skills regarding the collection, management, and sharing of plain data, including txt, xlsx, or PDF files, since these skills are generally needed as part of the essential digital competencies for performing many jobs or studies. However, some other levels, such as database management or pivoting tables, will only be available for specific professionals such as database administrators or data analysts. In this sense, only those citizens with some technical professional roles need to advance across the levels of expertise in this element.

The third element, *Engaging through data*, involves a deep conceptual understanding of data as well as knowledge of the actions that can be performed on data to enable taking decisions based on data, data activism, and advocacy, as well as understanding data-related policies and regulation. In this sense, the framework is conceptually aligned with the vision of citizenry, which focuses on the role of citizens to participate in social responsibilities and be engaged in local, national, and global issues (Chowdhury et al., 2019; Sutton, 2008). Additionally, the activism underpinning social change is closely related to the transformational implications of digital literacy in early work (Martin & Grudziecki, 2006). Therefore, this element implies developing higher-level cognitive processes and understanding the interplay between data and society -including ourselves as community individuals. These competencies go from straightforward day-to-day life decisions, such as optimising the selection of the data you will allow sharing after starting using a new mobile app (see, e.g., the Data Detox Kit[3]), to more collective endeavours, such as using X (former Twitter) or petition platforms to advocate for more restrictive regulation policies on geolocation tracking or targeted advertising. In this case, citizens need to learn how they can support efforts to protect the public interest by engaging in collective action by sharing or signing data-related petitions (e.g., those on Change.org) or taking part in activists' actions and projects (e.g., Xnet[4]). This relies on understanding the underlying data issues addressed by the first element of the framework.

Finally, the last and cross-cutting element, *Ethics & privacy*, addresses aspects that are inherently present in all the other elements due to the datafied society in which we live. Contrary to other frameworks, such as Learn2analyze where 'Data Ethics' is considered as an element by itself, from the point of view of the panellists of the DALI framework, ethics and privacy are intrinsically present in every action, and thus, in every element, that we carry out with data. Thus, this element implies that citizens need to be aware of data's ethical and privacy implications. At the most basic level, EU citizens have some awareness of privacy issues; for instance, according to Eurostat[5] 72% of the population (across 27 countries) know that cookies can be used to monitor the behaviour of internet users. However, they have a more limited understanding of how the data collected from them is used by third parties or what they can do to prevent that from happening. Research has stated that only a small portion of young adults have developed skills to manage their online data by uploading positive data about themselves and at the same time devoting time to manage data uploaded by others (Lorenz & Kikkas, 2014). Similarly, most citizens would see that stealing data would be ethically wrong. Still, ethical aspects such as algorithmic biases due to historical and societal minority discriminations are complex to understand without the appropriate technical knowledge. Therefore, these aspects of the *Ethics & privacy* element are also heavily influenced by the knowledge levels of the other elements.

Against this backdrop, the framework presented here results from a participatory and collaborative process of research and creation, which is currently used to develop learning materials and curriculum innovation (Villatoro & de Benito, 2021). We understand that having operationalised this framework can result in a more realistic educational approach, in that the indicators can lead to clear learning goals, which help in the definition and development of didactic strategies for their development. Innovation in education is not an easy process (Fullan, 2007). While top-down developments have not been successful, developments by experts and field practitioners have improved the possibilities for innovation uptake.

As the digital literacy has been described as a dynamic and constantly evolving field (Pérez-Escoda et al., 2019), the same can be expected regarding data literacy, which simultaneously requires framework proposals that might be flexible to integrate such changes.

As pointed out earlier, the Delphi technique through which the panellists have arrived at a consensus for the DALI approach is aligned with the co-creation and co-design processes that inspire the whole DALI project development. Like the Delphi technique, these collaborative processes allow joint work across "time zones, spaces, disciplines and cultures" (El-Jarn & Southern, 2020, p. 192), which can increase the chances of a successful product. In this way, we envision the DALI framework as a successful product to be implemented and adapted in several different cultural backgrounds, being enriched in diverse epistemic or international contexts. We expect it will be valuable for designing future pedagogical experiences that can be relevant and "overcome cross-cultural differences" (Vespestad & Smørvik, 2020).

Since Gilster coined the term digital literacy in 1997, it has dramatically evolved into a complex concept that goes beyond technical skills (Marín & Castañeda, 2022; Meyers et al., 2013). The recent emergence of data literacy among the wide range of digital literacies is a new benchmark in the field. Some aspects allow us to suggest that the DALI framework is a valuable effort and contribution toward developing DL. First, regarding its structure, it is a model that balances a comprehensive and analytical envision of DL by describing a relatively limited number of sub-elements whose coherence is guaranteed by being grouped into elements that work both in a complementary and cross-cutting manner. Second, its holistic envisioning is due to the target group (adults) for whom it is conceived and overcomes other somewhat professional or technical descriptions. Third, the ethics approach, along with the data activism element, allows for overcoming individual approaches and leads the framework to a vision of data literacies for political and ideological activism and commitment toward the good of collectives.

The DALI Framework is not only flexible and scalable but also holds significant importance in teacher education and the creation of activities applicable to teaching. Teachers play a crucial role in shaping citizenship through critical methodologies in their respective disciplines, and the university has a fundamental responsibility in fostering conscientious citizenship. The adaptability of the DALI framework allows for modifications and the inclusion of new elements, making it suitable for various subpopulations within society. Its methodological strength stems from consensus reached through interdisciplinary discussions among experts in education and educational technologies. Unlike frameworks based solely on literature reviews, our work combines expert insights with existing literature, resulting in a more ideologically coherent framework. We hope that our DALI framework, along with its methodology, inspires other collectives to engage in dialogic processes and reflect on frameworks that contribute to a deeper understanding of the world (Atenas et al., 2023; Markham, 2020).

Furthermore, the framework can have multiple applications, for example, to help shape the needed data competencies of society, as a support framework for developing the curriculum of formal courses, or to profile the required data-related competencies for different professional roles in our community, e.g., teachers, who should develop data strategies while maintaining participatory educational practices (Kippers et al., 2018; Stewart, 2023).

The framework's subject matter is influenced by current technological and societal contexts, making it inherently changeable. Adaptation to specific constraints and realities of implementation is necessary, as the framework is not universally applicable. Regular updates are essential to align with evolving technological and social changes. Exploring the framework in local contexts and adapting it to different subpopulations present fruitful avenues for future research. Further research studies are needed to validate the framework's content, elements, and their relationships. Case studies within the project will confirm its adequacy for specific purposes and contribute to its continuous improvement. Adapting the framework to changing data needs over time is necessary (Markham, 2020; Sander, 2020). Including perspectives beyond the project consortium and from countries outside Europe would refine the framework further. This paper presents the initial DALI framework, which is an evolving artifact reflecting technological and data evolution. Future refinements are enabled by the framework's flexibility and scalability.

Current research in the DALI project is exploring the use of the framework for the co-design of the DALI games and preparing training actions according to the elements and sub-elements. Future work will consider how the framework may vary depending on the target group and the different levels. Finally, it could be very promising to develop instruments that provide evidence of DL skills, both from self-perception surveys and other performance tests.

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NOTES

1. https://dalicitizens.eu/
2. Source: Eurostat, https://ec.europa.eu/eurostat/databrowser/view/isoc_sk_cskl_i21/default/table?lang=en, last data update 30/03/2022
3. https://www.datadetoxkit.org/en/home
4. https://xnet-x.net/en/
5. Source: Eurostat, https://ec.europa.eu/eurostat/databrowser/view/isoc_cisci_prv20/default/table?lang=en, last update 30/03/2022

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APPENDIX

Appendix 1

Key references submitted by the panellists

	Reference	Times included
1	Calzada-Prado, J., & Marzal, M. A. (2013). Incorporating Data Literacy into Information Literacy Programs: Core Competencies and Contents. Libri, 63(2), 123-134.	3
2	Pangrazio, L., & Selwyn, N. (2019). 'Personal data literacies': A critical literacies approach to enhancing understandings of personal digital data. New Media & Society, 21(2), 419–437.	3
3	Raffaghelli, J. E. (2019). Developing a framework for educators' data literacy in the European context: Proposal, implications and debate. In International Conference on Education and New Learning Technologies EDULEARN (pp. 10520-10530).	3
4	Carmi, E., Yates, S. J., Lockley, E., & Pawluczuk, A. (2020). Data citizenship: Rethinking data literacy in the age of disinformation, misinformation, and malinformation. Internet Policy Review, 9(2), 1-22.¶	2
5	Maybee, C. & Zilinski, L. (2015). Data informed learning: A next phase data literacy framework for higher education, Proc. Assoc. Inf. Sci. Technol., vol. 52, no. 1, pp. 1–4.	2
6	Wolff, A., Gooch, D., Cavero Montaner, J. J., Rashid, U., & Kortuem, G. (2016). Creating an Understanding of Data Literacy for a Data-driven Society. The Journal of Community Informatics, 12(3), 9–26.	2
7	Bhargava, R., Deahl, E., Letouzé, E., Noonan, A., Sangokoya, D., & Shoup, N. (2015). Beyond data literacy: Reinventing community engagement and empowerment in the age of data.	1
8	Carmi, E., & Yates, S. J. (2020). What do digital inclusion and data literacy mean today?, 9(2), 1–14.	1
9	Gummer, E., & Mandinach, E. (2015). Building a conceptual framework for data literacy. Teachers College Record, 117(4), n4.	1
10	Mandinach, E. (2012). A Perfect Time for Data Use: Using Data-Driven Decision Making to Inform Practice. Educational Psychologist, 47(2), 71–85.	1
11	Markham, A. N. (2020). Taking Data Literacy to the Streets: Critical Pedagogy in the Public Sphere. Qualitative Inquiry 26 (2): 227–37.	1

	Reference	Times included
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Key concepts for quality in online higher education

Conceptos claves para la calidad de la educación superior online

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ABSTRACT

This study aims to conceptualize the quality of online higher education (OHE) through the perspectives of diverse stakeholders. To this end, we asked students (n=3,152), teachers (n=727) and informants (n=50) from 18 higher education institutions (HEIs) in Chile with online degree programmes to indicate the concepts they associate with quality OHE. Employing a qualitative methodology that combines deductive and inductive methods and lexicometrics, we analysed the data collected through questionnaires and interviews. The findings of this study show how a traditional vision of educational quality coexists in OHE through concepts linked to the 'graduate profile', 'standardization and 'accreditation', with emerging perspectives that reinforce the particularities of online education, reflected in concepts such as work-life balance, pedagogical design, equity, the value of technology, institutional support, individual qualities or relevance to the labour market. It highlights that 'flexibility' and 'learning' are the concepts most frequently mentioned by students and teachers respectively. This article introduces novel categories to conceptualize the quality of OHE by incorporating elements of adult education and virtuality as part of its meanings. Approaching educational quality contextually from a focus on equity is one of the challenges of a continuously growing modality with enormous potential in the framework of a global digital society.

Keywords: online higher education; distance learning; adult education; quality of education; flexibility

RESUMEN

Este estudio tiene por objetivo conceptualizar la calidad de educación superior online (ESOL) desde el punto de vista de diferentes agentes partícipes de la modalidad. Para ello, pedimos a estudiantes (n=3.152), docentes (n=727) e informantes (n=50) de 18 instituciones de educación superior (IES) en Chile con carreras de grado en modalidad online, que señalaran los conceptos que asocian a una ESOL de calidad. A través de una metodología cualitativa que combina métodos deductivos e inductivos y lexicometría, analizamos los datos recogidos a través de cuestionarios y entrevistas. Los hallazgos de este estudio muestran como en la ESOL coexiste una visión tradicional sobre la calidad educativa a través de conceptos vinculados al "perfil de egreso", la "estandarización" y la "acreditación", con perspectivas emergentes que refuerzan las particularidades de la educación online, reflejadas en conceptos como la conciliación, el diseño pedagógico, la equidad, el valor de la tecnología, el acompañamiento institucional, las cualidades individuales o la pertinencia con el mundo laboral. Destaca que la "flexibilidad" y el "aprendizaje" son los conceptos más mencionados por estudiantes y docentes respectivamente. Este artículo aporta nuevas categorías para conceptualizar la calidad de la ESOL, al incorporar elementos propios de la formación de personas adultas y de la virtualidad como parte de sus significados. Plantear la calidad educativa de forma contextual y desde un enfoque de equidad es parte de los desafíos de una modalidad en continuo crecimiento y con enorme potencial en el marco de la sociedad digital global.

Palabras clave: educación superior online; enseñanza a distancia; educación de adultos; calidad de la educación; flexibilidad

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INTRODUCTION

Online education is effective in achieving learning outcomes (Martin et al., 2022). Furthermore, it is preferred by a segment of students who have opted for higher education (HE) later in life or have faced obstacles like economic constraints, challenges in achieving work-life balance, geographical limitations, and/or social barriers (Chung et al., 2017; Tieben, 2020). Gender and other variables such as type of work activity have been identified as key elements in understanding student and teacher experiences and preferences (Qazi et al., 2022). Flexibility and access without time or geographical restrictions have been identified as the most common reasons for preferring this mode of study. These attributes find particular resonance amongst individuals engaged in unpaid domestic responsibilities, caregiving responsibilities, or constrained by mobility issues (Lee et al., 2019; Veletsianos et al., 2021).

In recent times, online higher education (OHE) has experienced notable growth and worldwide expansion within educational systems. This phenomenon is attributed to rapid digital transformation and an escalating demand for lifelong learning (Guo et al., 2020). Nonetheless, persistent biases and resistance persist against its potential and multifaceted benefits (O'Dea & Stern, 2022). This is evidenced by the continuous exploration of novel frameworks to assess the quality of online education, aimed at substantiating its validity and optimal progress (Ortiz-López et al., 2021).

This study duly recognizes the significance and robust nature of the diverse models crafted for evaluating the quality of online education (La Rotta et al., 2020; Luna Serrano et al., 2018; Marciniak & Gairín Sallán, 2017; Ortiz-López et al., 2021; Waheed et al., 2016). However, the pursuit of standardized definitions, in our perspective, has somewhat distanced itself from the viewpoints and experiences of individuals engaged in online education, who are valuable contributors to the construction of meaning. Hence, this article aspires to conceptualize the quality of OHE through the lenses of students, educators, and various stakeholders from HEIs that have adopted online modalities. This will be achieved by uncovering both shared and distinct concepts employed by these actors in defining the quality parameters of online education.

THE CONCEPT OF QUALITY

Harvey & Green's (1993) proposition continues to hold prominence as a touchstone in discussions about educational quality (Cheng, 2017; Jungblut et al., 2015; Scharager Goldenberg, 2018). Their contributions have engendered pivotal categories that underpin the comprehension of quality: (i) quality as adjustment for purpose has a functional character that focuses on delivering what is proposed or offered; (ii) quality as value for money, bridging the realms of education and finance; this category assesses the economic efficiency of educational provision. It also delves into external accountability and audit processes aligned with business and service sector norms; (iii) quality as excellence, encompassing exclusive and challenging conditions; this dimension perpetuates an elitist perspective of education, emphasizing stringent achievements; (iv) quality as exceptional, defined by distinctive attributes within programs or study conditions compared to the wider system. It encompasses meeting pre-established minimum standards observed by external agents; (v) quality as transformation, focusing on the capacity of education to positively change the way of perceiving the world and the improvement or acquisition of new competencies; (vi) quality as student-centred refers to empowerment processes aimed at enabling students to participate in their own educational process; (vii) quality as added value refers to the perception of improvement resulting from an educational experience as a qualitative measure; (viii) quality as selectivity; this notion embodies an elitist stance, revolving around predetermined characteristics that determine access and persistence within specific institutional profiles; and finally (ix) quality as a virtue of professional practice is centred on the motivation and commitment of those involved in educational processes. This aspect is closely linked to workplace well-being.

ONLINE HIGHER EDUCATION

Online higher education (OHE) boasts an extensive research lineage. As outlined by Martin et al. (2020), the predominant research domains encompass three focal areas: students, courses and faculty, and institutions. However, certain pivotal themes, notably quality and access, equity, inclusion, and ethical concerns, have been underexplored. On approaches to measuring OHE quality, Esfijani (2018), highlights those studies that have mainly focused on resources, inputs and processes of online education. Nonetheless, a comprehensive, holistic perspective that addresses approaches to the conceptualization and measurement of quality in their entirety is lacking. These endeavours often hinge solely on the student's standpoint, thereby sidelining perspectives of faculty, institutional stakeholders, and corporate entities. Similarly, in the work of Marciniak & Gairín Sallán (2017), the absence of universally applicable criteria for diverse models of online education quality assessment is evident. Divergent definitions, interpretations, and dimension prioritization emerge within each model scrutinized. Two overarching streams are discernible: one advocating the adaptation of conventional (face-to-face) quality criteria, albeit with varied emphasis, and the other espousing the creation of fresh categories to align with digital contexts' distinct demands (Ortiz-López et al., 2021). This study aligns with the latter trajectory.

In an era steeped in digitalization, the intricacies of cyberspace and virtual learning environments warrant analysis which considers their individualities and disparities (Bendixen & Jacobsen, 2017). These domains thrive autonomously, free from reliance on the analog world for the creation of meaning. Concurrently, these virtual environments are intrinsically enmeshed within specific social and cultural frameworks, thereby shattering any claims of neutrality. Social inequalities and imaginations are redefined and perpetuated within these digital landscapes (Atenas et al., 2022; Wajcman, 2010). Against this backdrop, a critical exploration into the quality of such virtual spaces necessitates the translation of classical paradigms into models that resonate with these distinctive circumstances. Furthermore, a need arises to create new categories in order to accommodate these complex realities.

Approaching the quality of OHE from a fixed perspective mandates careful consideration of student and faculty specificities. The student demographic has been labelled 'non-traditional' due to such characteristics as being over 25 years old, balancing external responsibilities with studies, and financial independence. Notably, this group is characterized by a higher likelihood of attrition despite often demonstrating comparable or superior academic performance to their "traditional" counterparts. They also exhibit heightened resilience in the face of the barriers to access and persistence inherent to higher education. Yet, their engagement with the student community might be less intense, and their participation may lean more towards non-formal study programs, continuing education, and distance learning (Tieben, 2020). Additionally, Sánchez-Gelabert et al. (2020) indicated that older students perceive their educational journey distinctively, focusing on learning and theoretical knowledge acquisition. Unlike the homogenized student profile, OHE instructors embrace a diverse range of profiles. The institutional context of teaching support plays a fundamental role in shaping their practices and perspectives (Xavier & Meneses, 2021). This study particularly concentrates on educators who frame their teaching ethos around the concept of mentoring (Vlachopoulos & Makri, 2021), combines disciplinary, pedagogical, didactic, and technical competencies in order to facilitate the study process through feedback, guidance, motivation, and monitoring (Richardson et al., 2022).

The educational landscape has shifted significantly due to the COVID-19 pandemic, prompting the reassessment of online education across diverse conditions and educational systems (Green et al., 2020). This transformational period has recalibrated the perception of online education from a peripheral modality to one deemed relevant in various educational contexts. This transformation has diminished social biases long-associated with online education, dissolved labour market barriers for online graduates, established prominent online education institutions, and elevated the demand for online or hybrid programs. Notably, traditional institutions' interest in infusing their programs with flexibility has surged. Flexibility, therefore, emerges as a pivotal concept that is reshaping higher education post-confinement (Lockee & Clark-Stallkamp, 2022; Müller et al., 2023).

The concept of flexibility within OHE must align with scalability, a fundamental criterion for optimal resource utilization and broad-reaching impact (Ragusa & Crampton, 2017). Scalability mandates that online programs be ubiquitously accessible (Virtanen et al., 2018), enabling learners to engage with activities and resources at their convenience, regardless of location or time. This principle requires institutions to meticulously design courses for longevity and broad accessibility. To ensure this across an array of subjects and degree programmes, standardization of training provision is paramount. A critical examination of flexibility also necessitates an inquiry into its association with individual autonomy and neoliberal ideologies, which concurrently yield economic dividends in digitally commodified educational landscapes (Houlden & Veletsianos, 2021; Saura et al., 2023).

In neoliberal educational realms marked by deregulation and surging demand for access to higher education, quality often conveys adherence to external accreditation and accountability processes (Gerón-Piñón et al., 2021). This study seeks to broaden this perspective by infusing an equity-focused approach to quality in online education, as highlighted by Harrison & Mathuews (2022). This approach seeks to ensure that standardized and mass-designed modalities remain cognizant of the human and diversity-centred dimensions. Quality in this context is envisioned as a multidimensional and subjective construct that is created dialogically and collaboratively, rather than merely achieved (Stracke, 2019; Williamson, 2019). Thus, a thorough understanding of how individuals navigate learning processes and educational contexts mediated by technology is imperative.

METHODOLOGY

This research constitutes a segment of an ongoing doctoral thesis, grounded in a qualitative methodology that enables a profound understanding of the connotations attributed to a given concept by involved individuals (Flick, 2022). Employing semi-structured interviews and questionnaires as information generation techniques, this study delves into both institutional sources as well as students and teachers. The research was conducted during the Chilean academic year of 2021. Both instruments (interview guideline and survey) asked: "In your opinion, what concepts do you associate with a quality online higher education (OHE)?" In the case of the questionnaire, this question was open-ended, and three concepts were asked to be written down. The analysis encompasses deductive and inductive methods for interviews and the lexicometric method for the open-ended questionnaire question. A triangulation of outcomes from these methodologies yielded emerging categories conducive to conceptualizing OHE quality from the viewpoint of the engaged stakeholders. The specificities of each technique used are presented below.

Interview

At the beginning of 2021, 27 HEIs implementing online degree programmes in Chile before 2020 were invited to participate. Eighteen institutions agreed to participate: three Technical Training Centres (CFT, by its acronym in Spanish), seven Professional Institutes (IP, by its acronym in Spanish) and eight Universities. Private funding was characteristic of all institutions except one university. The selection of institutional informants followed a sampling approach based on certain defined criteria (Izcara, 2007). These encompassed profiles involving academic authority (i), quality assurance (ii), innovation and institutional development (iii), and pedagogical design for online education (iv).

Between March and May 2021, a total of 50 interviews were conducted, adhering to the theoretical saturation criterion (Glaser & Strauss, 1967). This criterion delineated the participation of informants, considering that further interviews would not significantly enhance the insights towards the intended objective (Guest et al., 2006; Nelson, 2017).

The institutional informant sample comprised individuals across universities (n=21), IP (n=24), and CFT (n=5). Gender-wise, the sample was equally divided, with 25 identifying as female and 25 as male. The distribution concerning institutional profiles included: profile i (n=10), profile ii (n=15), profile iii (n=13), and profile iv (n=12). In terms of professions, the majority hailed from the Engineering sector (n=22), followed by Education (n=19) and Social Sciences (n=5). Most participants held a master's degree (n=37 with a smaller number possessing a professional degree (n=3) and doctorate (n=3). The engagement with online education revealed that 44 individuals had undertaken online studies, while 28 had received training in OHE-related subjects.

Prior to commencement, the instrument underwent validation, including a methodological review by two academics from the Universitat Autònoma de Barcelona (UAB) (December 2021) and content validation via eight pilot interviews. Ethical considerations were duly followed, approved by the ethics committee of UAB (ref. CEEAH 5586). The interviews were conducted via the Zoom platform, lasting between 30 and 70 minutes. These sessions were audio-recorded, transcribed, and securely stored within the university's cloud infrastructure. Ensuring anonymity, informed consent was obtained prior to interview initiation.

Thorough analysis with NVIVO software employing open coding resulted in the formulation of 54 substantive codes capturing prevalent themes in the interviews (Rodriguez, 2019). Subsequently, these codes were structured into categories, adding analytical and theoretical weight to the coding process (Gibbs, 2018). The categories were defined through a combination of deductive and inductive logic (Neale, 2016), anchored in both the theoretical constructs outlined in the interview guidelines and the emergent topics deemed pertinent (Table 1). Finally, the most representative units of analysis were selected to elucidate the meanings ascribed by participants to each category.

Table 1

Codes for analysing perceptions of quality in OHE

Codes	Source
Quality as adjustment for purpose Quality as value for money	Harvey & Green, 1993
Quality as excellence Quality as exceptional Quality as transformation	Harvey & Green, 1993; Jungblut et al., 2015
Quality as student-centred Quality as an added value Quality as selectivity	Jungblut et al., 2015
Quality as virtue of professional practice	Cheng, 2017
Quality as accreditation Quality as standardization Quality as equity Quality as relevance to the labour market Quality as value of technological aspects Quality as pedagogical design Quality as work-life balance	emerging from the interviews

Source: own elaboration.

Questionnaires

In September 2021, all participating HEIs from the qualitative phase were invited to continue to the questionnaire stage, with 14 institutions (comprising three CFTs, six IPs, and five Universities) agreeing to participate. Sample selection within each institution adhered to defined criteria: inclusion of students and teaching staff who had either studied or taught subjects within any online degree program during 2021. Students and teachers were self-selected to answer the questionnaire.

In the student questionnaire, out of a total of 4,119 responses, 3,937 granted consent, with 644 solely engaging in the characterization section and 3,152 respondents answering from the first quality item (cases deemed valid). The sample distribution reflects 48.9% identifying as female, 50.6% as male and 0.1% (n=5) as non-binary, in addition to 0.2% who opted for "I prefer not to answer". The average age stands at 37.1 years (SD=8.7). Among them, 78.3% have a permanent contract (of which 61.2% identify as male), while only 6% engage solely in unpaid household work (of this group, 95.6% identify as female). The sample collected in this study amounts to 4.0% (n=3,152) of the total population of students who took an online degree course in Chile during the year 2021 (SIES, 2022).

Moving on to the teacher questionnaire, a total of 861 responses were received, with 841 consenting to participate. Out of these, 114 individuals responded solely to characterization items, and 727 participants answered starting from the first quality item (considered valid cases). The sample breakdown comprises 51.9% identifying as female and 48.1% as male, with no mention of non-binary genders. The mean age stands at 45.1 years (SD=10.6), with 79.6% holding temporary contracts with their respective institutions. In this aspect, gender parity prevails, and 46.4% possess less than three years of online teaching experience. However, the Chilean Higher Education Information System (SIES) lacks differentiation based on teaching mode for academic staff in institutions, thus precluding a determination of the sample's representativeness among teaching staff.

Two ad-hoc online questionnaires were created for students and teaching staff. A panel of nine expert judges conducted the validation process, assessing the instrument for its univocity, relevance and pertinence to the research objectives (October 2021). Ethical approval for these procedures was secured from the ethics commission of UAB (ref. CEEAH 6161). Questionnaires were disseminated using web links via the SurveyMonkey platform. The distribution strategy varied among institutions, utilizing survey platforms or mass mailings, along with subsequent reminders. Each respondent independently self-administered the questionnaire, without the presence of the research team (Cohen et al., 2009). Data collection spanned from November 2021 to January 2022.

In order to analyse the acquired responses, the lexicometric or textual statistics method (Lebart et al., 2000) was employed, following the approach proposed by Concha-Díaz & Léniz Maturana (2022) to quantitatively assess information derived from open-ended questionnaire sections. The analysis proceeded in two distinct phases. The initial phase involved revising original concepts (9,448 from students and 2,180 from teachers) standardizing their wording, rectifying typographical errors, and subsequently eliminating redundant concepts (e.g., "quality", "education", "distance learning", "good” as well as concepts necessitating additional context in order to understand their relevance to quality (e.g., "surprised," "educational inspector," "level"), and opinion-based comments (e.g., "first time studying online," "I have had a good experience at the institute"). Moreover, concepts and comments that negatively assessed or recounted poor OHE experiences were excluded. This led to a total of 8,161 student concepts and 1,712 teacher concepts. The second phase comprised a qualitative evaluation of the final concepts, aiming to construct categories for their systematic grouping.

RESULTS

The results are presented in three parts: (i) what quality means to institutional informants; (ii) what quality means to students and teachers; and (iii) emerging categories derived from the convergence of the aforementioned insights. In the case of institutional informants, the three most recurring codes, along with pertinent representative quotes for each code, are detailed. Similarly, for students and teachers, we commence by detailing the frequency of concepts according to variables and subsequently delve into the occurrence of emerging categories developed in order to categorize the concepts.

Perspective of institutional informants

Table 2 showcases the codes employed to analyse the interview data, ordered by recurrence of quotations. The analysed data pertains to responses to the query: "In your opinion, what concepts do you associate with quality online higher education (OHE)?

Table 2
Codes for analysing perceptions of OHE quality and recurrence

Codes	Recurrence
Quality as adjustment for purpose	93
Quality as accreditation*	64
Quality as standardization*	54
Quality as equity*	49
Quality as virtue of professional practice	44
Quality as relevance to the labour market*	43
Quality as student-centred	40
Quality as excellence	40
Quality as an added value	30
Quality as value of technological aspects*	29
Quality as transformation	29
Quality as selectivity	22
Quality as pedagogical design*	21
Quality as work-life balance*	17
Quality as value for money	16

*Emerging codes.
Source: by author.

As can be seen, reference to the classical perspective of "quality as adjustment for purpose" emerges as the most frequently cited, succeeded by "quality as accreditation" and "standardization". The prominence of "quality as equity" draws attention, particularly concerning the access that facilitates ubiquitous learning within the modality. Similarly, the minimal reference to "quality as selectivity" and "value for money" can be interpreted as a valorization of the modality's own potential for access to a non-traditional student profile. Below, we elucidate how institutional informants conceptualize the three most recurrent codes.

Quality as adjustment for purpose

Among the interviewees, adequacy to objectives within the context of OHE is perceived as the realization of the graduate profile, aligned with the regulatory framework of the country. This profile is converted into a commitment by institutions and a demand from students. Fulfilling the graduate profile is regarded as a means to meet student expectations, which, in line with the numerous references to business language, forms a part of the "client" contract. Additionally, it's noteworthy that respondents from profiles (i) and (ii) (academic and quality) place the graduate profile as the foundation encapsulating the objectives of HEIs undergoing institutional assessment.

> *En la medida, que si hay una carrera online que aspira a desarrollar una serie de competencias o habilidades (...) en la medida que eso se cumpla y que efectivamente esos egresados sean valorados en sus competencias, uno efectivamente puede decir: ¿sabes qué? Aquí hay una buena alternativa, hay una formación de calidad [To the extent that there is an online degree programme that aspires to develop a series of competencies or skills (...) to the extent that this is fulfilled and that these graduates are effectively valued in terms of their*

competencies, one can effectively say: "you know what? There is a good alternative here, there is quality training"] (University, profile i, male).

On another note, the significance of adhering to the graduate profile is seen as the pivotal factor ensuring uniformity across different modalities and the same study programme. The link between ensuring consistent objectives and OHE quality is nearly causal, according to the interviewees.

Cuando uno habla de la calidad en la virtualidad o en carreras que son online, lo que uno busca, es que el cumplimiento del perfil de egreso del estudiante virtual sea el mismo que del presencial [When one talks about quality in the virtual world or in degree programmes that are online, what one looks for is that the fulfilment of the graduate profile of the online student is the same as that of the face-to-face student] (IP, profile ii, female).

Quality as accreditation

Respondents view accreditation as a "burden." Despite public policy advocating for continuous or comprehensive quality, this notion remains distant in practice. Interviews suggest that the value of OHE must be substantiated, more so than with other modalities. The scarcity of Chilean references to online education and the absence of research in this domain further exacerbate the situation. As a result, HEIs devote a substantial portion of their resources and efforts towards external and international certification processes (ISO, Quality Matters, CALED, etc.) that pave the way for institutional accreditation.

Es sancionatorio, porque públicamente te sanciona, porque hay una puesta en escena pública publicitaria, porque la institucionalidad también asigna recursos a esa acreditación; porque las universidades hoy día tienen que desarrollarse casi en forma exponencial con recursos limitados en productividad [It is sanctioning, because you are publicly sanctioned, because there is a public promotional staging, because institutionality also allocates resources to this accreditation, because universities today have to develop almost exponentially with limited resources in terms of productivity] (University, profile ii, male).

The concept of quality as accreditation aligns with the interviewees' understanding that OHE is an integral part of a quality system underscored by conformity to standards, coupled with punitive mechanisms that significantly influence the institutions' future. The significance of self-assessment and internal quality assurance processes becomes clear in this context. These processes, grounded in adherence to internal regulations, serve to reveal compliance or non-compliance with the graduate profile across various locations, courses, and modalities within an institution. The internal administration of quality assurance systems for OHE mirrors the reality of several HEIs in the country, where a commercial and instrumental perspective and language regarding educational quality prevails.

Los mecanismos de aseguramiento de la calidad institucional es el cumplimiento de la normativa interna (...) Y es la verificación de que ese proceso que está definido y queremos que se cumpla en cualquier sede, en cualquier modalidad, en

> *cualquier jornada; se haga en forma como transversal, no de una forma distinta porque implica directamente o impacta directamente en el perfil de egreso del estudiante [The mechanism of institutional quality assurance is compliance with internal regulations (...) And it is the verification that this process which is defined and which we want to be fulfilled in any location, in any modality, on any day, is done in a transversal way, not in a different way because it directly involves or has a direct impact on the student's graduate profile]* (University, profile ii, male).

Quality as standardization

References to quality as standardization are delineated by interviewees as the harmonization of institutional resources to enable the fulfilment of the graduate profile across the institution's diverse formats. Standardizing the educational offer is perceived by those interviewed as a strategic means to provide students with a clear navigational path for their autonomous learning endeavours.

> *Porque de pronto entra en contradicción que tengamos tanta actividad estandarizada en una plataforma, cuando justamente nuestro modelo indica que la flexibilidad es una virtud de nuestro modelo (...) el estudiante para un mismo aprendizaje, él debería optar, ¿cuál es la mejor forma que tiene él de aprender? Acá en Chile los modelos incluyen todo, pero el estudiante necesariamente tiene que pasar por todos los pasos [Because suddenly it seems contradictory that we have so much standardized activity on a platform, when our model specifically indicates that flexibility is a virtue of our model (...) the student should be able to choose what is the best way for them to learn? Here in Chile, the models include everything, but the student has to go through all the steps]* (University, profile iv, female).

In this regard, it is interesting to observe that standardization serves as the mechanism facilitating the “management of flexibility". In pursuit of this objective, certain protocols and guidelines steer the efforts across various profiles and domains influencing OHE, ranging from the pedagogical sphere to the administrative realm

> *Nosotros hemos entendido que, para administrar la flexibilidad de manera responsable, uno tiene que tener cosas muy bien estructuradas, porque pretender lanzarse a la flexibilidad sin ordenar los procesos, es arriesgado [We have understood that, in order to manage flexibility in a responsible way, one has to have things very well structured, because trying to launch into flexibility without organizing the processes is risky]* (IP, profile i, female).

However, the deeper connotations of standardization in terms of OHE quality are intertwined with the objective of ensuring educational equivalence with the traditional face-to-face mode. Interviewees underscore a strong correlation between the uniformity of materials and resources and quality assurance, with the recurring notion of being on par with the quality of face-to-face education. Another facet of standardization's association with quality pertains to the consortia that some institutions are part of. The majority of these consortia consist of private foreign conglomerates that enforce a consistent editorial approach across HEIs, while also allowing for contextual adaptations that align with the nuances and distinct characteristics of the country.

Students and teachers

Table 3 presents the most frequently cited concepts offered by students and teachers in response to the question: "From your experience as an online student/teacher, write down 3 concepts that you associate with quality online higher education". It's important to note that the question doesn't request a ranking of the importance of each concept, thus, we compiled a unified list for the analysis. Each concept encompasses its plurals and related grammatical forms (e.g., flexibility: flexibilization, flexible).

Table 3

Most used terms by type of institution, profile and gender

Type of institution	Profile	Gender	Frequency of the most mentioned concepts
Technical Training Centres (CFT)	Students	Female	Teachers (43), Lessons (24), Platform (24), Flexibility (23), Responsibility (21), Study material (20)
		Male	Flexibility (17), Teachers (14), Study material (11), Communication (10), Platform (9)
	Teachers	Female	Feedback (11), Flexibility, Learning (10), Development (8), Engagement (7)
		Male	Teachers (9), Feedback (7), Constant (6), Communication (4), Learning (3)
Professional Institutes (IP)	Students	Female	Teachers (258), Study (194), Flexibility (192), Study material (111), Support (110)
		Male	Teachers (237), Study (207), Flexibility (205), Study material (109), Support (89)
	Teachers	Female	Flexibility (31), Teachers (25), Learning (23), Feedback (14), Autonomy (13)
		Male	Flexibility (29), Learning (24), Student (22), Teachers (20), Engagement (12)
Universities	Students	Female	Teachers (83), Flexibility (35), Lessons (30), Platform (27), Study material (26)
		Male	Teachers (81), Flexibility (70), Platform (37), Study material (31), Lessons (28)
	Teachers	Female	Learning (26), Student (23), Flexibility (19), Innovation (15), Communication (11)
		Male	Learning (30), Student (25), Participation (19), Teachers (18), Flexibility (18)

Source: by author.

Notably, the sole concept that resonates strongly across responses from students across all HEIs and genders is "flexibility." Meanwhile, the other concepts also exhibit similarities and traverse a spectrum of individual attributes and allusions to instructional approaches, methodologies, and platforms. This suggests the presence of a shared experience among online students, which holds interesting implications warranting further exploration. On the contrary, although flexibility holds significance for the teaching staff as well, their references lean more towards teaching practices and student dedication. Strikingly, there is a conspicuous absence of references to platforms or technological aspects of the modality. The underemphasis on technological facets might be construed within the context of the relatively brief experience of the sample to online teaching, thus possibly influenced by a predominantly face-to-face instructional outlook.

Drawing from the qualitative assessment of the aforementioned concepts, eight distinct categories emerged, serving as thematic clusters to encompass shared perspectives. Among these, four categories pertain to the pedagogical dimension (Quality as value of technological aspects, Quality as pedagogical design, Quality as virtue of professional practice, Quality as institutional support) while the remaining four pertain to the non-pedagogical dimension (Quality as individual qualities, Quality as work-life balance, Quality as equity, Quality as excellence) (Figure 1).

Figure 1
Categories of OHE quality of learners and teachers

*This category is the only one that is not emergent, as it corresponds to the conceptualization of Harvey and Green (1993).
Source: by author.

Table 4 illustrates each category alongside the concepts with the highest frequency within each one, delineated across the two distinct profiles constituting the sample. This presentation effectively illuminates which concepts give meaning to the various categories. Noteworthy in this context are the concepts intertwined with connectivity, underpinning the category of "Quality as a value of technological aspects". This discourse potentially alludes to a digital divide in internet accessibility, a dimension meriting thorough investigation through the lens of equity in educational provision. Additionally, a striking similarity emerges in the concepts employed by both students and teachers; within each category created, one or two of the four most prevalent concepts invariably overlap. This convergence in conceptual usage across profiles unveils a shared apprehension of the quality-related challenges intrinsic to the modality, which could be attributed to a certain generational proximity inherent in the samples.

Table 4

Most frequently occurring concepts by category

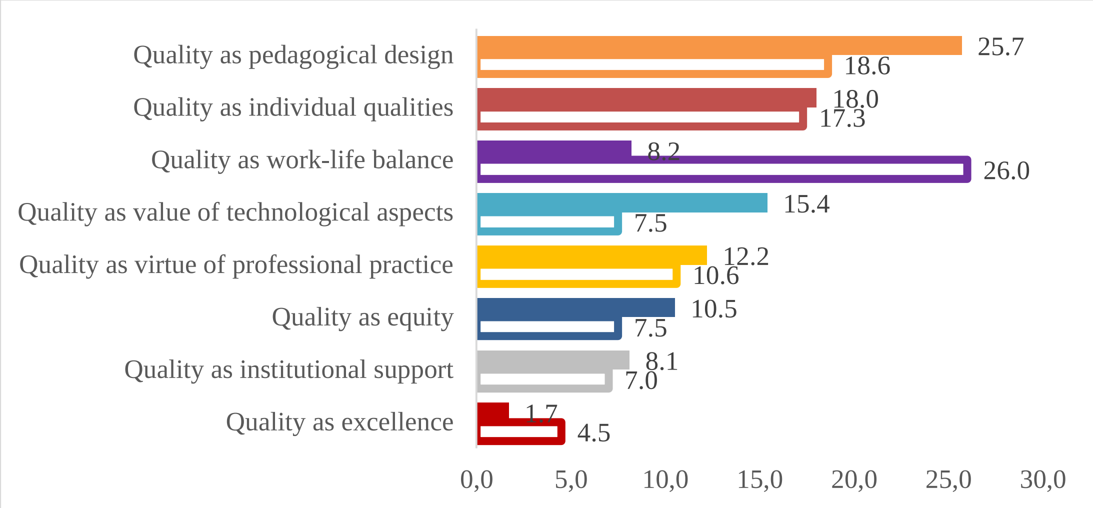
Dimension	Categories	Concepts	
		Students	Teachers
Pedagogical	Quality as value of technological aspects	Connectivity, Internet, Good platform, Interactive technologies	Connection, Platforms, Technologies, Virtuality
	Quality as pedagogical design	Content, Study material, Practice, Innovation	Meaningful learning, Innovation, Active methodologies, Evaluations
	Quality as virtue of professional practice	Lessons, Teacher communication, Good teachers, Feedback	Feedback, Teacher training, Teacher guidance, Support, Guiding teachers, Teachers
	Quality as institutional support	Support, Guidance Follow-up, Clear information	Guidance, Effective communication, Empathy, Follow-up
Non-pedagogical	Quality as individual qualities	Autonomy, Self-management, Responsibility, Organization	Autonomy, Participation, Engagement, Responsibility
	Quality as work-life balance	Flexibility, Time, Freedom, Convenience	Flexibility, Convenience, Time, Availability
	Quality as equity	Accessibility, Affordability, Economy, Inclusion	Accessibility, Opportunity, Inclusive, Diversity
	Quality as excellence	Accreditation, Academic Excellence, Recognition, Prestige	Excellence, High Standard, Indicators, Demanding

Source: own elaboration.

The eight categories distinctly carry different weight with students and teachers. Figure 2 offers a visual representation of this distribution relative to profiles. Among students, most concepts congregate within the category of “Quality as work-life balance” (2,123), followed by “Quality as pedagogical design” (1,519). Notably, the category experiencing the least aggregation of concepts is “Quality as excellence” (364). Conversely, among teachers, the majority of concepts cluster within “Quality as pedagogical design” (440) and “Quality as individual qualities” (308), whereas “Quality as excellence” contains the lowest number of concepts (29).

Figure 2

*Percentage distribution according to categories of teachers and students**



* Teachers (filled bar) and students (bar with borders).
Source: by author.

In summary, the analysis of interviews and questionnaires has revealed novel categories that hold significance in conceptualizing the quality of OHE. Among students and teachers, seven distinct categories emerged, complementing the traditional perspective of "Quality as Excellence." Likewise, for institutional informants, seven categories were identified, with five aligning closely with those discerned among students and teachers, while two categories were specific to this particular sample. These categories are presented in Table 5, segmented by profile.

Table 5

Emerging categories of quality in OHE

Categories	Students and teachers (questionnaire)	Institutional informants (interview)
Quality as equity	X	X
Quality as value of technological aspects	X	X
Quality as work-life balance	X	X
Quality as pedagogical design	X	X
Quality as institutional support	X	
Quality as individual qualities	X	
Quality as accreditation		X
Quality as standardization		X
Quality as relevance with the labour market	X	X

Source: own elaboration.

The categories that emerged from the questionnaires can be explained by the distinct attributes of the non-traditional student cohort and the salient features of online teaching, as underscored by the teaching staff. These categories exhibit a more subjective essence and highlight the pivotal role that both profiles play in the realm of quality. In contrast, the categories stemming from the interviews emphasize contextual, institutional, and external facets linked to quality assurance, and to a lesser extent, the modality itself.

DISCUSSION AND CONCLUSIONS

Online Higher Education (OHE) finds itself at a pivotal juncture, propelled by the confluence of circumstances prompted by the COVID-19 pandemic, digital transformation, and evolving labour market requisites, creating an optimal environment for OHE's continuous expansion and consolidation (Guo et al., 2020). An exploration of its quality, encompassing diverse stakeholders and realms within OHE, stands as a crucial facet for transcending lingering biases (O'Dea & Stern, 2022).

Traditional viewpoints on educational quality in higher education carry the weight of accreditation and instrumental approach (Gerón-Piñón et al., 2021). In education systems where online education remains peripheral, prevailing discourse on educational quality often marginalizes its significance, allowing conventional assumptions of face-to-face education to prevail. Consequently, online education is often perceived as merely an adjunct that modifies contextual factors (platforms) and instructional resources (design), rather than embodying a distinct educational paradigm. Within such contexts, the construct of quality tends to adopt a monolithic hue, occasionally shaded by specific attributes relevant to OHE. Contrarily, this study posits that online education doesn't merely reshape "how" and "what," but fundamentally reshapes the very meanings and objectives of education itself (Ortiz-López et al., 2021).

This dichotomy in perspectives resonates in the responses from students and teachers as well as institutional informants. The concepts that each group associates with OHE quality reveal divergent perspectives. Among institutional informants, quality aligns more closely with accreditation, fitness for purpose, and standardization, while themes of work-life balance and pedagogical design hold more sway for students and teachers. Remarkably, concepts linked to institutional accreditation or vocational relevance (emanating from interviews) are scarce in the open-ended questionnaire responses. This disparity underscores the coexistence of traditional educational quality paradigms alongside emergent viewpoints that reinforce the distinctiveness of online education (Ortiz-López et al., 2021).

For institutional informants, their perceptions reinforce perspectives rooted in external standards and exceptional circumstances (Barroilhet et al., 2022; Harvey & Green, 1993), coupled with an interpretation of quality grounded more in quantitative criteria than qualitative dimensions (Gerón-Piñón et al., 2021). This might stem from a mercantile education system (Oyarce et al., 2020), where prevalent neoliberal subjectivity engenders business-centric language, conceiving quality as a quantifiable outcome rather than an integral process (Houlden & Veletsianos, 2021; Simbürger & Donoso, 2020). These notions permeate the curriculum structure of online education, allowing it to be scalable and gauged by observable metrics. Here, the quintessential "graduate profile" assumes the mantle of defining OHE quality as perceived by institutional informants. This recurring concept stands as a guiding mantra, aligning institutional endeavours and, if deemed achieved, attaining quality almost incidentally. Nonetheless, delving into how this declarative objective is internalized by different facets within the OHE ecosystem—especially how HEIs gauge the realization of graduate profiles as occupational competencies and skills—would be a pertinent avenue for exploration. It could likely be substantiated through graduation rates, obtained qualifications, or, ideally, through graduates' trajectories in the labour market, as these profiles often correlate with real-world competencies.

In the case of students and teachers, perceptions of educational quality broaden conventional viewpoints by integrating elements intrinsic to their online experiences. The significance of categories like quality as work-life balance, pedagogical design, and individual qualities exemplify this trend. In this context, the importance of content and methodologies mirrors the heightened significance that "non-traditional" students attribute to learning and theoretical knowledge in their online education (Sánchez-Gelabert et al., 2020; Tieben, 2020). For online learners, OHE quality is perceived through more subjective and intrinsic prisms. Notably, the sense of individual agency they invest in determining study quality (articulated through traits such as "autonomy," "responsibility," "organization," or "engagement") is striking. This might be construed as a contemporary rendition of the classical student-centred quality perspective (Harvey & Green, 1993) adapted to the challenges of virtual learning for adult learners. Moreover, it aligns with neoliberal subjectivities ingrained in the educational framework, encompassing individualism, efficiency, and meritocracy (Houlden & Veletsianos, 2021; Simbürger & Donoso, 2020; Veletsianos et al., 2021).

For teachers, the emphasis on "methodologies," "learning," and their instructional roles ("tutor," "teacher," "educators") reveals how this understudied cohort perceives OHE quality, placing themselves at the core of education and recognizing their pivotal role in the instructional process, as evidenced by concepts like "feedback" or "participation." However, it's prudent to investigate the actual influence teachers wield from an institutional standpoint—such as their participation in decision-making, training, and educational programs, or the working conditions conducive to their roles, thereby underscoring the merits of this professional practice (Cheng, 2017).

References to platforms that foster participation and flexible learning methodologies, interwoven with concepts denoting OHE quality, encourage contemplation on how such ideals coexist within models governed by scalability and standardization in the milieu of commercialized education and digital capitalism (Ragusa & Crampton, 2017; Saura, 2023). Flexibility is understood more abstractly and commercially from an institutional perspective rather than as a pedagogical element (Houlden & Veletsianos, 2020). Therefore, probing into the practical implementation of flexibility and organizational perspectives, and analysing the ways flexible institutional cultures and strategies are concretely promoted, becomes crucial. Ample references to flexibility are ubiquitous among students and faculty, who position it as a pivotal element in conceptualizing OHE quality, which could reflect the prominence of the concept in higher education today (Huang et al., 2020; Müller & Mildenberger, 2021; Lockee & Clark-Stallkamp, 2022; Müller et al., 2023; Veletsianos et al., 2021). Nevertheless, the results show that in OHE, flexibility is inherent to the modality, rather than a distinctive facet of its quality. For students, the ability to harmonize studies, employment, and family life is reinforced through concepts linked to quality as work-life balance. A gendered analysis could potentially uncover disparities in how flexibility and work-life balance are experienced among diverse student profiles (Chung et al., 2017; Lee et al., 2019; Tieben, 2020). However, despite flexibility's current prominence, the concepts tied to access, equity, inclusion, or ethical dimensions remain relatively unexplored in the quality literature (Martin et al., 2020). Integrating flexibility as an integral component of OHE quality prompts an expansion of quality models and the creation of indicators to comprehend and evaluate its scope.

The findings of this study offer us a means to conceptualize the quality of OHE through novel concepts that arise from the diverse viewpoints of the various stakeholders engaged in this modality of higher education. The interplay amongst key concepts demonstrates the heterogeneous nature of the education system, as well as the distinctive attributes of each profile. However, above all, the outcomes underscore the imperative to establish shared conceptual frameworks that integrate the essence of OHE quality, reflecting its multifaceted nature from a myriad of perspectives. Integrating an equity standpoint into conceptions of educational quality has the potential to enrich the discourse amongst stakeholders of online higher education and engender a more introspective, contextually aware comprehension of OHE (Harrison & Mathuews, 2022; Stracke, 2019; Williamson, 2019). By shifting focus away from purely technical aspects or quantitative benchmarks, new inquiries could arise, probing the inherent conflicts intrinsic to educational markets shaped by digital technologies (Houlden & Veletsianos, 2021; Saura et al., 2023), while simultaneously illuminating disparities and gaps in various contexts, and accentuating the potential for increased democracy and equity. Certain contributions in this domain have employed a gendered perspective in order to challenge heteronormativity and prevailing narratives surrounding the quality of online education, thereby imbuing interactions on educational platforms with a political dimension (Sepúlveda-Parrini, 2023). Nevertheless, these emergent issues remain nascent and warrant further exploration.

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An effective video-based learning approach: a solution for complex university subjects

Una propuesta efectiva de aprendizaje basado en videos: solución para asignaturas universitarias complejas

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ABSTRACT

This research presents a tool that offers an agile solution for university subjects perceived by students to be significantly complex. The tool combines, on the one hand, video-based learning and, on the other hand, a system for assessing difficulty prior to the production of videos. As a starting point, student feedback was used to obtain a map of subject difficulty. Based on the identifying markers on this map, a set of ad hoc videos was prepared to address the key and most difficult issues. After using these videos in their preparation in the subject, students completed a satisfaction survey, which was qualitatively validated by experts and quantitatively validated with a Cronbach's alpha test. The results of this survey reflect the usefulness of the designed learning proposal and the interest aroused in the students. Likewise, through statistical analysis, an improvement in the academic performance of students with access to these videos compared to the control group was revealed. Using an accounting subject for a pilot test has enabled the construction of a learning proposal that can be extrapolated to any field of knowledge. The proposed system thus contributes an effective teaching process for students and allows them to be protagonists in their own academic training.

Keywords: difficulty map; visual learning; accounting; feedback; higher education.

RESUMEN

Esta investigación presenta una herramienta que ofrece una ágil solución para aquellas asignaturas universitarias percibidas por los estudiantes con mayor complejidad. La herramienta combina, por un lado, el aprendizaje basado en videos y, por otro, un sistema de baremación de la dificultad, previo a la elaboración de los videos. Como punto de partida, se utiliza el feedback del estudiante para la obtención de un mapa de dificultad de la asignatura. A partir de las balizas identificativas de este mapa, se ha elaborado ad hoc un conjunto de videos para abordar las cuestiones clave y de mayor dificultad. Tras utilizar estos videos en la preparación de la materia, los estudiantes han realizado una encuesta de satisfacción, validada cualitativamente por expertos y cuantitativamente por el test Alpha de Cronbach. Los resultados de la encuesta reflejan la utilidad de la propuesta de aprendizaje diseñada y el interés despertado en los estudiantes. Asimismo, mediante un análisis estadístico, se pone de manifiesto una mejora en el rendimiento académico de aquellos que sí tuvieron acceso a estos videos, en comparación con el grupo de control. Utilizando como prueba piloto una asignatura de contabilidad, se ha conseguido llegar a una propuesta de aprendizaje que resulta extrapolable a cualquier ámbito de conocimiento. El sistema propuesto contribuye a un proceso de enseñanza eficaz para los estudiantes y les otorga el rol de protagonistas en su propia formación académica.

Palabras clave: mapa de dificultad; aprendizaje visual; contabilidad; retroalimentación; enseñanza superior.

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INTRODUCTION

Initially, this educational research was inspired by continuous efforts to solve two problems in an effective way. On the one hand, difficulties to understand are inherent in accounting matters (Fogarty, 2020; Zhao, 2019); on the other hand, there is a considerable lack of time with regard to teaching all the content included in the teacher's guide for the subject of Financial Accounting II. However, using this subject as a pilot test, a learning proposal has been derived that can be extrapolated to any field of knowledge.

In a global context where virtuality is positioning itself as a necessary modality to achieve the goals of higher education, in terms of improving the coverage and quality of education that guarantee the continued presence and graduation of students (Segovia-García et al., 2022), the COVID-19 pandemic situation arose suddenly. This was undoubtedly the most exceptional scenario that society has had to face recently and led to the closure of academic institutions worldwide (Caurcel & Crisol, 2022), driving the university community to develop different strategies to adapt to this new situation (Cleland et al., 2020; Martín-Cuadrado et al., 2021).

Information technology-enabled learning became the heart of education during the COVID-19 crisis, and many teachers have expressed their desire for evidence-based best practice guides and examples in this area (Sangster et al., 2020). This has given rise to the essential need to remedy the difficulty raised by its presence in teaching, further reinforcing our need to develop material adjusted for this purpose through videos on more complex issues based on the feedback of the students, thus converting them into active collaborators in creating material concurrent with the circumstances of the moment.

Video has unique characteristics that make it an effective approach for improving learning outcomes and student satisfaction, given its flexibility and high motivational potential, enabling it to partially improve and replace traditional learning approaches (Yousef et al., 2014a).

Video-based learning has proven to be an effective teaching tool for teachers in the development of collaborative critical debates, public promotion of teaching practice, and theoretical research related to practical problems (Brame, 2016; Ljubojevic et al., 2014; Kay 2012; Sablić et al., 2021; Vedder-Weiss et al., 2019). Regarding the subject of accounting, Camacho-Miñano et al. (2016) find that multimedia resources are a motivating and valid didactic instrument for learning financial accounting.

Additionally, the "frequently asked questions" instrument is increasingly being used to reduce response times; these are lists of questions and answers that arise regularly, within a specific context and related to a certain topic (Villaseñor, 2014). Undoubtedly, they can become a useful methodological tool in the academic field to meet certain information needs. Hence, they were the germ of the idea that led to the present investigation of questions that are more complex for students and that are raised more frequently when approaching the subject.

Learning based on training videos appears recurrently in the literature (Sablić et al., 2021, Yousef et al., 2014b). However, we have not found any research that combines this teaching methodology with a previous system for assessing difficulty.

The purpose of this research does not lie solely in showing a video-based learning activity through customary training videos. This research aims to contribute to the literature showing the process that leads to the improvement in teaching practice in higher education through the creation of a training asset prepared by teachers and based on student feedback. In relation to feedback, numerous authors analyze this central component of the learning process as a tool, which, more than a corrective instrument, should be understood as one capable of helping students classify their doubts, as well as a means for improving learning, that is, a way of measuring their knowledge, skills and understanding (Chugh et al., 2022; Evans, 2013; Nicol et al., 2014; Scott, 2014).

Currently, there is evidence of a change in the feedback representations focused on student transmission; students are increasingly positioning themselves as active actors in feedback processes (Winstone et al., 2022). This work focuses precisely on this direction; feedback received from students and directed to teachers to ensure they are aware of students' learning difficulties.

The objective of this experience is to reinforce the teaching-learning process in complex university subjects through collaboration between students and teachers, that is, to generate accessible material that can positively influence the motivation of students, thereby demonstrating the effectiveness of this multimedia resource while contrasting it with perceptions.

Based on this objective, the present study aims to test the following hypotheses:

H1: Students positively value the usefulness of video-based learning and its contribution to their preparation in the subject.

H2: The use of the proposed video tool, based on a system of difficulty assessment, can improve the results of the students.

The first hypothesis conditions the structure of the satisfaction survey to enable analysis of its results from the triple perspective of its usefulness in deepening the preparation of the material, its usefulness as a tool that complements the common material of the subject and, its usefulness as a process designed to be a teaching methodology.

The second hypothesis is evaluated by means of a statistical analysis of students' qualifications, that is, of the sample group with access to the videos and of the control group without such access.

METHODOLOGY

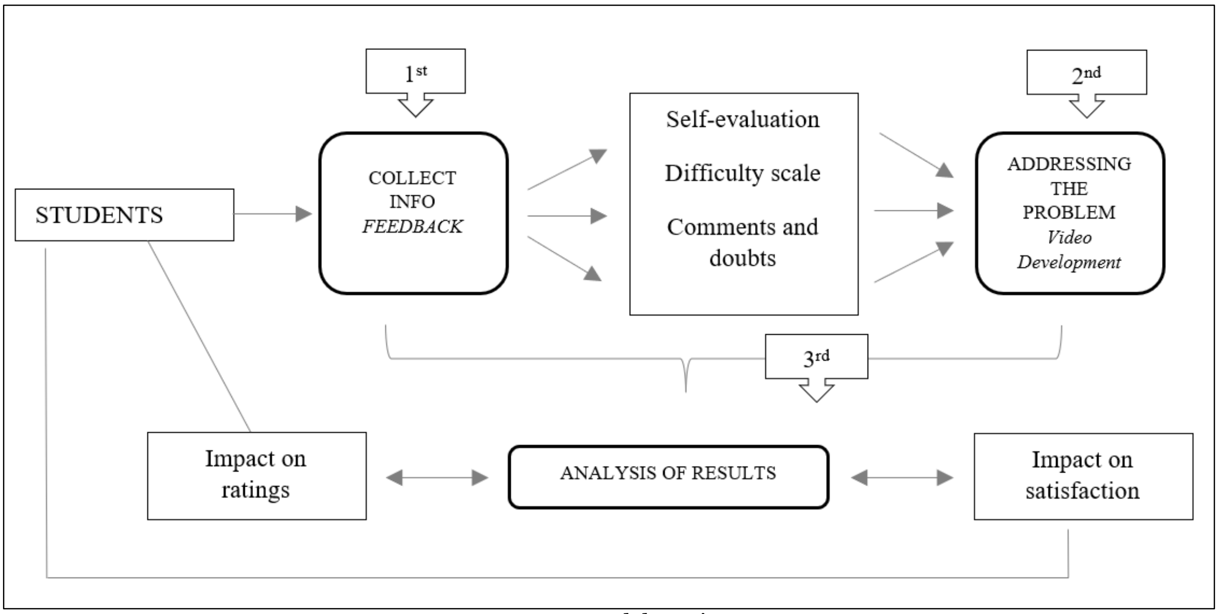
In this section, the entire process followed in the development of the project is explained including its phases, the students who participated and the tools used in its development.

Procedure

The subject that has been used as a pilot test, Financial Accounting II, in the degree of Business Administration and Management, suffers from two problems that need to be addressed. On the one hand, the subject has very broad content that requires a large number of hours of work in the classroom; on the other hand, the reiteration of very common doubts that students raise in individual tutorials is evident. The subject in question consists of five topics, each with a very important and practical function.

The project is developed in three stages, which are represented in Figure 1.

Figure 1
Stages of the project



Source: Own elaboration.

The first stage is the stage of feedback. At the end of each of the topics, students were given a questionnaire to complete. As a result of this first phase, the difficulty map of the subject was obtained, providing identification beacons for the issues that entailed greater complexity for the students. In addition, this offered a reinforcement and improvement tool for the students, since it allowed them to check in which parts of each topic they had failed the most and thus had more questions to resolve.

In the second stage, the problem is addressed and the videos are made. This took place in the following academic year. In this course, these videos were used for the first time as support material for a group of students, a pilot group, with whom we were able to verify their usefulness. In addition, because the teaching modality was not totally face-to-face due to COVID-19, it was possible to reinforce these students' material in an interactive and dynamic way.

Finally, the third stage includes the analysis of results. This took place in the third class, which is the object of this study. New recordings were made for all the videos with a professional technical service, and these were made available to a wide group of students who studied the subject. These students completed a satisfaction survey that made it possible to evaluate the degree of usefulness of this project and its possible application in other subjects. In the present study, an analysis of the results achieved by the students was performed to compare the qualifications obtained in these groups and in others without these videos, which were considered to be the control groups.

Participants

The main idea is to involve students in each of the phases that make up the project. Having been carried out over three academic years, this study was able to differentiate four groups of students with different roles depending on the phase of the project.

1. *Group of students who participated in the phase of obtaining feedback* in the first year of the research. These students completed the questionnaire prepared at the end of each topic of the subject (collected in Section 2.3.1).
2. *Group of students who used the videos for the first time and provided a first evaluation of their usefulness* in the second class, which is the object of this research. This stage reinforced the idea of continuing the project with a greater scope in the next round.
3. *Groups of students who used the videos during the third round.* The videos were made available to a total of 210 students with three different teachers. One of them participated in the recording of the videos, and the other two did not. These students were given a satisfaction survey to evaluate the usefulness of the project.
4. *Groups of students used as control groups who learned the subject in the second class without access to the videos*. To determine whether the videos improve their results, the qualifications of the 230 students the three teachers taught without access to the videos are analyzed and compared with those of the 210 students with such access.

Instrument

This section explains the tools used in each of the phases of the project.

Preparation of questionnaires for obtaining student feedback

The starting point of the project is the development of a questionnaire to be completed by the students at the end of each topic. This system allowed us to collect the necessary information for the later elaboration of the videos. These questionnaires were parameterized through the free access *Socrative* platform, which allows interactions with students through different functionalities. They contain three clearly differentiated parts:

The first part contains a self-assessment system on the knowledge acquired on the topic (see Annex I, where an example for Topic 3 on financial instruments is shown).

In the second part, students indicate the degree of difficulty of the different questions addressed in the topic using a Likert scale from 1 to 5 (see Annex II, where an example for Topic 3 on financial instruments is shown).

Finally, a third party could openly express doubts and comments on the topic.

To check the reliability of the responses of the students, a Cronbach's alpha test was performed on the self-assessment questions and the scale of the degree of difficulty. Table 1 shows how for the questionnaires across all the topics a minimum result of 0.7 is reached. Acceptable values range between 0.70 and 0.95 (Bland & Altman, 1997; Hair et al., 2019; Reyes-Menéndez et al., 2019), which indicate a low dispersion in recorded responses and a certain homogeneity or trend.

Table 1

Cronbach's Alpha values of the quantifiable feedback questions

Topic	Case Processing Summary	N	%	Reliability statistics Cronbach's alpha	N of elements
Topic 1	Valid cases	130	94.2	0.820	18
Topic 2	Valid cases	100	94.3	0.711	17
Topic 3	Valid cases	95	94.1	0.711	17
Topic 4	Valid cases	87	87.9	0.732	16
Topic 5	Valid cases	75	84.3	0.727	16

Source: Own elaboration.

Elaboration of the videos

The production of the videos took place in two phases. In the first phase, the teachers participating in the project recorded the videos by their own means through free access tools. This first recording was the one that was made available to students for the first time, in their second class, to obtain their first impression thereof. In the second phase, in order to make a professional recording of the videos, funding was obtained in the 1st Call for Teaching Innovation Projects of the Faculty of Legal and Social Sciences of the Rey Juan Carlos University.

These videos were posted on a YouTube channel to share their links with the students in a virtual classroom of the university. The videos can be viewed via the links in Table 2.

Table 2

Access links to videos on YouTube

TOPIC	LINK
TOPIC 1. Property, plant and equipment.	
TOPIC 1.1 The calculation of impairment	https://youtu.be/l3MGI953bPY
TOPIC 1.2 The recalculation of the amortization fee after impairment	https://youtu.be/SP32ENY50sY
TOPIC 1.3 Reversal of impairment and reversal limits	https://youtu.be/nfNWPoX-3z4
TOPIC 2. Intangible assets.	
TOPIC 2.1 Final result of the expenses of R&D in balance. Part 1	https://youtu.be/l_0xRovF4Nc
TOPIC 2.1 Final result of the expenses of R&D in balance. Part 2	https://youtu.be/CnrUmTsa9vg
TOPIC 2.2 Difference between transfer rights and lease expenses	https://youtu.be/xAOob-fw0Fc
TOPIC 2.3 Goodwill	https://youtu.be/UkgAE3-RnPg
TOPIC 3. Financial instruments I.	
TOPIC 3.1 Dilution effect	https://youtu.be/HkZcpPsfCeI
TOPIC 3.2 Securities and premiums in fixed income	https://youtu.be/AkPIiLVqfn0
TOPIC 3.3 Profitability accrued and not due before purchase	https://youtu.be/6kz8fOL4fT8
TOPIC 4: Financial instruments II.	
TOPIC 4.1 Amortized cost as an evaluation criterion. Part 1	https://youtu.be/PNvZea7Qd30
TOPIC 4.1 Amortized cost as an evaluation criterion. Part 2	https://youtu.be/Xik_bZEcAHM
TOPIC 4.2 Explicit and implicit interest rate	https://youtu.be/cpyqa_xylFU
TOPIC 4.3 Accrued interest due and not due	https://youtu.be/GFfPuyACXhk

Source: Own elaboration.

Satisfaction questionnaire for evaluating the usefulness of the videos

The satisfaction questionnaire given to the students underwent qualitative validation by three expert reviewers in educational innovation from three different public universities[1]. Table 3 summarizes the validation process.

Table 3

Qualitative validation of the satisfaction questionnaire by experts

INITIAL	REVIEWER 1	REVIEWER 2	REVIEWER 3	COMMON	FINAL
QUESTION 1	✔	•	✔	•	QUESTION 1
	+	+	+	+	QUESTION 2
QUESTION 2	✔	✔	✔	✔	QUESTION 3
	+	+	+	+	QUESTION 4
	+	+	+	+	QUESTION 5
			+	+	QUESTION 6
	+			+	QUESTION 7
QUESTION 3	✔	✔	✔	✔	QUESTION 8
QUESTION 4	✔	✔	✔	✔	QUESTION 9
QUESTION 5	✔	✔	✔	✔	QUESTION 10
QUESTION 6	✔	•	•	•	QUESTION 11
QUESTION 7	•	✔	✔	•	QUESTION 12
QUESTION 8	•	✔	•	•	QUESTION 13
QUESTION 9	✔	✔	•	•	QUESTION 14
	+	+	+	+	QUESTION 15
			+	+	QUESTION 16
QUESTION 10	✔	✔	✔	✔	QUESTION 17
QUESTION 11	✔	✔	✔	✔	QUESTION 18
QUESTION 12	✔	✔	✔	✔	QUESTION 19

Legend: ✔ Validated; ✕ Eliminated; + Added; • Modified

Source: Own elaboration.

Likewise, this satisfaction survey was quantitatively validated via a Cronbach's alpha test, yielding a result of 0.925 for a total of 106 students. Acceptable values range between 0.70 and 0.95 (Bland & Altman, 1997; Hair et al., 2019; Reyes-Menéndez et al., 2019), which indicate a low dispersion in the survey responses. Annex III lists the questions on the final questionnaire.

RESULTS

In this section, the results achieved in each of the phases of the project are analyzed.

Evaluation of student feedback and obtaining the map of difficulty of the subject

Starting with the information gathering phase, the results were analyzed, differentiating each of the three parts of the questionnaire and obtaining the generated difficulty map. All this information comprised the basis for the development of the videos.

Analysis of the responses obtained from the self-assessment

In this first part, the students had to answer five questions of a theoretical-practical nature on each topic. The results obtained are detailed in Table 4 and show that in general, across all the subjects, an average of three correct answers was not reached, indicating the degree of difficulty that this subject may entail for students.

Table 4
Descriptive statistics of the self-assessment questions

	Descriptive statistics				
Correct answers	**N**	**Min**	**Max**	**Mean**	**Dev.**
TOPIC 1	138	0	5	2.72	1.25
TOPIC 2	107	0	5	2.54	1.35
TOPIC 3	106	0	5	2.72	1.45
TOPIC 4	98	0	5	2.84	1.34
TOPIC 5	89	0	5	2.74	1.18

Source: Own elaboration.

From a statistical point of view, the greatest dispersion is found in Topic 3, which is where more doubts may arise. If these results are assessed by topic, few questions reach a percentage of 75% correct answers.

Analysis of the difficulty rating questions

In this second section, students identify the degree of difficulty of the items that make up each topic using a Likert scale from 1 to 5, where 1 is the least complex and 5 is the most complex.

Regarding Topic 1, corresponding to tangible fixed assets, according to the answers in Table 5, none of the responses to the above items falls below 3 as a medium degree of difficulty. Therefore, we estimate that the degree of difficulty of this topic is medium-high. If we delve into the contents that create more difficulty, we observe that two in particular are close to 4. These points correspond to the subsequent valuation of nonfinancial assets, specifically, the problem of the reversal of the impairment of value and its accounting record.

Table 5
Descriptive statistics of the difficulty rating questions

	TOPIC 1			**TOPIC 2**			**TOPIC 3**			**TOPIC 4**			**TOPIC 5**		
	N	**Mean**	**Dev.**	**N**	**Mean**	**Dev.**	**N**	**Mean**	**Dev.**	**N**	**Mean**	**Dev.**	**N**	**Mean**	**Dev.**
LIK 1	133	3.16	1.01	104	2.98	1.01	95	3.19	1.10	90	2.72	1.10	79	2.67	0.93
LIK 2	132	3.35	0.95	101	3.10	0.85	95	3.00	1.15	90	2.88	1.16	79	3.11	1.03
LIK 3	132	3.02	0.99	101	3.22	0.95	95	3.33	1.00	90	3.27	1.07	77	2.56	0.92
LIK 4	132	3.14	1.09	101	3.49	0.84	95	3.69	0.92	89	3.53	0.91	77	3.16	0.97
LIK 5	132	3.32	0.98	101	3.27	1.02	95	3.28	1.02	89	3.24	1.01	77	3.16	1.04
LIK 6	132	3.29	1.06	101	3.23	0.97	95	3.45	0.98	89	3.36	1.07	76	2.91	1.09
LIK 7	131	3.47	0.96	100	3.39	0.99	95	3.41	0.94	88	3.42	1.12	75	2.84	1.09

LIK 8	130	3.55	0.97	100	3.37	0.98	95	3.29	0.99	88	3.32	1.09	75	2.77	1.03
LIK 9	130	3.86	1.02	100	3.59	1.03	95	3.43	1.03	88	3.64	0.98	75	3.57	1.08
LIK 10	130	3.39	1.08	100	3.19	0.93	95	3.53	1.02	87	3.55	0.89	75	3.16	1.05
LIK 11	130	3.24	1.10	100	3.05	1.10	95	3.48	1.04	87	3.45	0.93	75	3.27	0.92
LIK 12	130	3.37	0.99	100	3.46	1.02	95	3.83	0.97	-	-	-	-	-	-
LIK 13	130	3.72	1.04	-	-	-	-	-	-	-	-	-	-	-	-

Source: Own elaboration.

When analyzing the results obtained in Topic 2 on intangible assets, in general, we observe a degree of difficulty greater than three, which is medium-high. The concepts that are more complex refer to the subsequent evaluation. Therefore, the videos that are made for the previous topic are also useful for this topic. Another point that is difficult for students to understand is the assessment of research and development expenses and their activation process. The continuous changes and regulatory developments regarding goodwill, as well as the difference between transfer rights and rental expenses, are other points to which special attention is given in the development of the videos.

Topic 3, financial instruments, is one of the most complex topics in the course, as found when analyzing the self-assessment exercises. In this topic, the classification and characteristics of these financial instruments are studied, establishing the differences between shares and debt securities. These are the operations with shares, specifically, capital increases, which students perceive to have a high degree of difficulty. Specifically, more detailed explanations of the dilution effect generated in these extensions are needed, an aspect that is included in question LIK3.4 *(Topic 3, question 4)* in Table 5. When the representative debt values are studied, the students need to reinforce the calculation of their initial assessment, reflected in question LIK3.12. Specifically, students allude to difficulty when profitability is announced or accrued before the acquisition.

The results obtained in the assessment of Topic 4 referring to financial assets and liabilities at amortized cost reflect a medium-high degree of difficulty. The concepts that generate the greatest complexity are related to the amortized cost valuation criterion, the difference between implicit and explicit interest, and their accounting record. This information is recorded in questions LIK 4.4, LIK4.9 and LIK4.10.

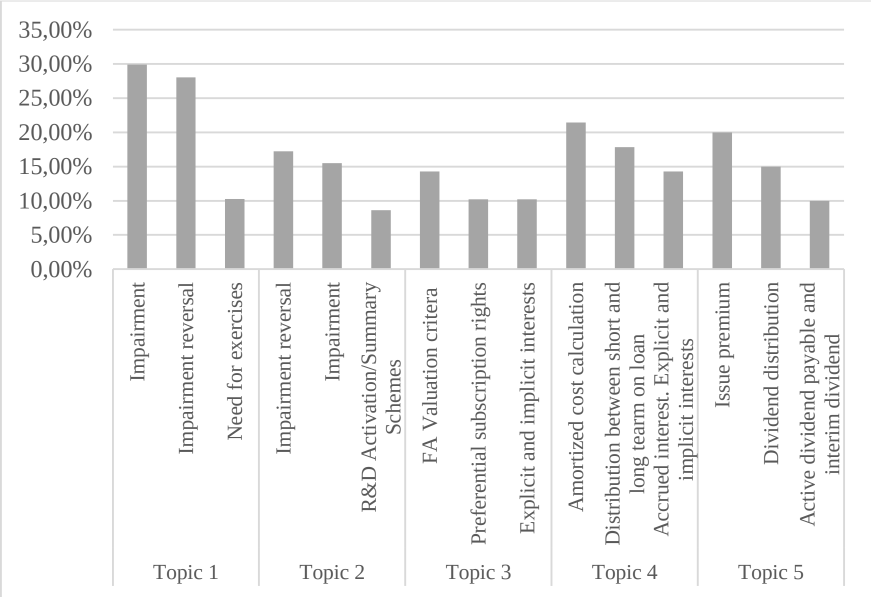
Topic 5, in which the contents of net worth are explained, is generally the one that students perceive to have the least complexity. As Table 5 shows, there are fewer points in which the average degree of difficulty of 3 is exceeded. The issue that needs a more detailed explanation is the concept of refundable and nonrefundable grants and their accounting record when financing a nonfinancial asset.

Open question analysis

As Figure 2 illustrates, in the open question posed, the concepts that are more complex for the students are once again revealed in a free and unconditional way via questions from teachers. The responses recorded are typified by a search for links or common denominators.

As additional questions, they highlight the need to increase the number of exercises to be performed or to provide diagrams to facilitate understanding. This further justifies the use of videos as a tool in this project.

Figure 2
Typification of responses to the open-ended question



Source: Own elaboration.

Obtaining the difficulty map

To allow complexity assessment in a visual way, the difficulty map was constructed for each of the topics that make up the subject. For its elaboration, a series of criteria has been established that allows us to designate different colors akin to a traffic light, as Table 6 shows.

Table 6
Definition of criteria for the construction of the difficulty map

Established criteria	Result
PART ONE: self-assessment	
Records in correct answer (in%)	
Over 50	Green
Between 30 and 50 (or equal)	Yellow
Less than or equal to 30	Red
Records in wrong answer (in%)	
Less than or equal to 10	Green
Between 10 and 30 (or equal)	Yellow
Over 30	Red
SECOND PART: Degree of difficulty. Only if responses> 30%	
Likert 1 and 2	Green
Likert 3	Yellow
Likert 4 and 5	Red
PART THREE: open question (in%)	
Related concepts less than or equal to 2	Green
Related concepts between 2 and 10	Yellow
Related concepts equal to or greater than 10	Red

Source: Own elaboration.

Figure 3 presents the resulting map for Topic 3 on financial instruments, showing the overall result for each question raised, which indicates low, medium, or high difficulty according to whether the color is green, yellow or red, respectively. To do this, previously defined criteria were applied to the recorded responses.

For example, for question 3, a low degree of difficulty is obtained because a percentage greater than 50% is registered concerning the correct answer and a percentage less than 10% was registered for each of the incorrect answers.

Figure 3

Difficulty map of Topic 3-Financial Instruments

EX3.1	In relation to representative debt securities:	A. They involve participation in the capital of another company.	15%	B. They generate variable profitability since it depends on the company's results and the board of directors' decisions.	34%	**C. They generate fixed and guaranteed profitability by contract.**	47%	D. None of the above.	6%
EX3.2	Indicate which of the following items is not a financial asset:	A. Long-term financial investments.	7%	**B. Debits for commercial operations, suppliers and various creditors.**	64%	C. Credits to third parties: such as loans granted.	12%	D. Cash and other equivalent liquid assets.	18%
EX3.3	The equity securities acquired with the aim of selling them in the short term will be classified as follows:	A. An investment held to maturity.	9%	**B. A financial asset held for trading**	77%	C. A financial asset valued at historical cost	8%	D. A loan to collect.	5%
EX3.4	Company ABC owns 200 shares of the capital stock of company XYZ. XYZ carries out a capital increase in the proportion of 1 new share for every 4 old ones. ABC decides to subscribe for 25 new shares. Mark the correct answer:	A. The ABC company has 50 Preferential Subscription Rights in the expansion.	35%	**B. The ABC company uses 100 PSR to buy the 25 new shares.**	44%	C. The ABC company will sell 50 surplus PSR in this operation.	12%	D. The company needs to purchase additional PSR to purchase the 25 new shares.	8%
EX3.5	The JKL company owns 1,250 shares of the PQR company for the purpose of selling them in the short term. The purchase price was €12, and its nominal value was €10 per share. As of December 31, the share price is €13. On this date, the JKL company must:	A. Accounting for impairment in the amount of €1,250.	14%	B. Accounting for a loss of a financial nature of €1,250.	19%	**C. Post a profit of a financial nature of €1,250.**	56%	D. You do not have to make any accounting records.	8%

LIK3.1	Indicate from least to greatest degree of complexity, where (1) is very little complex and (5) very complex, the study, understanding and learning related to the elements that should be considered as financial assets.	1	11%	2	9%		42%	4	26%	5	12%
LIK3.2	Indicate from least to greatest degree of complexity, where (1) is very little complex and (5) very complex, the study, understanding and learning related to the difference between an equity instrument and debt security.	1	12%	2	20%		36%	4	22%	5	11%
LIK3.3	Indicate from least to greatest degree of complexity, where (1) is very little complex and (5) very complex, the study, understanding and learning related to the operations with preferential subscription rights.	1	5%	2	12%		40%		32%	5	12%
LIK3.4	Indicate from least to greatest degree of complexity, where (1) is very little complex and (5) very complex, the study, understanding and learning related to the calculation of the dilution effect in a capital increase.	1	1%	2	8%		31%		40%	5	20%
LIK3.5	Indicate from least to greatest degree of complexity, where (1) is very little complex and (5) very complex, the study, understanding and learning related to the classification of financial assets for the purposes of their valuation.	1	3%	2	21%		32%	4	33%	5	12%
LIK3.6	Indicate from least to greatest degree of complexity, where (1) is very little complex and (5) very complex, the study, understanding and learning related to the amortized cost as a valuation criterion for financial assets.	1	3%	2	13%	3	34%		37%	5	14%
LIK3.7	Indicate from least to greatest degree of complexity, where (1) is very little complex and (5) very complex, the study, understanding and learning related to the fair value as a valuation criterion for financial assets.	1	3%	2	11%		40%		35%	5	12%
LIK3.8	Indicate from least to greatest degree of complexity, where (1) is very little complex and (5) very complex, the study, understanding and learning related to the historical cost as a criterion of valuation of financial assets.	1	3%	2	18%		36%		33%	5	11%
LIK3.9	Indicate from least to greatest degree of complexity, where (1) is very little complex and (5) very complex, the study, understanding and learning related to the calculation of the impairment of financial investments.	1	5%	2	9%	3	38%	4	32%	5	16%
LIK3.10	Indicate from least to greatest degree of complexity, where (1) is very little complex and (5) very complex, the study, understanding and learning related to understanding the different values that a fixed income or debt instrument can have (NV, EV, RedempV.).	1	1%	2	17%	3	29%	4	34%	5	19%
LIK3.11	Indicate from least to greatest degree of complexity, where (1) is very little complex and (5) very complex, the study, understanding and learning related to the difference between implicit and explicit interests associated with debt securities.	1	2%	2	16%		33%		31%	5	19%
LIK3.12	Indicate from least to greatest degree of complexity, where (1) is very little complex and (5) very complex, the study, understanding and learning related to the influence on the initial valuation of financial investments of the profitability of said investments announced or accrued and not due before the acquisition.	1	2%	2	6%	3	25%		39%	5	27%

OP.3.1	Ask a question that needs to be explained, clarified or solved by the teacher:	FAIR VALUE	4%	NV, EV, RedempV & PREMIUMS	6%	REPRESENTATIVE DEBT SECURITIES	8%	EXPLICIT AND IMPLICIT INTERESTS	10%	FA VALUATION CRITERIA	14%
OP.3.2	Ask a second and final question that needs to be explained, clarified or solved by the teacher:	OTHERS (10 ÍTEMS)	25%	IMPAIRMENT	4%	ACCRUED INTERESTS	6%	FINANCIAL ASSET CONCEPTS	8%	PREFERENTIAL SUBSCRIPTION RIGHTS	10%

Source: Own elaboration.

Satisfaction survey results

Once the videos are made available to students, it is necessary to acquire their opinions of their usefulness in students' preparation in the subject. For this, a satisfaction survey was carried out; 106 responses were obtained, which we analyze below.

Regarding their perception of the subject, 62.26% of the students perceive it as difficult or very difficult, entailing work of more than 10 hours a week for 91.51% of respondents. The video tool, based on student difficulty rating, can reduce the degree of complexity of a subject in any field of knowledge without the need to significantly increase the time invested. Such videos have a predefined teaching orientation that guides students in their preparation. For instance, 80% of the students affirm that these videos allow them to deepen their learning of and preparation in the topics, and 85.85% consider their experience with the videos useful or very useful. Regarding technical quality, there is greater dispersion; on a scale of 1 to 5, 21% show a rating of 3, although, in general, students rating the format as high and professional quality total 77.36%.

These percentages indicate a real assessment, as more than 82% of the students claim that they have viewed all the videos or have left only one or two of them pending.

Notably, 82% of the students found them interesting or very interesting, reinforcing the usefulness of this methodology, given that none of the respondents deemed them a waste of time.

Finally, the positive perception of the degree of usefulness of the video tool reached 91% in the responses, a starting point for the promotion of the use of these applicable materials in both remote and face-to-face teaching.

Based on all the above results combined with the data obtained, we can therefore confirm that Hypothesis 1, "Students positively value the usefulness of video-based learning and its contribution to their preparation in the subject", is supported.

Evaluation of grades achieved without videos and with videos

First, Table 7 shows the main descriptive statistics differentiating the scores of students in the control group without access to the videos and those with it. The results are shown for both the ordinary call (May), the extraordinary call (June) and the final grade of the entire group while accounting for both.

Table 7
Descriptive statistics scores

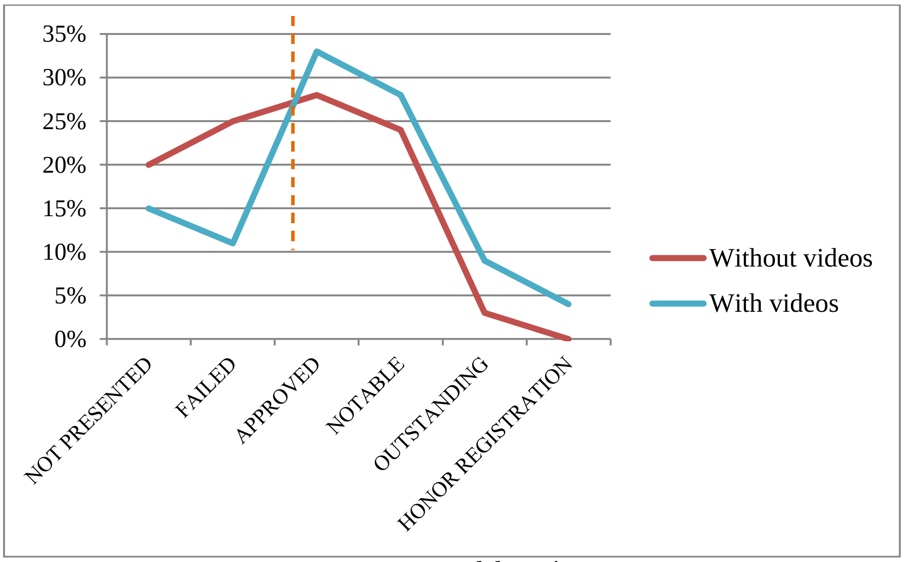
		Mean	Dev.	Min	Max
No access to videos	May	5.19	2.18	1	9.6
	Jun	5.06	1.72	0.75	8.75
	End	5.81	1.96	0.75	9.6
Access to videos	May	5.30	2.89	0.38	10
	Jun	6.04	1.81	1.01	9.2
	End	7.73	2.04	0.74	10

Source: Own elaboration.

According to the data in the above table, for both calls, improvement occurred among the groups of students with access to the videos. This improvement is reflected in a more significant way if the final grades obtained by each group of students are compared. In Figure 4, these final grades are graphically compared by category.

Figure 4

Comparison of final grades by category



Source: Own elaboration.

At the global level, among the groups of students with access to the videos, there was less absenteeism during exams, which may indicate greater security among students who have this tool in their preparation in the subject. Likewise, there is a lower percentage of failure and a higher volume of passing. Notably, the highest scores are practically not recorded for the control groups. In addition, as Figure 4 shows, there is a very significant and pronounced change in the trend between failure and passing for the groups of students with access to the videos.

Statistically validating this comparison of results, Table 8 shows the results of the test of the difference of means among the final grades of students with or without access to the videos. Likewise, the results are shown for each call and each group, differentiated according to each of the three teachers.

Table 8

Test of difference of means and statistical significance

Variable	No access to videos		Access to videos		Difference of means test (p value)
	Mean	Dev.	Mean	Dev.	
Final_total	5.81	1.96	6.73	2.03	-4.43*** (0.00)
Final_Teach_1	5.82	1.72	6.40	1.72	-1.57* (0.06)
Final_Teach_2	6.70	1.85	8.44	1.58	-5.30*** (0.00)
Final_Teach_3	4.80	1.88	5.85	1.83	-3.14*** (0.00)
May_Teach_1	*4.98*	*2.02*	*3.57*	*2.56*	*3.27*** (0.00)*
May_Teach_2	6.29	2.03	7.98	2.23	-4.01*** (0.00)
May_Teach_3	4.17	1.98	4.75	2.06	-1.50* (0.07)

Variable	No access to videos		Access to videos		Difference of means test (p value)
	Mean	Dev.	Mean	Dev.	
Jun_Teach_1	5.24	1.46	6.47	1.61	-3.42*** (0.00)
Jun_Teach_2	5.54	2.17	7.70	1.28	-2.79*** (0.00)
Jun_Teach_3	4.66	1.59	4.36	1.76	-1.96** (0.03)

Note: ***, ** and * indicate significance levels of 1%, 5% and 10%, respectively.

Source: Own elaboration.

According to the above data, the final grades obtained by students were higher on average in the groups with access to the videos, except for those of Teacher 1 in the May call. Furthermore, across all cases, the results are statistically significant.

Given this reiteration in the improvement in results for the groups with access to the videos, it seems reasonable to affirm that the video tool, based on the subject's difficulty, contributes to an improvement in students' performance.

Accordingly, the results obtained, both the descriptive findings and the difference of means test results, support Hypothesis 2, posited at the beginning of the study.

DISCUSSION

Video-based learning is becoming increasingly common in this era in which educational technology and multimedia learning are valued in society (Madariaga et al., 2021). Likewise, the literature suggests that its impact on the quality of learning requires involving students "during" the video design process. Along these lines, in this research, students were involved as the most important actors in the process; their feedback was considered a starting point, since they are the ones who best know what content is most difficult for them. They are thus precisely the ones who have positively valued the usefulness of the videos and their contribution to their preparation in the subject.

According to Campoverde-Luque et al. (2022), to achieve significant knowledge transfer, it is necessary for teachers to be properly equipped with digital tools and manage the resolution of exercises effectively and online; this notion reinforces the learning proposal based on videos presented in this research. In addition, to build this knowledge, there must be professional training in innovative methodological strategies, and that knowledge should be linked to practice (Bravo & Cáceres, 2006; Barrera et al., 2017), the main objective of these elaborate videos. The preparation of material obtained through this methodological process contributes to a reduction in the perceived difficulty, as well as to an improvement in results.

In relation to difficulty, Han and Ellis (2019) describe a methodology for developing the understanding of complex scientific concepts consisting of three stages: (1) identify the sources of misunderstanding of scientific concepts among students; (2) implement an effective instructional design to teach difficult and abstract scientific concepts; and (3) locate actionable elements in the experiences of students and their learning to find ways to impact the quality of their results. In line with this, a process has been carried out that can improve teaching practice in higher education when addressing content with a high degree of difficulty consisting of three stages: (1) collect information directly from students' feedback and by assessing their degree of complexity through a "map of difficulty"; (2) once the most complex issues have been identified, address them through training videos prepared ad hoc, as in the above study; and (3) analyze the impact of the results, both in terms of satisfaction levels and ratings. The relevance of this methodology is that it can be completely extrapolated to any area of knowledge and educational level.

The present research confirms that this method, whose videos address highly focused questions and are adapted to specific learning objectives, allows students to delve into their preparation in focal topics. In contrast, it is less effective for them if these questions are formulated in a more generic way, in line with Schworm and Renkl (2007) and Renkl and Scheiter (2017).

Regarding the technical quality of videos in education, Dong and Goh (2015) analyze how to integrate videos into a teaching program, describe the technical requirements when producing such videos and advise, among other issues, on the quality thereof. The successful integration of video into a curriculum must be guided by the understanding of this technology. Videos must be credible and of good quality. In the methodology of this study, this perception was taken into account; the videos were first made by teachers and then later rerecorded by professionals in this field, ensuring the videos were perceived by more than 77% of students to be high-quality and professional.

In a previous study, Kim et al. (2021) have analyzed self-regulated learning strategies in an asynchronous online course, finding that an increase in students' engagement predicts their course performance. Additionally, the results of both the descriptive analysis and test of difference of means in the present study confirm improvements in both the motivation and academic performance of students. However, this study does not include a prediction study akin to that of Kim et al. (2021), opening a future line of research comparing the results of the above questionnaires with academic results to predict behavior. Such research can be completed by including, as a variable, the role of the emotions and socioemotional profiles of students in multimedia learning environments.

CONCLUSIONS

Following several years of a total break with previous teaching models and in a global context where virtuality is positioning itself as a necessary and complementary modality, we must maintain the adaptations and advances with respect to the previous methodologies, procedures and available resources. This means resuming teaching activities as they were previously carried out and incorporating improvements that have been proven advantageous for teaching quality (Medina López et al., 2021). In this context, information technology-enabled learning has become the heart of education since the COVID-19 crisis, with many teachers expressing their desire for good practice guides based on evidence and examples in their subjects (Cleland et al., 2020; Sangster et al., 2020). Notably, multimedia resources are a valid educational resource and, in a certain way, innovative, concerning instruction in university subjects, as long as they are oriented to specific knowledge objectives, as they constitute a very motivating element for students in the EEES framework (Camacho-Miñano et al., 2016).

Giannakos et al. (2016) state that video-based learning has tremendous potential, when it is pedagogically appropriate and purposefully designed, to facilitate teaching and learning. To use video as a pedagogical tool, it is necessary to examine its impact on students' overall experience, given that the way in which intelligent learning can improve the didactic potential of video systems is of vital importance.

The emergence of digital tools has created new learning conditions, allowing an educational transformation (Rodríguez et al., 2023). In line with this, we have analyzed the usefulness of applying video instruction based on difficulty in complex subjects, using, as a pilot test, the subject of Financial Accounting II, to show that such instruction can be extrapolated to any field of knowledge. This work was openly presented to students through questionnaires specially elaborated for this purpose, enabling their analysis of the degree of difficulty of the different contents and allowing the final selection of the videos to be made. Once these videos were made and viewed by the students, we analyzed their impact and usefulness through two different methods: analysis of the results of a satisfaction survey subsequently carried out with the students and statistical analysis of the results in terms of the grades among students with or without (the control group) access to these videos for their preparation in the subject.

The first conclusion obtained is that videos are a very useful tool for students, providing them with complementary material adapted to their most frequent learning difficulties, which allows them to prepare for a subject with greater autonomy and greater chances of success. The second conclusion is that this system can be perfectly extrapolated to any subject; it is very interesting for teachers since it allows the identification of scales of difficulty in their subjects to address them in the best possible way.

In line with Gil-Galván and Gil-Galván (2021), this study is committed to the continuous development of the teaching process and the implementation of new methodologies that enable students to be protagonists in their own intellectual growth. Given all of the above, the results of this study should broaden the horizon of this project and be applied in related subjects, and even enable other teachers to implement the video tool in other areas of knowledge, thus providing greater robustness to the results obtained.

NOTES

1. The University of Las Palmas de Gran Canaria, the Complutense University of Madrid and Rey Juan Carlos University.

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Annex I. Examples from the first part of the questionnaire for Topic 3- Financial Instruments

1. **In relation to representative debt securities:**
   a. They involve participation in the capital of another company.
   b. They generate variable profitability since it depends on the company's results and the board of directors' decisions.
   c. They generate fixed and guaranteed profitability by contract.
   d. None of the above.

2. **Indicate which of the following items is not a financial asset:**
   a. Long-term financial investments.
   b. Debits for commercial operations, suppliers and various creditors
   c. Credits to third parties: such as loans granted.
   d. Cash and other equivalent liquid assets.

3. **The equity securities acquired with the aim of selling them in the short term will be classified as follows:**
   a. An investment held to maturity.
   b. A financial asset held for trading.
   c. A financial asset valued at historical cost.
   d. A loan to collect.

4. **Company ABC owns 200 shares of the capital stock of company XYZ. XYZ carries out a capital increase in the proportion of 1 new share for every 4 old ones. ABC decides to subscribe for 25 new shares. Mark the correct answer:**
   a. The ABC company has 50 Preferential Subscription Rights in the expansion.
   b. The ABC company uses 100 PSR to buy the 25 new shares.
   c. The ABC company will sell 50 surplus PSR in this operation.
   d. The company needs to purchase additional PSR to purchase the 25 new shares.

5. **The JKL company owns 1,250 shares of the PQR company for the purpose of selling them in the short term. The purchase price was €12, and its nominal value was €10 per share. As of December 31, the share price is €13. On this date, the JKL company must:**
   a. Accounting for impairment in the amount of €1,250.
   b. Accounting for a loss of a financial nature of €1,250.
   c. Post a profit of a financial nature of €1,250.
   d. You do not have to make any accounting records.

Source: Own elaboration.

Annex II. Examples from the second part of the questionnaire for Topic 3-Financial Instruments

Indicate from least to greatest degree of complexity, *where (1) is very little complex and (5) very complex*, the study, understanding and learning related to:

1. The elements that should be considered as financial assets _____
2. The difference between an equity instrument and debt security _____
3. Operations with preferential subscription rights _____
4. The calculation of the dilution effect in a capital increase _____
5. The classification of financial assets for the purposes of their valuation _____
6. Amortized cost as a valuation criterion for financial assets _____
7. Fair value as a valuation criterion for financial assets ______
8. The historical cost as a criterion of valuation of financial assets
9. The calculation of the impairment of financial investments______
10. Understanding the different values that a fixed income or debt instrument can have (NV, EV, RedempV.) _______
11. Difference between implicit and explicit interests associated with debt securities _______
12. Influence on the initial valuation of financial investments of the profitability of said investments announced or accrued and not due before the acquisition ______

Source: Own elaboration.

Annex III. Satisfaction questionnaire regarding the usefulness of the videos

1. Enter your URJC email.
2. Indicate your year of birth.
3. Indicate your gender
    a. Female
    b. Male

4. In relation to the time you dedicate to the subject, please indicate how many hours you dedicate per week:
    a. I dedicate nothing or practically nothing.
    b. I spend up to 10 hours a week.
    c. I spend between 10 and 20 hours a week.
    d. I dedicate more than 20 hours a week.

5. Indicate how many times you have enrolled (counting on the current course) in Financial Accounting II:
    a. 1 (that is, only this year that we are studying)
    b. 2
    c. More than two.

6. Indicate, in your opinion after having taken this subject of Financial Accounting II (second semester), the DEGREE OF DIFFICULTY that you consider it to have compared to other subjects that you have taken in your studies, where 1 is the minimum value "very easy" and 5 the maximum "very difficult".

7. Do you think that the videos have allowed you to go deeper into your learning and preparation for the topics? Indicate the degree, where 1 is the minimum value "very little" and 5 the maximum "a lot".

8. Indicate your DEGREE OF SATISFACTION toward FINANCIAL ACCOUNTING SUBJECT II (second semester), where 1 is the minimum value "not satisfied" and 5 the maximum value "completely satisfied".

9. Indicate the DEGREE TO WHICH YOU LIKED the way in which the subject material has been complemented by the videos, where 1 is the minimum value "I liked it very little" and 5 the maximum value "I liked it very much".

10. Indicate the DEGREE OF USEFULNESS of this video experience, where 1 is the minimum value "very little useful" and 5 the maximum value "very useful".

11. Below is a list of the different videos made during this course for the subject of Financial Accounting II (they are not all broken down; because of some topics, several videos have been made, but there are all the topics that we ask you to evaluate). Please take a moment to remember and assess your DEGREE OF SATISFACTION with each of the videos (referring to the degree of understanding), where 1 is "very bad" and 5 "very good". *(The videos are listed by theme)*

12. Indicate, in general terms, if the TECHNICAL QUALITY of the videos seemed professional and adequate (the way in which they have been recorded), where 1 is the minimum value "very low/very basic format" and 5 the maximum value "very high/very professional format".

13. Indicate, based on your opinion as a student, the DEGREE OF USEFULNESS of the video tool for incorporating and promoting this type of material, applicable in remote teaching, where 1 is the minimum value "very little useful" and 5 the maximum value "very useful".

14. Do you consider the application of videos based on difficulty an interesting methodology for the better use, learning and study regarding a subject such as Financial Accounting II? Here, 1 is the minimum value "very uninteresting" and 5 the maximum value "very interesting".

15. Have you watched all the videos?
    a. Yes
    b. No (indicate in the following line the number of videos that you have been able to see)

16. Do you consider that viewing the videos has been a waste or a good investment of time? To indicate this degree, 1 is the minimum value "(they represent a waste of time") and 5 the maximum value "(they represent a good investment in time").

17. We are very interested in your opinion regarding the continuity of this experience. Briefly indicate the aspects that you consider could be improved in any of the areas (format, content, examples, sound, etc.). Thank you very much.

18. Indicate, with a simple sentence, any comment on your experience of using the videos in the study of the subject of FINANCIAL ACCOUNTING II. Thank you very much.

19. Do you give your consent to use the results of your survey in the teaching innovation project regarding the videos, based on difficulty? (any personal data will always remain anonymous). YES. NO.

Source: Own elaboration.

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Gamification-Education: the power of data. Teachers in social networks

Gamificación-educación: el poder del dato. El profesorado en las redes sociales

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ABSTRACT

Social networks are spaces for teachers to exchange content on new methodological approaches to gamification, raising questions about the integration of gamification in current and future digital trends. The present research aims to determine the behaviour of posts with gamification content on the social networks Twitter, Instagram and TikTok. Web scraping techniques for Instagram and TikTok, together with the Twitter API, collect 189,414 posts with the keywords gamification and education in Spanish and English during the year 2022. These large volumes of data are made available to stakeholders through Microsoft Power Business Intelligence. Using deliberative sampling, an in-depth analysis of the 100 most viral posts on each social network was conducted to respond to the research objective. The results highlight the presence of teachers on social networks, predominantly on Instagram for the Primary Education stage, and the influence of gender on the posts. The male gender has a greater number of followers and posts, but the female gender has followers with a greater number of likes. Commercial interests in the gamification theme are accentuated in digital trends, although they are lower in comparison to sharing non-profit resources. It is concluded that teaching staff who use social networks become emerging agents in the design of materials and, therefore, mediators between the curriculum and practice.

Keywords: social network; education; teaching staff; big data; gamification.

RESUMEN

Las redes sociales son espacios de intercambio de contenido para el profesorado sobre nuevos planteamientos metodológicos en torno a la gamificación. Nos preguntamos sobre la integración de la gamificación en las tendencias digitales presentes y futuras. La presente investigación tiene como objetivo determinar comportamientos de las publicaciones con contenido de gamificación en las redes sociales de Twitter, Instagram y TikTok. Las técnicas de «Web scraping» para Instagram y TikTok, junto con la API de Twitter, recopilan 189.414 publicaciones con las palabras clave de gamificación y educación en español e inglés, durante el año 2022. Estos grandes volúmenes de datos se ponen a disposición de los interesados mediante *Power Business Intelligence* de Microsoft. Mediante un muestreo deliberativo profundizamos en el análisis sobre las 100 publicaciones más virales de cada red social para responder al objetivo de investigación. Los resultados destacan la presencia del profesorado en las redes sociales, predominante en Instagram para la etapa de Educación Primaria, y la influencia del género en las publicaciones. El género masculino dispone de un número mayor de seguidores y publicaciones, pero el femenino tiene seguidores con mayor apoyo en «like». Los intereses mercantiles en la temática gamificación se ven acentuados en las tendencias digitales, aunque son menores en comparación con compartir recursos sin fines lucrativos. Se concluye que los docentes usuarios de las redes sociales se convierten en agentes emergentes de diseño de materiales y, por tanto, en mediadores entre el Curriculum y la práctica.

Palabras clave: redes sociales; educación; personal docente; big data; gamificación.

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INTRODUCTION

Gamification is an emerging methodology that uses games or game mechanics to facilitate learning in non-game contexts. It is associated with additional learner motivation (Kim et al., 2018; Sailer & Homner, 2020) that is linked to positive effects on engagement in learning, socialisation and teamwork (Uz-Bilgin & Gul, 2020) for the enhancement of face-to-face and distance education (Mahmud et al., 2020). Furthermore, it can lead to the enrichment of visual skills and creativity in the educational community (Wai-yee, 2021), as well as to technological literacy and the development of digital competences (Almeida & Simoes, 2019).

In line with the above, authors such as Buckley and Doyle (2016) investigated more than 100 university students studying online for gamified learning. They showed a practical interest for teachers, which can be extrapolated to various educational contexts with an increase in intrinsic and extrinsic motivation. Sánchez-Rivas et al. (2019) carried out an intra-group comparison between Primary Education teachers using traditional exams (control group) and those using a gamified exam-based model (experimental group). The results showed that this group obtained the best results due to the high motivation and learning ability of the students. Nolan and McBride (2014) applied digital game-based learning in the Early Childhood Education stage, obtaining relevant results for inclusive and equitable integration, although they criticise the idealism within the curriculum of educational institutions.

However, there are critical currents that identify negative effects, such as a decrease in academic performance (Toda et al., 2018), lack of understanding, ethical problems in the game, curricular irrelevance, as well as excessive competitiveness and impulsivity (Almeida et al., 2023), even if it is indicated that gamification has positive effects if applied correctly in the classroom. Online educational gamification has also attracted interest from the business world, although it can become a business due to the sales interests and advertising embedded in the games (Terlutter & Capella, 2013).

Nowadays, digital platforms employ gamification elements to attract and retain users, so understanding social networks is crucial and requires data analysis skills. Klašnja et al. (2017) discuss the importance of data science, and expose the significance of Big Data and Learning Analytics techniques in education for educational achievement through the promotion of research. Other studies, by Bourkoukou and El-Bachari (2022) and Hu et al. (2020), determine the feasibility of applying Big Data technologies in education, given the large amount of data generated with Learning Management Systems (LMS), Massive Open Online Courses (MOOC), Learning Object Repository (LOR), OpenCourseWare (OCW), Open Educational Resources (OER), and Social Media, among others. The real feasibility is demonstrated by multiple authors such as Calvera-Isabal et al. (2023), who automate the extraction and analysis of information from web pages for educational purposes, and Barroso-Moreno et al. (2023), who, using *Business Intelligence* (BI) techniques, detect hidden behavioural patterns in social networks to promote critical digital citizenship.

Digital trends in education are a present and future reality, although it is currently unknown which technologies will succeed and what educational value they will have. Ezquerra et al. (2022) apply Artificial Intelligence (AI) techniques to determine emotions and behaviours in physics learning through facial expressions. Nespor (2019) applies blockhain techniques for the certification of students in an American school. Salas-Rueda (2021) uses machine learning to detect classroom perceptions during the

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use of Geogebra in Mathematics. However, these trends are not exclusive to the field of education; in other contexts they are of interest, as is the case of using Big Data to establish management strategies in the tourism sector (González-Serrano et al., 2021), sentiment analysis of Twitter content to determine the potential impact of political campaigns (Rodríguez-Ibáñez et al., 2021), or the use of *Machine Learning* techniques in the medical field to predict the probability of vitamin D deficiency and risk of cardiovascular disease (García-Carretero et al., 2021). The progressive and rapid momentum of technological development is setting digital trends for various applications in different fields and for different purposes. The manner in which these trends are realised in education leaves us with an open panorama that is not without ethical concerns that make a public debate necessary in the light of scientific research clarifying the contributions to education.

Recent studies analyse the functioning of digital platforms to detect behavioural patterns and transfer them to the classroom. In this regard, Marín et al. (2021) identify several current trends around digital competence in teaching and digital tools of social networks in education. Lozano-Blasco et al. (2023) determine that social networks are new relationship ecosystems among young people because they generate a critical analysis of information and define spaces in which to share values and ideology. Along the same lines, Samad et al. (2019) establish a positive relationship between social network presence, social well-being and students' academic performance, although Zimmer (2022) identifies the need for self-control in students so that they do not develop inappropriate habits on social networks.

In relation to the topic at hand, Ladislav et al. (2019) examine the hashtag #gamification on Instagram with 17,994 posts, identifying five communities from highest to lowest modularity: education, entrepreneurship, general gamification, social and fun. Hristova and Lieberoth (2021) examine the educational social interactions of gamification on Snapchat, Facebook, Twitter and Instagram through a manual analysis. The study concludes that these interactions can be beneficial in education, but they also criticise the underlying business practices for supporting gamified offerings, and question the sustainability of these types of educational interactions. Roig-Vila and Álvarez-Herrero (2019) analyse the presence of active methodologies on Twitter, with gamification being one of the most prevalent. Studies of TikTok for educational gamification are scarce, although Deng and Yu (2023) detect a model of short videos to increase hedonic motivation in a university in China. They conclude that this model strikes a balance between curiosity and boredom as a meaningful experience. The present research is far from unconnected with the diverse and even disparate outcomes of digital trends and social media.

Therefore, the purpose of this research is to investigate the behaviour of the most viral posts with gamification and education content on Twitter, Instagram and TikTok, which guides the following hypotheses:

- H1. The profile of teachers is the most active on social networks in terms of publishing educational and gamification content.
- H2. The "influencers" concentrate the virality of the social networks and advertising provides evidence of the commercial interests in the subject of gamification.
- H3. Posts on gamification in education address Digital Education trends to promote adaptive and personalised learning.

METHODOLOGY

This research analyses gamification on Twitter, Instagram and TikTok to identify correlations between post properties and post content. Figure 1 represents the data flow diagram during the research; the first three blocks correspond to the three stages of the mixed methodology developed. The first stage performs an exploratory analysis to determine the descriptors that the posts should contain through the keywords gamification and education. The posts must contain these words, as the audiovisual content is not analysed. Social network monitoring uses the SocialNetworkTool software, owned by the DETECESE research group, which runs on Microsoft Azure to optimise workloads and have the necessary computational elasticity at times of high postings. The software collects posts in real time and stores them with an unambiguous identifier if they contain the keywords; otherwise they are discarded. After seven days, the identifier is retrieved to search the network and compile the properties of the publication. This methodology has two significant direct consequences: it is not possible to collect posts retroactively to the activation of the software, and the publication properties are not updated periodically. This last consequence is acceptable in terms of bias in data collection, as posts that do not go viral on the day of publication do not change their trend afterwards; even so, a margin of one week is used.

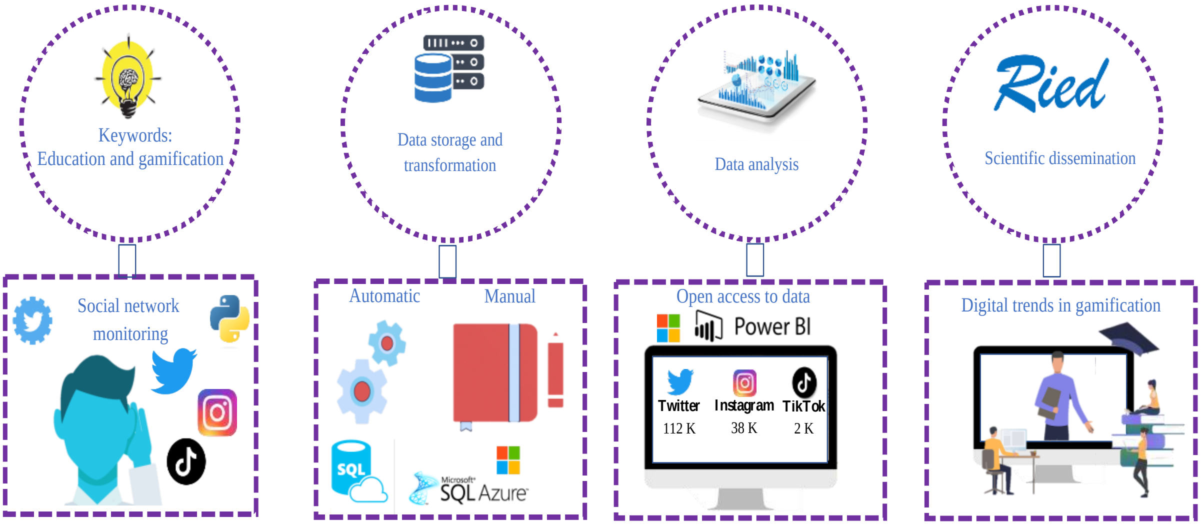
The second stage stores the posts collected in the first stage and applies data transformation through automatic processes, executed on a daily basis, and a manual process, which is performed on an ad hoc basis. The database administration is carried out with the SQL language that allows queries to be made on the relational data systems and access control to them (Gorman et al., 2020). Among the automatic processes, sentiment analysis is performed with the *Azure Cognitive Service for Language* software, which determines the associated sentiment quantitatively through the content of each publication. This software integrates a collection of machine learning and AI algorithms in the cloud for the analysis of written language.

The third stage analyses the data using the Power BI tool to provide interactive visualisations with business intelligence capabilities (Knight et al., 2018), but with a heuristic strategic view. The connection to the second-stage database is made with Azure Analysis, a connector integrated into the Power BI platform. The loaded data allows different graphs to be generated according to the needs of the researcher. Initially, graphs are generated to extract mathematical statistics and perform the relevant data analysis to find behavioural patterns. This novel way of presenting the data allows the research to be disseminated in a visual and intuitive way that is freely accessible.

The process is simple to implement as it is a common technique for enterprise data management. For the research environment it is inexpensive: most readers with Office 365 packages can use *Azure Service* (Microsoft) with a free 100$ credit and Power BI Desktop (Microsoft) free of charge. Interested parties can check the veracity of the data and graphs presented for free at the following Power BI link: https://bit.ly/3MoI67j. The manual analysis corresponds to the 100 most viral posts on each social network, totaling 300 posts, which can be downloaded in full via *FigShare* (m9.figshare.22991627), the contents of which include an Excel file with pivot tables used for the percentages shown.

Figure 1

Data flow diagram of gamification data in research



Source: own elaboration.

In the second phase of the methodology, automated and manual techniques are applied to gamification and education posts. The automated variables are used on the complete database, and common variables are objectively collected by properties of the publication: identifier, content, number of likes, visualisations and geolocation. In addition, informational value is generated by applying algorithms on the content variable: post title, sentiment, word frequency and hashtags. This last variable is collected in Instagram directly; however, in Twitter and TikTok it is not a property of the post and requires a division of the content by the # character. Similarly, there are variables available in each social network that provide information in the general analysis, but do not allow for objective comparisons: retweet 100% concentrated in Twitter, hashtag 82.7% in Instagram or 93.1% reproductions in TikTok. Therefore, the number of likes is determined as a comparative element of virality as it is common to the three networks and there is no uniform criterion (Zamora et al., 2021).

Virality in the networks marks the consumption trends of users and the acceptance of a content or topic that advise a deliberative, non-probabilistic sampling of the posts that clearly represent their influence in the networks, visibility and popularity. Consequently, the categorisation of the manual variables is applied to the 100 most viral posts on each social network, the range of which meets the selection criteria indicated. Table 1 shows the variables analysed, their categories and subcategories, which are completed through the digital trace generated in the social networks, whose authors are regular users who publish their information in blogs or similar easily accessible social networks.

Table 1
Manual categories and subcategories of posts

Identification	Person Company Educational event Digital platform Other	**If educational, it is...**	Generalist Therapeutic Pedagogy Hearing and Language Physical Education English Spanish Language Early Childhood Other/Unspecified
What for (type of post)	Sharing educational resources Educational experience Dissemination Reflection Other	**Educational content creator**	Yes No Not known
Gender	Masculine Feminine Unknown	**Economic remuneration for content creation**	Yes No Not known
Work profile	Company Entrepreneur Organization Teacher Other	**Context in which they are used**	Formal Non-formal
		Content creator for other areas	Yes No Not known
Educational stage	Early childhood educ. Primary education Secondary Education and Baccalaureate University	**Mentioning others**	Yes No
		Profile of those mentioned	Teachers Company Other

Source: own elaboration.

RESULTS

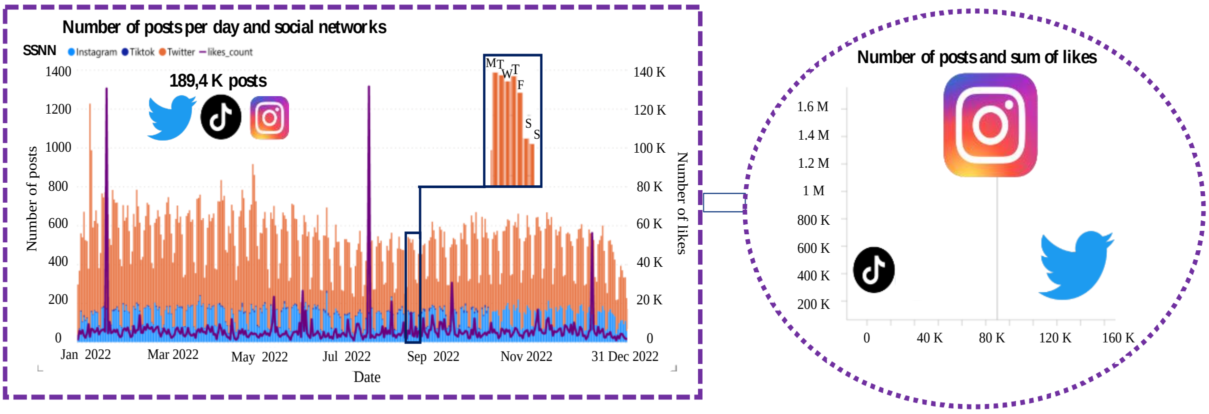
The database consists of a total of 189,414 posts: Twitter with 137,726 (72.71% of the total); Instagram with 49,937 (26.36%); TikTok with 1,751 (0.92%). In relation to the positive and negative sentiment associated with the social network posts, Twitter has 30.75% that are positive (*n*=42,344) and 5.62% negative (*n*=7,738); Instagram has 43.88% that are positive (*n*=21,911) and 1.51% negative (*n*=755); TikTok has 31.30% that are positive (*n*=548) and 2.91% negative (*n*=51). The rest of the posts correspond to neutral messages, whose sentiment load per word is not remarkable. Figure 2 (left) represents the aforementioned volumetries by social network, highlighting the presence of Twitter. In addition, a pattern of behaviour is detected for all networks over time, with five days of high and two days of low posts corresponding to weekdays and holidays, respectively.

Another notable aspect of Figure 2 (right) is the number of likes per post ratio. Instagram stands out with a ratio of 29.4 likes/post, although TikTok is much higher with 201.50 likes/post, but due to its low number of posts the total impact is lower. Twitter is in the opposite situation: with its high number of posts, the ratio drops to

3.03 likes/post. If we look at the 100 posts on each social network with the greatest impact (virality), they account for 23.5% of the likes and barely 0.1% of the posts, and due to their importance, the posts are analysed manually.

Figure 2

Timeline for counting posts per social network and likes ratio



Source: own elaboration.

In summary, the following results become evident in a macro view of gamification: (i) Twitter is the social network with the highest number of posts and polarisation. (ii) Instagram has a lower number of posts than Twitter, but has a higher total of likes and a predominance of positive sentiment. (iii) TikTok is the network with the lowest number of posts, but its virality is extreme, occupying the ranking with the highest virality. (iv) The top 100 most viral posts capture the attention of users, relegating the rest of the disseminations to second place. (v) On weekdays, educational gamification is very active compared to holidays. The conclusions drawn from the volume and sentiment of each social network are confirmed by previous studies. However, it is worth investigating the reason for the concentration of likes on Instagram and the pattern of gamification activity on weekdays, the latter of which could be motivated by teaching or business breaks. The current results on this point are indicative of the research line, but do not confirm any hypotheses.

The role of teaching staff in the dissemination of resources

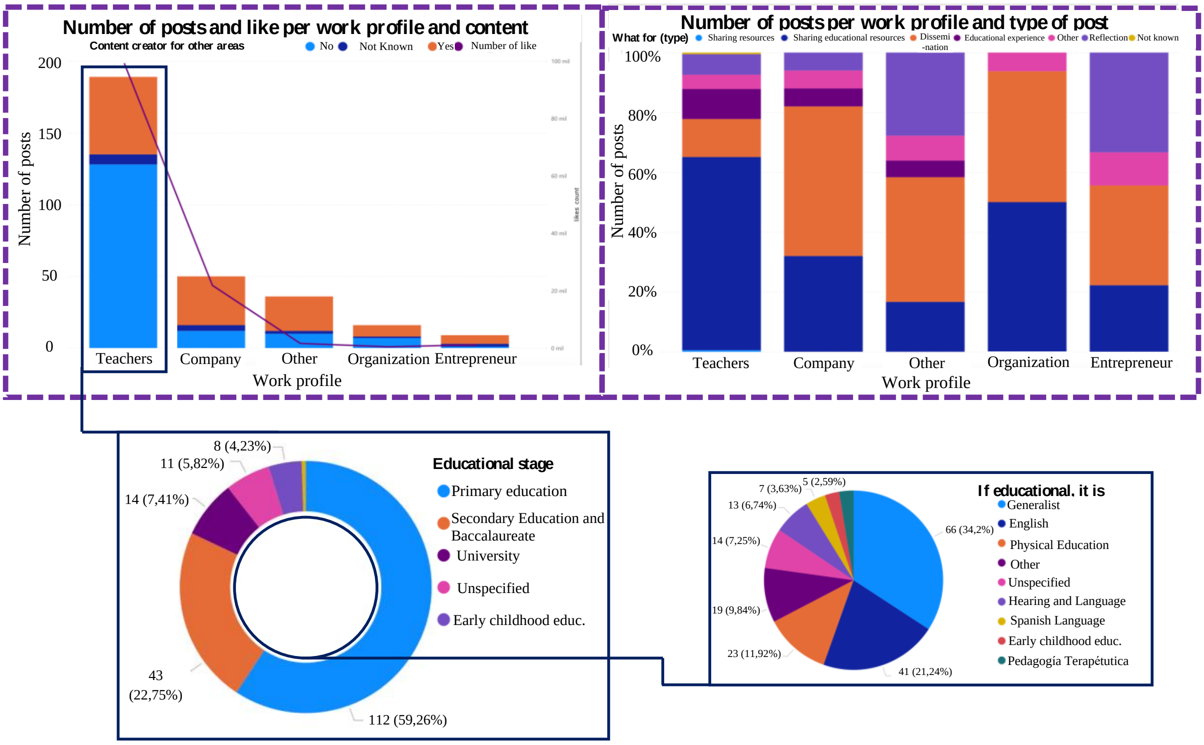
The most viral posts with gamification and education content on Twitter, Instagram and TikTok are mostly made by individuals (76.7%; *n*=230), followed by companies (11.3%, *n*=34), digital platforms (6%, *n*=18*)* and organisers of educational events (3%, *n*=9). Most are used to share educational resources (51.7%, *n*=155) and to disseminate activities of various kinds (24.7%, *n*=74).

The posts made by teachers (63%, *n*=189) stand out in the three social networks (Twitter: 12%, *n*=35; Instagram: 29%, *n*=86; TikTok: 23%, *n*=68), and belong in greater numbers to Primary Education teachers (59%, *n*=112), followed by Secondary Education and Baccalaureate teachers (23%, *n*=43), university teachers (7%, *n*=14) and, lastly, Pre-school teachers (4%, *n*=8). With regard to Primary Education teachers, it is evident that the profiles that publish the most are generalist teachers (34%, *n*=66), followed by those with curricular specialisations in a specific area of education:

Physical Education (12%, *n*=23), Hearing and Language (7%, *n*=13), English (21.24%, *n*=41) and Therapeutic Pedagogy (3%, *n*=5). With regard to Secondary Education and Baccalaureate teachers (23%, *n*=43), it was found that posts by teachers specialising in English (63%, *n*=27), Language and Literature (16%, *n*=7) and Physical Education (2%, *n*=1) prevailed.

Figure 3

Histogram of job profiles according to the content and purpose of the publication, and pie charts classifying educational stage and curricular subjects



Source: own elaboration.

In this sense, teachers at all educational stages tend to publish content that is developed for pedagogical purposes, with the aim of sharing resources (41%, *n*=123) in order, for example, to introduce the metaverse in education [P01]. They also tend to disseminate diverse content (8%, *n*=23): Escape Room games, tutorials on Canva or tools that allow them to work on reasoning [P02], among other contents. They also share educational experiences (6%, *n*=19) that can be useful for the networked community; posts that contribute to reflection (4%, *n*=13) and other actions related in some way to education (3%, *n*=9), such as nominations for teacher awards, magic tricks with cards, etc. (Figure 3, right).

The data shown confirm that (i) almost two thirds of the posts correspond to teachers, (ii) of which more than half create content exclusively for education with the aim of sharing educational resources, (iii) teachers mostly use gamification in the educational stages of Primary and Secondary (6-16 years) with preferences in English and Physical Education, (iv) although the companies do not specialise, they create content of various kinds whose purpose is to give visibility to the product or service they offer.

H1 is confirmed, as the profile that stands out on the social networks is that of teachers, especially those who teach in the Primary Education stage, with a greater prominence on Instagram.

Instagram: the gamified teaching staff's preference

The content of the posts published to share educational resources is found on Instagram (26%, *n*=78), followed by Tik-Tok (9%, *n*=27) and Twitter (6%, *n*=18). The prominence of Instagram is in line with one of the main uses of this network, which is to bring together and share resources in different formats (text, images, sound and videos). In this sense, the 10 most viral posts (range of likes: 1389-3512) belong to Primary Education teachers (Table 2). The publication with the highest number of likes is the one by a Therapeutic Pedagogy teacher who, on this occasion, uses games such as Dobble, Lince or Pictureka to work on processing speed, attention and hand-eye coordination [ID01]. However, generalist teachers [IG02, IG05, IG07, IG08] and teachers of Hearing and Language [IG03, IG06, IG10] have more posts in this list of outstanding teachers. Of these four posts, generalist teachers share material with the intention of promoting audio-visual literacy through the use of films (Encanto, Holly Moon, etc.) and short films (El puente, El puercoespín, etc.) [IG05], reviewing the contents worked on in different subjects using Halloween [IG08] with the support of a Escape Room, among others. If we look at the three posts by teachers specialising in Hearing and Language, they publish, among other aspects, content which contributes to improving reading comprehension through the menus of a restaurant [IG06]. The publication of an English teacher who shares resources for working on regular and irregular verbs through Monopoly with the *Genially Game* tool [IG09] is particularly noteworthy.

Table 2

Most viral educational resource sharing posts on Instagram

ID	Link	ID	Link
IG01	https://bit.ly/43iQVqd	**IG06**	https://bit.ly/3Mmb8V9
IG02	https://bit.ly/45lFVdi	**IG07**	https://bit.ly/3MJA6iJ
IG03	https://bit.ly/3IvDZFs	**IG08**	https://bit.ly/3BHcbdm
IG04	https://bit.ly/3IuxDGb	**IG09**	https://bit.ly/3MJoMDb
IG05	https://bit.ly/3ItjwRB	**IG10**	https://bit.ly/3BLmiOu

Source: own elaboration.

The posts by Early Childhood Education teachers (4%, *n*=8), despite being fewer in number compared to those of Secondary Education and Baccalaureate (23%, *n*=43), receive more likes (range: 18-1290), and deal with different aspects such as virtual bookmarks (likes=127) or the preparation of details to give to children at their graduation (likes=1,274). Occasionally, there are posts about projects, such as El Universo, coinciding with the type of methodology used at this educational stage (likes=1,290). As for the posts by Secondary and Baccalaureate teachers that receive fewer likes (range: 12-971), the most notable are Sintaximinó [P03] (likes=836), which allows students to review simple syntax while playing dominoes, and Genomia [P04] (likes=798), a game based on basic concepts of human genetics. University teaching staff do not post on Instagram.

In reference to TikTok (9%, *n*=27), the impact for sharing educational resources is moderate and concentrated in Primary Education teachers (8%, *n*=25) with a generalist profile (8%, *n*=23) and only in Secondary and Baccalaureate teachers (1%, *n*=2) do they publish anything. Particularly noteworthy is the publication related to the capture of Pokémon [P8], whose activity involves solving questions in teams to work on curricular content (likes=7,747). Pre-school and university teachers do not share educational resources on this network.

With regard to Twitter, teaching staff from all educational stages publish content for the purpose of sharing educational resources. The presence of Primary Education teachers (2%, *n*=6) decreases, but they stand out on Instagram and TikTok. The situation is similar for Secondary Education and Pre-university Education teachers (0%, *n*=1). However, it is on Twitter where university teachers are present (2%, *n*=6) with posts of scientific content such as, for example, an article [P05] (likes=68), or the dissemination of a conference [P06] (likes=16). This presence does not arouse the interest of the networked community if we evaluate the number of likes. It is clear that the most viral posts are grouped around teachers of compulsory education stages, focused on exchanging materials that can be reused in their classes.

In view of the data presented, three ideas can be synthesised: (i) a differentiated behaviour of the educational stage of the teaching staff depending on the social network; (ii) Instagram is the preferred medium for Primary Education teachers due to the audiovisual appeal of the materials that support specific activities; (iii) Twitter is the preferred medium for university teachers, who are oriented towards sharing scientific materials that do not arouse the interest of the networked community.

H2 is partially confirmed; the most viral profiles in terms of number of likes are found on Instagram with multimodal content

Gender matters in social networks

Of the total number of most viral posts on the three social networks, 40.3% (*n*=121) belong to the female gender, 38.3% (*n*=115) to the male gender and 21.3% (*n*=64) are unknown. This predominance coincides with what is reported on the Instagram social network, with the female gender (21%, *n*=64) posting more posts than the male gender (8%, *n*=25). However, this pattern changes in the posts on the social networks Twitter and TikTok, where the male gender predominates (14%, *n*=43 and 16%, *n*=47, respectively) compared to the female gender (5%, *n*=16; 14%, *n*=41). The differences between the two genders on the Twitter social network are evident.

However, if we focus on the posts made by teachers (63%, *n*=189) on the three social networks, we find that the female gender predominates (35%, *n*=105) compared to the male gender (28%, *n*=83). Female teachers prefer Instagram (21%, *n*=63) and male teachers prefer TikTok (12%, *n*=36). Both genders excel in the number of posts aimed at sharing educational resources (F: 27%, *n*=81; M: 14%, *n*=42), although, as can be seen, they are lower in the latter. Teachers use social networks to share educational resources and take on the role of content creators, with a prominent use of Instagram by the female gender.

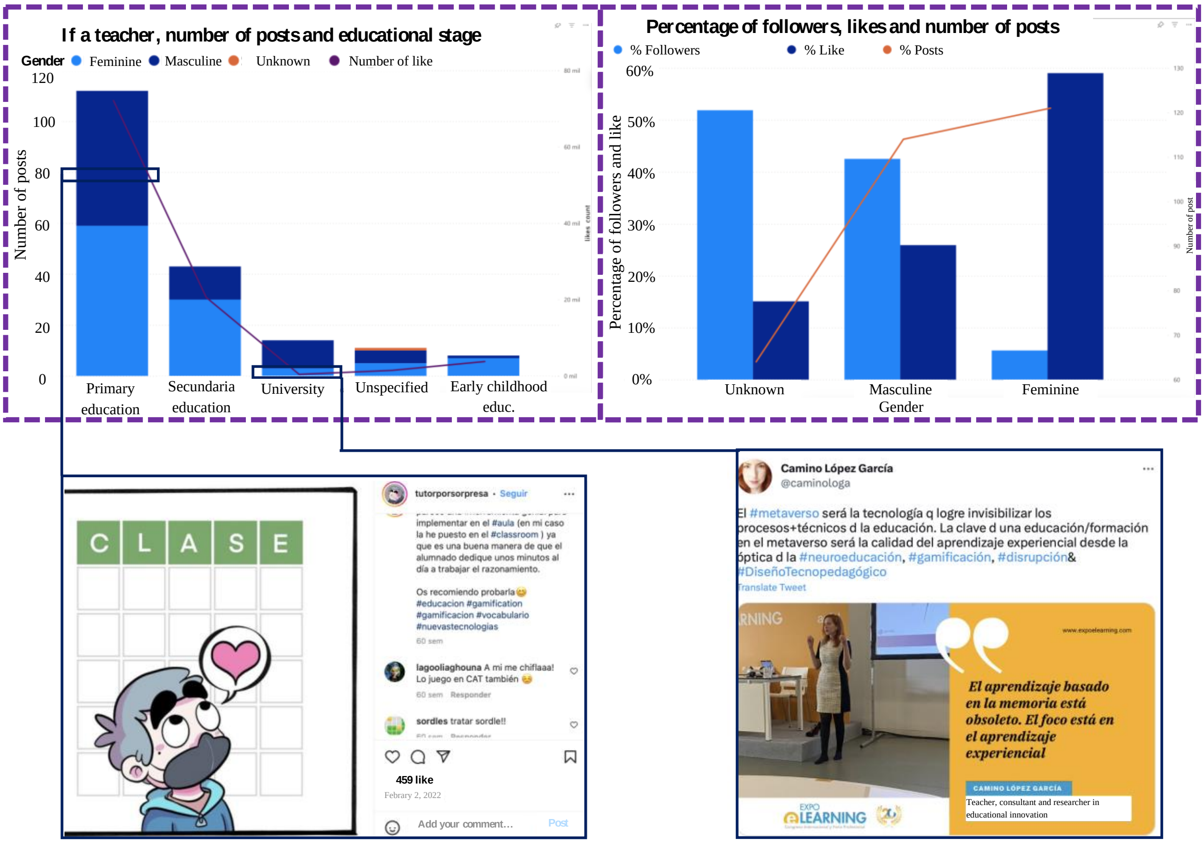
In relation to the educational stages, Figure 4 (left), the teachers publish more posts associated with Early Childhood Education (F: 2%, *n*=7; M: 0%, *n*=1), Primary Education (F: 20%, *n*=60; M: 18%, *n*=53), Secondary Education and Baccalaureate (F: 10%, *n*=30; M: 4%, *n*=13) and university teachers (F: 1%, *n*=3; M: 4%, *n*=11). The topics vary depending on the educational stage: in Early Childhood Education, educational proposals that complement space missions are collected [P10] (likes=1290); in Primary Education, Pokémon video game resources are shared (likes=4,887); in Secondary and Baccalaureate, web pages for creating comics are disseminated [P07] (likes=971); and in University, thought-provoking questions are posed, such as, for example, whether it is possible to educate with video games [P09] (likes=44).

The data analysed show that female teachers (29%, *n*=87) disseminate more educational content than male teachers (11%, *n*=34) in the educational stages characterised by a feminisation of teaching, i.e. early childhood education and primary education.

Figure 4 (right) shows the notable differences for the gender variable. The male gender has a large number of followers, 42.51%, but its percentage of likes decreases to 25.90% of the total number of likes (*n*=115). The female gender has a small number of followers with 5.62%, but captures the highest number of likes, 59.02% of the total (*n*=121). Finally, the unknown gender groups companies or organisations, with 51.87% of followers due to their advertising campaigns, such as "follow us and get a 5% discount", but only account for 15.08% of the likes. They publish 64 posts with a majority of content that is not specialised in education, which may not be very attractive for the educational profiles analysed.

Figure 4

Histogram of teaching staff according to educational stage and gender associated with the sum of likes and two examples of publication



Source: own elaboration.

*Post(left): implement in the #class (in my case I've put it in the #classroom) as it is a good way for students to spend a few minutes a day working on reasoning. I recommend you to try it :) #educacion #gamification #gamificacion #vocabulario #nuevastecnologias #newastecnologias
**Post (right): The #metaverso will be the technology that manages to make the technical+processes of education invisible. The key to education/training in the metaverse will be the quality of experiential learning from the perspective of #neuroeducación , #gamificación , #disrupción & #DiseñoTecnopedagógico

In summary, social networks are a reflection of today's society. (i) The female gender is in the majority at the early childhood stage and the male gender at university, with a balance in the intermediate educational stages. (ii) The male gender has more users, followers and posting activity than the female gender, but with followers who are less inclined to like. At the other end of the spectrum, (iii) the female gender has a smaller number of followers, but with loyal support for each post as measured by like ratios. (iv) The unknown gender, mostly from companies and organisations, has the largest number of followers, but lacks virality in terms of number of likes, which would show little educational harmony with the online community.

Given these results, H2 adds two new dimensions: virality is influenced by gender and educational stage. Bearing in mind that Primary and Compulsory Secondary teachers account for most posts on Instagram and TikTok and university teachers on Twitter, further research is needed to answer H2.

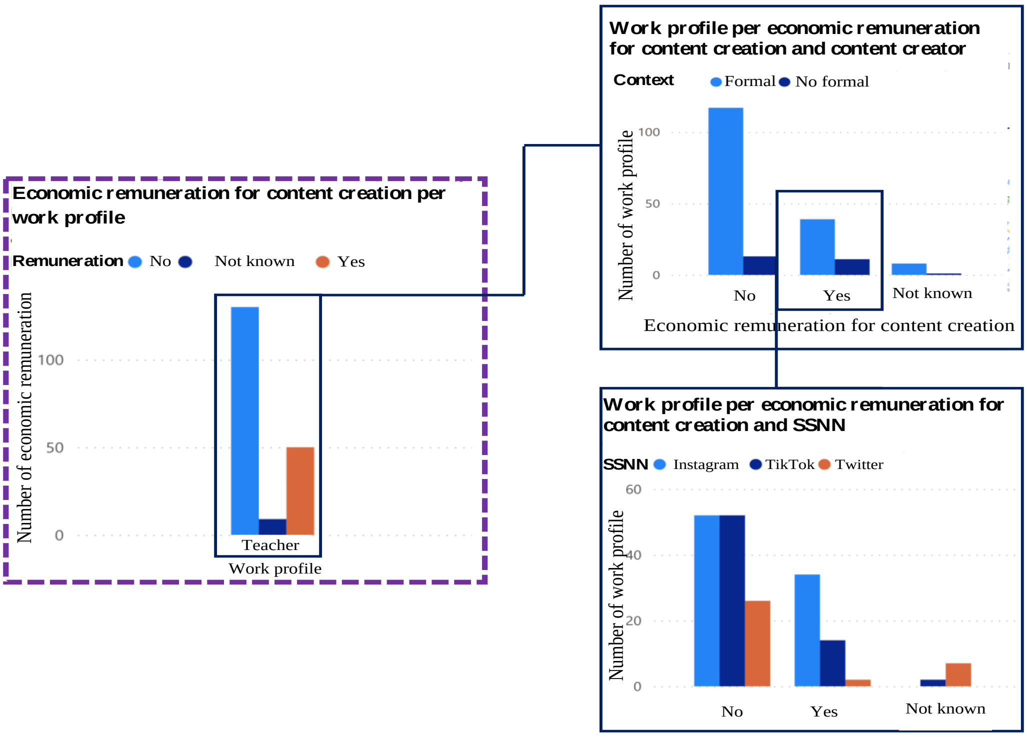
Social network merchandising for gamification and educational content

Of all the educational content created, 17% (*n*=50) of teachers use the designed materials for commercial purposes, and it is the generalist teachers (9%, *n*=26) who show the greatest preference for commercialisation. Materials are made available to users at a price ranging from €1 to €5. For example, the "Psicoeducando" account, developed by a teacher of Therapeutic Pedagogy, hosts various materials including the "Juego de atención" ("attention game") for €1.5, whose purpose is to practice processing speed and verbal fluency. The account "Paula's Slate" is an educational materials shop that hosts materials such as "the verbal suitcase" [P27] (€1), which contains the morphological description of verbs. Most of the profiles that market the materials are active in formal teaching contexts (13%, *n*=39) and create them to be used in these contexts, compared to those profiles that create materials for non-formal contexts (4%, *n*=11). The "deporteeducacion" account, held by a PE teacher, hosts didactic resources for the speciality, such as detectiveEF [P11] or acrosport cards [P28] (€3).

In addition, 5% (*n*=15) of teachers who create educational content in formal contexts and market it, also create content for other areas, generally focused on video games or books. One such material is "En clase sí se juega" ("In the classroom you do play") [P29], a practical guide for creating games in the classroom, or "Aprender lenguaje: sin papel ni lápiz" ("Learning language: without paper and pencil") [P30] comprising various activities to do at home and at school.

Figure 5

Histogram of teaching staff according to financial remuneration and context, as well as focusing the social network on market posts



Source: own elaboration.

The global database has digital trends such as: artificial intelligence [P12], computational thinking [P14], chatbots [P15], virtual assistants [P16], machine learning [P17], blockchain [P18], intelligent tutoring, metaverse [P19], virtual reality [P20], immersive environments [P22], adaptive and personalised learning [P25] and Big Data [P26]. The profiles associated with these trends are various: teachers sharing videos where they represent activities linked to programming with game activities, or companies showing the advantages of their products or services in teaching. The value of these trends in education will have to go beyond the flow of fads that promulgate their innovative nature in order to sustain transformative actions that combine quality and equity. However, these technologies could mark a new path in education without being linked to commercial interests. This situation of private interest is clearly reflected in the posts related to remote and virtual laboratories [P24], augmented reality products [P21], extended reality training plans [P23] and robotics workshops [P13].

H3 confirms (i) the presence in social networks of digital educational trends for promoting motivation in learning and adaptation to the interests of students in online and face-to-face environments. Additionally, (ii) a commoditisation of the network in digital trends derived from the need for specialised products and services is detected.

The data presented above provide a partial answer to H2. (i) There are commercial interests in the subject of gamification and education that are increasing in digital trends, (ii) but these are minor in comparison with those teachers who create traditional materials and share them for non-profit purposes. In summary, the answers to H2 allow us to affirm the virality of Primary and Secondary Education teachers on Instagram. Two thirds of the posts are aimed at sharing resources for altruistic purposes, and one third of them, together with companies, seek economic returns through advertising on the network.

DISCUSSION AND CONCLUSION

Teachers play a relevant role as creators of educational content in the three networks analysed, compared to companies in the education and technology industry. However, their behaviour is differentiated on the three digital platforms. It can be seen that the male gender has more followers and publication activity than the female gender, but the number of followers does not correspond to the number of likes that would be expected. These are interesting results considering it is the female gender that attracts loyal support if we look at the ratios of likes per publication, even though their profiles do not show the same loyalty in the number of followers. Female profiles are recognised for their shared content, a paradoxical behaviour for the visibility of gamification-education content. This is a relevant behaviour that deserves to be explored if we take into account that the greater the number of followers, the greater the possibility of visualisation-viralisation. The posts recognised on the networks are unequal depending on the gender of a profile. Once again, the same pattern of behaviour already evidenced for other educational content appears (Barroso-Moreno et al., 2023).

In this research, Instagram is shown to be a favourite space in which to show and share educational materials and projects. Teachers' preference for this social network and for these purposes modulates it as a space for professional exchange. This is confirmed by the concentration of likes on this social network and the pattern of activity on weekdays, a time frame in which educational gamification is very active compared to holidays. In other words, the use of this network appears to be a part of the professional concerns and occupations of those teachers who are network users. Instagram is the social network with the greatest dissemination of educational gamification, in line with Ladislav et al. (2019) and in response to H1. Posts aimed at questioning and reflecting on the value of gamification to improve learning are relegated to the background. In this sense, it is on Twitter where we identify posts that are more likely to question the value of gamification from scientific interests, associated with university faculty, but do not attract the attention of the online community. This problematisation of gamification could explain the polarisation and negative feelings of the posts analysed. These results are relevant for two reasons. The first is that research on the value of gamification is scarce and inconclusive regarding the positive effects on motivation, engagement and learning enhancement, as understood by Toda et al. (2018), Nolan and McBride (2014) and Almeida et al. (2023). The other reason is that this questioning is alien to Primary and Secondary teachers, as evidenced by the type of material they are willing to share, mainly worksheets to support learning on Instagram; on Twitter their presence is scarce.

Other results obtained allow us to conclude that Instagram is a network with a certain influence on the professional development of teachers, albeit of the opposite sign. On the one hand, it is a space for meeting and altruistic professional exchange. On the other hand, they offer a decontextualization and a vision of gamification as a set of detailed tasks, which could point towards a clear trend, the preference for prescriptive materials. Teachers, in relation to gamification, would assume a role as emerging agents for the distribution of materials and, therefore, as mediators between the curriculum and practice based on visually attractive cards. This type of material is very similar in its aesthetics to the materials for Early Childhood and Primary Education marketed by publishers. A question for further research is the didactic rationality that informs the design of materials that guides the teachers' mediating action between the Curriculum and practice. The multimodal nature of communication on Instagram might legitimise the content exchanged. It should be noted that the most viral posts do not include problematising discourses on gamification on this social network. What is published on this social network are activities that, in themselves, seemingly justify gamification in education. This lack of pedagogical and didactic references would naturalise gamification as an innovation that is reduced to applying aesthetically and visually attractive cards (Wai-yee, 2021) that highlight their playful and motivating nature (Kim et al., 2018; Sailer & Hommer, 2020) for specific curricular topics, especially in the curricular area of English and Physical Education.

Mention should be made of another relevant function from which teachers are not exempt, a mercantile use of the networks analysed, thus playing the role of content creators with financial interests. The danger lies in the mercantile logic, which is alien to educational interests, spreading among teachers and defining the creation of materials in favour of products that, although aesthetically appealing, are lacking in solvent didactic references. Economic interests become visible for gamification in the category of sharing resources associated with technological products, in which there may be corporate business interests. This relevant trend has been identified by Terlutter and Capella (2013), who consider that companies can draw attention to their products and make them attractive by associating their products with online educational gamification.

In the same vein, another set of relevant results shows the association of gamification with novel digital trends, these being undiscovered scenarios that require clear and quality pedagogical frameworks and approaches. Note that H3 in this study is confirmed. Computational thinking or virtual reality in the classroom are promising for the future, but require a sustained and shared effort from different actors to discuss what educational model and teacher training are needed to make use of the potential of these digital trends, in line with Bourkoukou and El-Bachari (2022), Hu et al. (2020) and Calvera-Isabal et al. (2023). This is a complex and multidimensional issue on which shared critical vigilance needs to be developed. The value of AI or computational thinking will be a reality in classrooms (Ezquerra et al., 2022), more because of political decisions and rigorous institutional commitments than because of advances in technological development. However, the social networks analysed function as spaces that generate new semantics and languages through the inclusion of hashtags that relate the game to the products of technological development. The hashtags define an association between educational gamification and technologies that serve as unquestionable and a priori legitimate descriptors which could function as an advertising claim without a clear pedagogical basis. H2 is confirmed by the commercial interests in the most viral posts that fail to provide an educational vision, along the lines we have been discussing.

The results obtained show the complexity of the behaviour of the networks analysed for gamification and educational content, and point to two paths for further exploration. The first is to delve deeper into the content of the most viral posts, as advocated by Calvera-Isabal et al. (2023). The materials analysis approach, a relevant line of research in the field of Curriculum, could be a good alternative to develop in social networks. Determining what conceptions of learning and teaching underlie the shared materials and what values are associated with gamification (competitiveness or cooperation) will clarify the didactic implications of what has clearly become established as a clear trend;the relevance of social networks as spaces for sharing materials. The second is to analyse in depth the most viral posts aimed at sharing company products in order to identify the influencing actions of business agents who do not have an educational profile, but who target their products at teachers.

This research is a future digital trend, big data in education-themed social media. The questions of what social networks are used for, who has the most influence and to what extent they transform learning and teaching mark a roadmap in the study of the power of networks to either generate or not generate educational change.

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ANNEX

Table 3
Identifiers and corresponding links cited in the text

ID	Word in the text	Link	ID	Word in the text	Link	ID	Word in the text	Link
P01	Metaverse in education	https://bit.ly/45hrVBq	P11	detectivEF	https://bit.ly/3pWwctZ	P21	And augmented reality	https://bit.ly/3Iuco9f
P02	Working on reasoning	https://bit.ly/3MqBiWT	P12	Artificial Intelligence	https://bit.ly/3WqkKTl	P22	Immersive environments	https://bit.ly/3WlcnIC
P03	Sintaximinó	https://bit.ly/43bv1oH	P13	Robotics	https://bit.ly/3MMGWnK	P23	Extended reality	https://bit.ly/3MmdJyn
P04	Genomia	https://bit.ly/3BGLooK	P14	Computa-tional thinking	https://bit.ly/3Ism8iy	P24	Extended and virtual laboratories	https://bit.ly/3BLmdKq
P05	Article	https://bit.ly/45jW8zJ	P15	Chatbots	https://bit.ly/43f4QNT	P25	Adaptive and personalised learning.	https://bit.ly/3BJOzVq
P06	Congress	https://bit.ly/3q2iSnW	P16	Virtual assistants	https://bit.ly/41UnIRh	P26	Big data	https://bit.ly/3omEZoA
P07	Comic	https://bit.ly/3MBwvC5	P17	Machine learning	https://bit.ly/43baq3Q	P27	The verbal case	https://bit.ly/41UZWo7
P08	Pokémon	https://bit.ly/45DTkgU	P18	Blockchain	https://bit.ly/3MFVXaF	P28	Acrosport	https://bit.ly/438ODJW
P09	Educating with videogames	https://bit.ly/3C3zi1Q	P19	Metaverse	https://bit.ly/3MuKM3w	P29	In class you can play	https://bit.ly/3odEpcL
P10	Space missions	https://bit.ly/3C2wzG3	P20	Virtual reality	https://bit.ly/45lIc8k	P30	Learning language: without pen and paper	https://bit.ly/3OAVk3o

Source: own elaboration.

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Didactics and technology. Teaching lessons from long-term emergency remote education

Didáctica y tecnología. Lecciones docentes desde la escuela remota de emergencia de larga duración

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ABSTRACT

The Covid-19 crisis forced schools around the world to close their doors, but not all for the same length of time. Countries such as Peru had to find technological alternatives to continue education for an excessively long period: two academic years. At the end of the pandemic, in April 2022, the students returned to face-to-face classes, but in addition to the studies reporting the negative impact of long school closures on learning, what new pedagogical relationship did teachers establish with technology in this context? To answer this question, this paper sought to understand Peruvian teachers' perceptions of the relationship between didactics and technology that emerged after two years of technological mediation forced by school closure measures. This long-term exposure to technology makes the data in this study unique. To find out more about this change, an ad hoc questionnaire was carried out. The open-ended questions of the questionnaire were answered by 154 Peruvian basic education teachers in the metropolitan area of Lima. The information collected was analysed using a qualitative methodology. Their responses were used in an emergent coding process and the resulting codes were grouped into categories. After two years of school closure and in addition to the demand for better training and access to technology, teachers believe that all technology-mediated educational practices used in the emergency school should be part of the face-to-face experience. The only exception would be those that invade the privacy of teachers, students and families.

Keywords: Education technology, Peru, Basic education, Post Covid-19, Education.

RESUMEN

La crisis por Covid-19 obligó a las escuelas del mundo a cerrar sus puertas, pero no todas por el mismo tiempo. Países como Perú tuvieron que buscar alternativas tecnológicas para poder continuar ofreciendo educación por un periodo excesivamente largo de dos cursos académicos. Finalizado la pandemia, las clases volvieron a ser presenciales en abril de 2022, pero además del impacto negativo en el aprendizaje señalado por los estudios en periodos largos de cierre escolar, ¿qué nueva relación didáctica establecieron los docentes con la tecnología en ese contexto? Para dar respuesta, este trabajo buscó comprender la percepción del docente peruano en torno a la relación entre didáctica y tecnología generada tras dos años de mediación tecnológica provocada por el cierre de la escuela. Esta larga exposición a la tecnología es el marco que añade singularidad a los datos de este estudio. Para conocer este cambio se realizó un cuestionario *ad hoc* con preguntas de respuesta abierta contestado por 154 docentes peruanos de Educación Básica de Lima Metropolitana. La información recopilada fue analizada a través de una metodología cualitativa gracias a un proceso codificación emergente de las respuestas agrupando los códigos obtenidos en categorías. Luego de dos años de cierre escolar, además de la demanda de formación didáctica y acceso tecnológico, los docentes creen conveniente que todas las prácticas didácticas con tecnología de la escuela de emergencia formen parte de la escuela presencial, a excepción de aquellas que invaden la privacidad de docentes, alumnos y familias.

Palabras clave: Tecnología de la educación, Perú, Educación básica, Post Covid-19, Enseñanza

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INTRODUCTION

Education in uncertainty (Mèlich, 2019) has become visible as a result of two processes, one slow but inexorable, the other dizzying but powerful. The crisis we are slowly experiencing today is caused by climate change, which manifests itself as an integral global challenge that requires the design of new solutions. These solutions, as Latour (2023) points out, must involve hope and political will. The other crisis, the coronavirus pandemic, which marked a turning point in all areas of our lives and for which no field and no one was prepared, is still fresh in our minds. The determination to continue educating in spite of Covid-19 – educating in health uncertainty – was far from being a simple and mechanical task. It was an act of resistance that has marked the history of students, parents, teachers, managers and politicians, from which educational lessons can be drawn (Marshall et al., 2022; Lobos et al., 2023; Suárez-Guerrero et al., 2021). We can still find alternatives to address the climate crisis, but we need to take note of what we have learned from the health crisis. This paper follows the second line: what the lessons are that can be drawn from this unprecedented experience to inform the study and debate on a potential post-Covid school and education environment.

The dimensions of analysis of basic education during a health crisis are broad and can touch on sensitive issues such as access, equity, teacher training, digital literacy, socio-emotional needs, school-home relationships, etc. (Huck & Zhang, 2021; Suárez-Guerrero & Lloret-Catala, 2022). However, from a pedagogical point of view, the emergency remote learning school (Hodges et al., 2020) – i.e., the version of the school that used multiple media (TV, radio, internet, etc.) and was the singular response to the pandemic – posed a unique didactic and technical challenge for teachers, in addition to the vital challenge of teaching with the deadly threat of the virus. There is evidence that, in addition to widespread digital literacy gaps among teachers (Martínez-Garcés & Garcés-Fuenmayor, 2020), many teachers were unfamiliar with distance or blended learning (Darling-Hammond & Hyler, 2020), from which they could draw models for teaching during the emergency. We could say that there was no validated pedagogical formula for teaching during the pandemic, everything had to be organised by trial and error. But even if there had been one, teachers lacked the digital skills to maintain it.

When technology became the only school interface, teachers – and students – did not react automatically. Learning slowed down and everyone went through a process of change in the way they thought about and implemented education. This time, however, the process was mediated by technology, which had to be reconstructed simultaneously. Part of this new teaching knowledge had to do with establishing a new theoretical and practical relationship between teaching and technology in a context of physical distance. In the context of the pandemic, teachers all over the world had to test, to a greater or lesser extent, their educational knowledge, attitudes and skills and prove that they could be effective in a technology-enabled emergency environment. Before the pandemic, technology was just one variable in education. With the pandemic, it became the educational environment. Thus, the technological dimension of post-Covid schools became a core area of work, not purely technical, but connected to various critical and current aspects where pedagogical knowledge is key (Jandrić & Hayes, 2022). This work inevitably opens up the debate on the hybridisation of teaching and learning (Cohen et al., 2020).

Suárez-Guerrero, C., Lloret-Catala, C., & Mateu-Luján, B. (2024). Didactics and technology. Teaching lessons from the long-term emergency remote school. [Didáctica y tecnología. Lecciones docentes desde la escuela remota de emergencia de larga duración]. *RIED-Revista Iberoamericana de Educación a Distancia, 27*(1), 397-415. https://doi.org/10.5944/ried.27.1.37686

Among the critical pedagogical aspects worth mentioning is the new relationship that teachers have established with didactics and technology, which is particularly important in a long-term distance learning situation (World Bank, 2022). In order to understand how this new relationship between teaching and technology was established, this paper studies the perspective of teachers in a country that unfortunately had to resort to emergency remote schooling for almost two long and unfortunate academic years (Liberato & Alvarado, 2023). This type of work is related to the study of teachers' beliefs about technology (Tondeur et al., 2017), and this is where the particular research question of this study comes in: What new relationship have teachers established between education and technology over such a long period of emergency distance learning?

LONG-TERM EMERGENCY REMOTE SCHOOLING

People the world over experienced the pandemic, but not everyone with the same intensity. Good health care was not enough to contain the epidemic and mitigate its various effects. Although able to help mitigate the impact, the quality of each country's overall response depended on several key factors, including human development, political management and the Covid-19 strategy (Medina-Hernandez et al., 2022). In many countries, however, Covid-19 highlighted deep, pre-existing inequalities. One indicator of this is the Covid-19 death rate, which according to Worldometer[1] was extremely high in countries such as Yemen (18.1%), Sudan (7.9%), Syria (5.5%), Somalia (5%) and Peru (4.9%). This critical health factor, combined with economic disparities, poor governance and precarious living conditions, was a breeding ground for the disruption of all social dynamics, including the school system.

Latin America was one of the hardest hit regions in the world, along with Africa and Asia, where the pandemic led to significant health, economic and educational setbacks (World Bank, 2022). According to Acevedo et al. (2022), the reduction in school hours and the high percentage of students who dropped out of emergency education due to lack of connectivity reduced opportunities and lowered learning outcomes in the region. Today, however, there are still major educational disparities in Latin American countries that hinder the transition to post-Covid schooling. The main reason is their education policies, which have longstanding shortcomings in terms of equity and effectiveness (Darling-Hammond et al., 2021). Among these countries is Peru, which is used in this paper as a case study for the region.

According to UNESCO[2] monitoring data on the impact of the pandemic on global education, schools in Peru were closed for 75 weeks (two full school years) due to the pandemic. In Peru, as in other countries in Latin America, the pandemic affected the educational experience of both students and teachers. It negatively impacted academic performance and emotional and mental health (Almonacid-Fierro et al., 2021; Lobos, et al., 2023). But the Peruvian school was already suffering from other crises. Gómez-Arteta and Escobar-Mamani (2021) highlight two key facts: the first is that long before the pandemic, the Peruvian education system already had a marked inequality of access to quality educational services – and the emergency effectively exacerbated this inequality, reducing educational coverage and, even more so, its quality. Second, the long-term digital education response exacerbated the weaknesses of Peru's education system and widened social inequalities. For economic, geographical, and technological reasons, the Covid-19 school system prevented many students and their families from taking advantage of their right to education. Peruvian schools may have reopened their doors in April 2022, but they are not the same schools. In terms of learning and social development, the country has suffered an incalculable loss that will be difficult to compensate for and will set the agenda for the years to come (Azevedo et al., 2021; Espinal, 2021). This work is framed within this educational crisis, exacerbated by the long period of closure of Peruvian schools.

The emergency response of the Peruvian Ministry of Education (Minedu) with a programme called "Aprendo en Casa" ("Learning at Home") (Andrade & Guerrero, 2021) was insufficient to mitigate the impact of the pandemic on Peruvian education. This educational service was intended as an alternative to maintain the school system during the two years of school closure and distancing. "Aprendo en casa" provided a series of educational programmes in different media (television and radio) and a platform with learning experiences, resources and guidance for students and teachers during the pandemic. However, not all Peruvian schoolchildren were able to access this alternative, as economic or geographical inequalities – the material conditions of virtuality – were an obstacle to access; as Narcizo (2021) points out, the digitisation of Peruvian schools is a poorly distributed good.

In general, Peruvian schools went through two years with a new health problem in addition to the existing challenges: social and economic inequality. Those most affected by the pandemic in general, and by remote emergency education in particular, were people living in poverty, women and indigenous Peruvians (Iguíñiz & Clausen, 2021). The technological alternative was inadequate and could not compensate for the old problems of Peruvian education that persisted during the pandemic. Why was this the case? According to Cáceres-Muñoz et al. (2020) and Van Lancker and Parolin (2020), because the opportunities offered by digitisation reproduce structural inequalities in students' homes. Thus, there is no cause and effect relationship between the use of technology and learning if we do not take into account the social conditions in which they are embedded.

However, in addition to the negative impact of the pandemic on learning, we also need to know its impact on teaching. Therefore, this paper seeks to answer the following: What new pedagogical image do teachers have of technology-based education after two years during which technology was the only interface between them and their students? As shown in this study, what the Peruvian teachers observed regarding the relationship between education and technology may be representative of most countries where the remote emergency school system lasted for more than 44 weeks (with some adjustments depending on the context).

Therefore, it is particularly important to understand how teachers redefined technology-based teaching during these two years of school closure, as they were exposed to the situation for a very long time. Apart from giving a voice to teachers by registering their ideas about education and technology (Tondeur et al., 2017), this type of study tries to focus not only on what technology can do, but also under what conditions it is possible to integrate it in education (Hidalgo Cajo & Gisbert-Cervera, 2022). This type of study can provide clues about the educational experience of the teacher during the school closure. With this in mind, we can advance the long-awaited recomposition of Peruvian education (Saavedra, 2023). Specifically, this study aims to identify which elements of an emergency education system can be maintained and strengthened, and which should be abandoned in post-Covid-19 schools. The aim was to understand Peruvian teachers' perceptions of the relationship between education and technology after two years of emergency digital education forced by Covid-19. The long-term exposure to technology makes the data in this study unique.

METHOD

Design

This study develops a qualitative research based on information collected from Peruvian teachers in the jurisdiction of the Local Education Management Unit (UGEL) of Lima 02[3] between May and July 2022, after the end of the health emergency period and the reopening of schools.

Population and sampling

The population consists of teachers who taught during the two academic years of emergency remote education in UGEL 02, a decentralised educational management body of the Regional Directorate of Education of Metropolitan Lima. UGEL 02 covers the districts of Rímac, San Martin de Porres, Independencia, and Los Olivos, and within regular basic education there are 1,394 early childhood education teachers, 2,959 primary education teachers, and 3,264 secondary education teachers (Ministerio de Educación de Perú, 2023). The questionnaire designed for this research was distributed through LimeSurvey. It was sent by UGEL 02 management to teachers who had taught in the remote emergency education period. A total of 281 teachers replied. After a filtering process, mainly based on the elimination of questionnaires with incomplete data, 154 respondents (120 women and 34 men) aged between 26 and 64 years ($\bar{x}$ = 49.22; Me = 50; SD = 8.76) were considered valid. Our study is descriptive because we are interested in the processes, meanings and understandings that emerge from teachers' words and/or descriptions. As this is a qualitative study, it is not our aim to obtain a representative sample and generalise the results. Of the respondents, 25% are early childhood teachers, 38% teach in primary schools and 37% in secondary schools. All of them teach in public schools (145 in state-run schools and 9 in privately-run public schools). Regarding teachers' home internet connection, all but one have this service and use it mainly through their mobile phone and computer (laptop or desktop). The use of tablets is very limited (4 teachers).

Instruments

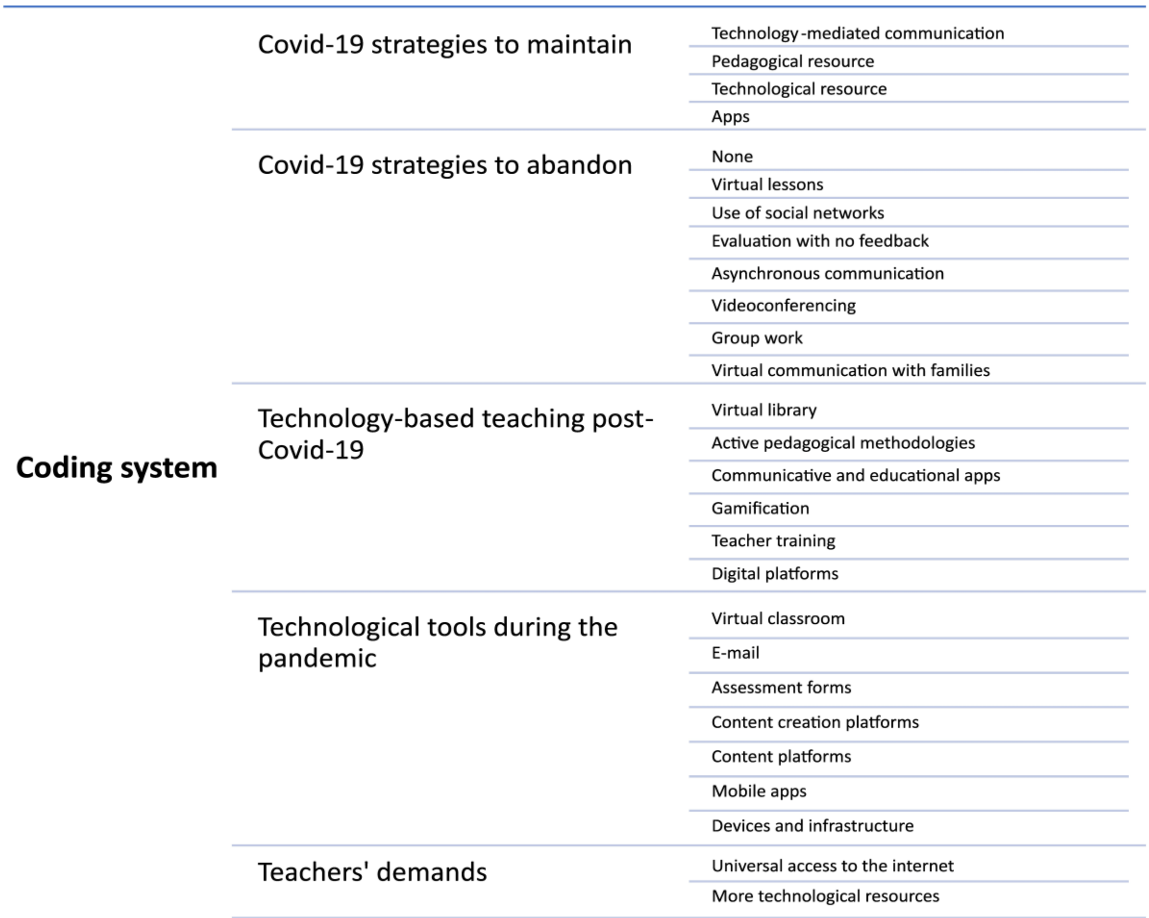
An ad hoc questionnaire[4] was used to collect the information, consisting of two sections: I. General data (age, gender, level, type of school, years of service, region, type of internet connection and device) and II. Four open-ended questions about (1) educational digitisation strategies that worked during the health emergency and should be implemented in the face-to-face school, (2) technological emergency education strategies that should be discontinued in the face-to-face school, (3) pedagogical innovations needed to improve technology-based education in a post-Covid face-to-face school, and (4) main technological tools used during the pandemic.

Analysis procedure

We carried out a qualitative analysis of the responses to the second section of the questionnaire using Maxqda 2020 software in a process of inductive thematic analysis (Braun & Clarke, 2006). This allowed categories to emerge based on the four main themes raised in the questionnaire, as well as an additional category: teacher demands.

The latter included a large number of coded segments related to the demand for universal access to the internet and the request for more technological resources for both students and teachers. Figure 1 shows the result of the analysis (Lloret-Catala et al., 2023):

Figure 1
Coding system after qualitative analysis



Source: Created from Lloret-Catala et al. (2023).

RESULTS

Based on the coding system shown in Figure 1, the analysis of the 5 categories obtained according to the 3 educational levels in which the respondents teach (early childhood, primary or secondary) is presented in detail below. The results are presented through a combination of academic exposition and verbatim quotes from the participants.

Teaching digitisation strategies that worked in the emergency school and should be implemented in regular classrooms

Table 1 shows the frequencies of the codes used in the analysis of this category. The coded segments collected are analysed below for each level of education.

Table 1

Number of coded segments on technology-based teaching strategies that worked in the emergency school and should be maintained

	EARLY CHILDHOOD	PRIMARY	SECONDARY
Communication with technology	15	4	8
Educational resource	12	20	17
Technological resource	14	35	24
Apps	11	16	27
TOTAL	**52**	**75**	**76**

Source: Created from Lloret-Catala et al. (2023).

In early childhood education, teachers report that the teaching strategies that worked best are those related to communication using technology to keep in touch with students, parents and other teachers. The aim of these strategies is to communicate, send information, give feedback and meet virtually. The most commonly used applications to maintain this communication were WhatsApp, Google Meet and Zoom.

> *"The virtual meetings with parents have worked for us. They bring us closer so that we can keep them informed and they can support us in the strategies and projects that the children are doing at school (EC, 29, 1)".*

At this educational stage, the most commonly used educational resources were those based on gamification, such as interactive stories, interactive educational games, songs, educational videos, and readings. Technological resources included the use of slides, videos, infographics, recordings, educational software games, and songs. In terms of the applications most used by children in early childhood, "Aprendo en Casa" and the applications defined in the previous paragraph stood out.

At the next level, primary education, teachers also report that virtual communication was one of the most used resources. However, we observe that there are fewer coded segments and they are less relevant than in early childhood education. WhatsApp was the most widely used application for this purpose.

In relation to educational resources, educators report using the following in order of frequency: collaborative virtual group work, flipped classroom, and gamification via apps such as Kahoot, interactive worksheets, chain reading (producing texts collaboratively), and research activities. Finally, concerning primary education, the technological resources commonly used at this stage included videos, virtual classrooms, websites, blogs, and virtual libraries for information searches, online questionnaires, educational games, and interactive worksheets. The most frequently used applications were Kahoot, Google Forms, Classroom, Padlet, Meet, Zoom, WhatsApp, and Facebook.

In secondary education, as in previous stages, the use of digital media to communicate with students and their families was found to be effective in the emergency education period. Regarding educational resources, teachers utilised a range of techniques such as the flipped classroom, videos/songs/short films to stimulate reflection, collaborative brainstorming, feedback, project and challenge-based learning, cooperative work, virtual forums and debates, autonomous learning, readings, ongoing assessments, and cooperative learning groups. In terms of technological resources, and in order of relevance, we find the use of the flipped classroom, LMS (Learn Management System) platforms, videos and video tutorials, motivational audio to encourage participation, videoconferencing, and applications to create infographics and presentations. Finally, regarding the applications, the most used (starting with the most common) were LMS (Edmodo, Classroom, Aprendo en Casa), WhatsApp, Zoom, Meet, Padlet, Jamboard, Khan Academy and Quizz.

> *"The use of videos/songs/short films to enhance the students' reflection and analysis at the beginning of the learning session (SE, 107, 1)."*

Technology-based teaching strategies in emergency education that should be discontinued in regular classrooms

In relation to this question, most teachers stated that all e-learning strategies should remain in face-to-face education, as most of them are very useful as complementary strategies. As shown in Table 2, it is worth noting that the higher the educational stage, the more coded segments were in favour of not eliminating any virtual education strategies.

Table 2

Number of coded segments of technology-based emergency schooling strategies that should be discontinued

	EARLY CHILDHOOD	PRIMARY	SECONDARY
None	11	15	23
Virtual classes	8	4	4
Use of social media	0	5	7
Evaluations without feedback	0	2	3
Virtual submission of work	0	7	0
Asynchronous communication	2	0	2
Group video calls	3	3	0
Virtual communication with families	2	0	0
Virtual group work	0	0	2
TOTAL	**31**	**36**	**41**

Source: Created from Lloret-Catala et al. (2023).

> *"I would not eliminate any of them, I think that the variety of strategies strengthens the teaching and learning process (EC, 79, Pos. 3)"*

> *"None. I believe that this virtual learning experience during the pandemic has taught us that digital technology is a great ally to strengthen students' learning in all circumstances, environments, spaces and contexts (SE, 38, Pos. 4)"*

However, looking at the data in Table 2, the use of mobile devices, especially WhatsApp and social networks for communication and feedback, emerges as the most expendable. Teachers at all three educational stages agree that mobile devices and instant messaging are the first things they would like to eliminate. The other strategies they mentioned they would eliminate in face-to-face education are virtual classes (especially in initial education), videoconferencing, assessment without feedback, and group work.

> *"Whatsapp lessons should not happen… Not anymore… nor should feedback be given via Whatsapp (PE, 265, 3)"*

Educational innovations needed to improve technology-mediated education in post-Covid-19 schools

In this context, it is worth noting, as we can see in Table 3, that teachers at all three educational stages need technological and didactic training in order to be able to use technology correctly in the classroom.

Table 3

Number of coded segments on educational innovations needed to improve technology-mediated education in post-Covid schools

	EARLY CHILDHOOD	PRIMARY	SECONDARY
Virtual library	2	0	0
Active teaching methodologies	0	0	5
Gamification	6	4	0
Teacher training	14	22	14
Digital platforms	0	0	7
Communication and educational apps	0	5	0
TOTAL	**22**	**31**	**26**

Source: Created from Lloret-Catala et al. (2023).

> *"The most important thing would be to be trained in technological resources, but these must be according to our level. (EC, 127, Pos. 3)"*

> *"There is a need for personal or institutional training in the use of educational strategies to be able to develop innovative actions. (EC, 279, Pos. 4)"*

> *"The integration of technological resources as a constant and sustainable strategy for the achievement of learning (PE, 193, Pos. 4)"*

> *"Ongoing training in the use of software to help teachers keep up with digital teaching. (SE, 133, Pos. 3)"*

As far as specific innovations are concerned, we observe that they differ according to the educational stage. In early childhood education, there is a demand for a virtual library; in primary education, applications for communication, literacy and feedback; and in secondary education, integrated learning management platforms that allow for better communication, delivery and feedback. Secondary school teachers want virtual classrooms and platforms with multiple functionalities to manage the learning process.

> *"Establish integrated digital platforms where students have access to all information related to their studies and parents can also have access and be informed about their children's learning process and assessment. (SE, 38, 5)"*

Number of coded segments on technological tools used during the pandemic

With regard to the last question, concerning the main technological tools used during the pandemic, segments were coded by device and purpose (Table 4). Firstly, we found that in all three educational stages, participants connected from both mobile devices and computers. In terms of applications, communication applications (Whatsapp, Meet, Zoom) continue to be the most used, followed by collaboration applications in the case of primary and secondary education (Padlet, Virtual Whiteboards, Google Drive, etc.), content creation applications in the case of primary and secondary education (Power Point, Genially, Canva, Mindomo, audio and video editing applications, etc.) and gamification applications such as Kahoot in the case of primary education. Finally, YouTube stands out among content repositories. In secondary education, in particular, we see extensive use of the virtual classroom.

Table 4

Number of coded segments on technological tools used during the pandemic

	EARLY CHILDHOOD	PRIMARY	SECONDARY
Virtual classroom	2	13	31
E-mail	2	1	3
Evaluation questionnaires	0	11	3
Creating content	11	14	15
Consuming content	8	12	7
Collaborative apps	6	27	20
Gamification apps	4	18	6
Communication apps	25	35	36
Mobile device/Smartphone	10	7	8
Computer (laptop or desktop)	10	7	7
Internet	4	7	4
TOTAL	**82**	**152**	**140**

Source: Created from Lloret-Catala et al. (2023).

Teachers' demands

Finally, although this is not a specific educational issue, we found a large number of statements related to the teachers' demands for universal access to the internet and for more technological resources at school and at home (Table 5).

Table 5

Number of coded segments on teaching demands

	Early childhood, primary and secondary school
Universal access to the internet	29
More technological resources	50
TOTAL	**79**

Source: Created from Lloret-Catala et al. (2023).

"There is a need for more multimedia spaces, more modern and less slow machines or equipment, for students to enjoy doing their work, stable internet connections, digital libraries with a variety of subjects and access to all areas of development. (SE, 117, 3)"

"First of all, students must be provided with the technological tools; without that, we can't move forward. (PE. 140, 6)"

"Every family should have an internet connection so that they can work on the virtual platforms. (219, Pos. 3)"

DISCUSSION AND CONCLUSIONS

There is no doubt that the Covid-19 pandemic has generated its own line of educational research on an international level (Colás-Bravo, 2021). There is a wide range of studies that address the impact of the pandemic on basic education worldwide, around different thematic axes such as: educational policies, access to technology, emotional health, socio-educational inequalities, etc. Despite the diversity, according to the review by Hammersteine et al. (2021), there is a consensus in pandemic education research: school closures had a negative impact on learning across the board, but this was more pronounced for younger students and students from lower socio-economic backgrounds. The information we contribute to this powerful and necessary line of research is not about how the closure affected students, but rather how it impacted on teaching practice. The idea is to study this new representation of a teacher's previous knowledge (didactics) in a new environment (technology) and in abnormal conditions such as those created by the pandemic. This line of research, which studies the value of educational perception (Tondeur et al., 2017), is of great interest to better understand the impact of pedagogical representations of technology in education (Blau, 2018; Suárez-Guerrero et al., 2023). The present work is in line with this approach.

In this sense, we can highlight four areas that make our object of study stand out: To begin with, such a long closure due to the pandemic forced Peruvians to rethink their basic education system – which was already in crisis – for two years (Cáceres-Muñoz, 2020). Second, far from being neutral and harmless, the use of digital technology directs attention and is an active part of decisions about self-awareness, mutual interactions, and conceptions of and interactions with reality (Floridi, 2015). Third, the experiences of teachers around the world are a source of knowledge about what happened during the pandemic. Together with their testimonies (Almonacid-Fierro et al., 2022), they constitute a scenario for the development of educational theory and practice. Finally, the pedagogical image constructed by teachers about the purpose of technology (Tondeur et al., 2017) is key to making its use meaningful in an educational context. Therefore, this paper is based on the assumption that in a unique educational context of long exposure to technology, technology adds a specific action system and teachers, in turn, use technology based on their conception of its purpose and functionality. Based on this assumption, what is the new relationship between education and technology that has developed among this group of teachers?

The pandemic not only accelerated the trial-and-error process of digitisation in all countries – a process for which none was fully prepared (Onyema et al., 2020) – but also exacerbated the deterioration of the weakest education systems, creating new educational problems and aggravating existing ones (Pokhrel & Chhetri, 2021). In Peru, as in other countries where the duration of school closure was long (more than 44 weeks), we can observe a before and after in terms of academic performance (Espinal, 2021; Gómez-Arteta & Escobar-Mamani, 2021; Liberato & Alvarado, 2023). The pandemic therefore forces us to speak of the post-Covid-19 school not only as a return to normality, but as the beginning of a *new abnormal*.

Thus, among the wide range of variables that explain the presence of technology in pandemic education (Williamson et al., 2020), our focus here has been on the representation of didactics with technology. Regarding the representations that teachers believe should be maintained in face-to-face basic education after Covid-19, two main conclusions can be drawn from this study.

The first relates to technology-based teaching strategies in the context of long-term school closures. Teachers in our sample at all educational stages (early childhood, primary and secondary) indicated that they would continue to use all technology-based teaching strategies implemented during the pandemic. The exceptions are those, such as instant messaging, that may cross the line of privacy in the relationship between teachers, students and families. All teachers at all three stages have used communication applications on mobile devices, especially WhatsApp and social networks, and found them useful. However, they believe that they should be the first to be phased out in post-Covid education, along with videoconferencing – especially in early childhood education – assessment without feedback, and group work, which the respondents mentioned to a much lesser extent. However, there are also differences according to the educational stage. Early childhood teachers highlight some technology-based teaching strategies that focus on communication and gamification. Primary and secondary teachers, on the other hand, mention a much wider range of teaching strategies, including those related to fostering higher levels of student autonomy – such as virtual collaborative work, flipped classroom strategies, or task- or challenge-based learning.

The second conclusion concerns teachers' demands for the educational use of technology. On the one hand, the teachers in the sample stress the need to promote access to the internet and technological devices in both the family and school contexts. This point should not be underestimated, as many students still have no access to digital resources. On the other hand, this group of teachers makes a recurring demand. They make it clear that, after two years of emergency remote schooling, there is still a need for more training in virtual pedagogy, technology, and teaching strategies. This demand is a priority in the current teaching scenario (Portillo & López de la Serna, 2021).

Overall, this paper shows that the various technology-enhanced teaching strategies implemented in long-term basic education still have a place in face-to-face education. This suggests that teachers are developing increasingly hybrid conceptions of teaching and learning processes for post-Covid-19 education (Cohen et al., 2020). Therefore, the pandemic seems to have reinforced, at least from the teachers' perspective, the idea that teaching strategies can and should be thought of in a unified way. We need to overcome the dichotomy between face-to-face and virtual education and move towards a single blended scenario. In addition to greater flexibility and an additional level of teaching innovation, such a scenario can be a fertile field for reflection on didactics in hybrid environments.

NOTES

1. https://web.archive.org/web/20230307225341/https://www.worldometers.info/coronavirus/
2. https://www.unesco.org/en/covid-19/education-response
3. http://www.ugel02.gob.pe/
4. https://ir.uv.es/OTUy7yn

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E-textiles for STEAM education in primary and middle school: a systematic review

E-textiles para la educación STEAM en educación primaria: una revisión sistemática

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ABSTRACT

The growing interest in implementing maker education has highlighted the potential of electronic textiles (e-textiles) in the field of education. This article employs a systematic review methodology to characterize the scientific literature related to the educational use of e-textiles in primary education, focusing on their role in activities that stimulate diverse knowledge, abilities, and skills within the framework of Science, Technology, Engineering, Art, and Mathematics (STEAM) competencies. The review covers the period from 2006 to 2021, adhering to the PRISMA standards. Four prestigious international databases (Scopus, ERIC, WoS, and ACM) were consulted, resulting in the identification of 483 articles. After screening, 35 articles that met the predefined eligibility criteria were selected for analysis. The results and discussions elucidate that the majority of studies were conducted in non-formal educational settings, predominantly utilizing the LilyPad kit as the primary tool. The findings provide data supporting the effectiveness of e-textiles in facilitating learning related to computing, circuits and computational thinking. Numerous studies suggest that the use of e-textiles contributes to equity in STEAM competency acquisition, particularly notable due to the prevalence of female authorship in this field. In conclusion, our study demonstrates that the integration of e-textiles into educational activities for students aged 6 to 13 promotes STEAM skills across all domains. This impact extends to both formal and non-formal contexts, with methodologies designed to encourage student participation and competency-based learning.

Keywords: e-textiles; STEAM; *maker* culture; primary and middle school; systematic review.

RESUMEN

El creciente interés por implementar la educación *maker* ha puesto de relieve que los textiles electrónicos (e-textiles) ofrecen numerosas posibilidades en el ámbito educativo. El artículo se basa en la metodología de revisión sistemática con el objetivo de caracterizar la producción científica relacionada con el uso educativo de los e-textiles en educación primaria[1] como elemento de acción en actividades que buscan despertar diversos conocimientos, habilidades y destrezas en el aprendizaje competencial de Ciencia, Tecnología, Ingeniería, Arte y Matemáticas (STEAM). La revisión se realiza entre los años 2006 al 2021 siguiendo los estándares PRISMA. Se consultaron cuatro bases de datos de reconocido prestigio internacional (Scopus, ERIC, WoS y ACM), encontrando, tras el cribado, 483 artículos, de los cuales se seleccionaron los 35 que cumplían con los criterios de elegibilidad establecidos. Los resultados y discusión arrojan que la mayoría de los estudios se desarrollan en la educación no formal, siendo el kit LilyPad la herramienta de uso predominante. Se evidencian datos de la eficacia del uso de e-textiles para el aprendizaje de computación, circuitos, el pensamiento computacional. Existen numerosos estudios que determinan que los e-textiles promueven el fomento de la equidad y el aprendizaje competencial STEAM, siendo un campo dominado por la autoría femenina. Nuestro estudio concluye que el uso de los e-textiles en actividades educativas para estudiantes de 6 a 13 años, promueve habilidades en todas las áreas STEAM, en contextos formales y no formales, utilizando metodologías que fomentan la participación entre el alumnado y el aprendizaje competencial.

Palabras clave: e-textiles; STEAM; cultura *maker*; educación primaria; revisión sistemática de literatura.

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INTRODUCTION

STEAM (Science, Technology, Engineering, Arts and Maths) education is a new educational competency model that emphasises the theorisation and integration of the arts in learning in the fields of science, technology, engineering, and mathematics, often grouped under the acronym STEM (Aguilera & Ortiz-Revilla, 2021). This model stands out because it is committed to teaching and learning processes through transdisciplinarity (White & Delaney, 2021). As it is closely rooted in maker education (Jia et al., 2021), it seeks to guarantee the acquisition of transversal knowledge, in which the contents of each of these fields are not worked on in isolation, but in an interdisciplinary way in order to ensure competent, functional, contextualised, and meaningful learning. The commitment to this approach has resulted in the incorporation of new teaching resources such as e-textiles, which, similarly to educational robotics due to their multidisciplinary nature, are effective in preparing teachers to integrate computer science and computational thinking into the curriculum (Fields et al., 2019). For this reason, we consider it essential to incorporate maker skills in initial and continuous teacher training (Valente & Blikstein, 2019). As demonstrated in the E-STITCH program, e-textiles are put forward as one of the key factors for STEAM subjects to operate at the same level (Tofel-Grehl et al., 2021; Tofel-Grehl et al., 2022). This program, led by US teachers Colby Tofel-Grehl and Kristin Searle (2023), who are leaders in the field of e-textiles applied to university education, is an example of a growing trend of incorporating this methodology in university classrooms.

E-textiles are textiles that have embedded digital and electronic components (Buechley et al., 2008). Researchers such as Buechley et al.2 (2013) and Jayathirtha and Kafai (2020) point out that carrying out e-textile projects is an effective way of educating in STEAM and developing skills from an early age. In the results of their meta-synthesis of 64 papers over a decade of e-textiles, 8 of which are included in our study, Jayathirtha and Kafai state that e-textiles constitute an exciting and promising field for equitable participation and broadening access to computer science education. They conclude that it is necessary to advocate for more in-depth research to determine the opportunities they provide for students to access the field of computer science. Buechley et al. (2013) provide empirical evidence of the benefits of using e-textiles in education and how e-textile construction kits are reshaping technology education.

At this time of expansion of maker education, it is of interest to examine the effectiveness of e-textiles in arousing curiosity for scientific and technological subjects at an early age. In this paper, a systematic literature review is provided, examining the use of e-textiles as an educational resource to support STEAM learning in students aged 6 to 13. In order to meet this goal, the following research questions were made:

- Which STEAM areas are worked on through e-textiles, and using which technologies?
- What methodological approaches are used to integrate e-textiles in primary education?
- In what contexts is e-textile learning addressed for students aged 6-13?

BACKGROUND

E-textiles in the context of the maker movement

Electronic textiles or e-textiles are "fabric artefacts that include embedded computers and other electronic devices" (Peppler, 2013, p. 38). The creation of these artefacts is associated with the field of wearable technologies, which has traditionally been reserved for scientists, textile engineers, health professionals, and pioneers in the arts and fashion design (Ryan, 2014). This multidisciplinary field stems from 1990s research in the field of interaction design applied to wearables, and it is characterised by the use of new flexible, conductive, and smart materials, by means of which highly visual and aesthetic results can be achieved (Berzowska, 2005; Orth et al., 1998). The creation of these artefacts brings together engineering and computing to create computers that are "soft, colourful, accessible, and beautiful" (Buechley et al., 2013, p.1), allowing for the possibility of combining art and creative expression with engineering, delving into knowledge domains such as programming, manual work, and electronics (Kafai et al., 2019).

This field was complex and inaccessible until the late 1990s, but around 2006 the emergence of the maker movement and the Do it Yourself (DIY) philosophy made its democratisation possible (Posch & Fitzpatrick, 2021; Perner-Wilson & Buechley, 2013). Maker culture emerged in the United States and became popular globally through Maker Faires (Dougherty, 2013). Makers (Hatch, 2014) carry out activities that consist of creating objects in both physical and digital collaborative learning spaces, and their projects are associated with the use of 3D printers, robotics or e-textiles, among others (Anderson, 2012). Maker education advocates making (or creating/building) as a way of learning (Peppler & Bender, 2013) and stands out for contributing to the so-called 21st-century skills (González-Pérez & Ramírez-Montoya, 2022). The roots of this movement are associated with Papert's constructionist theory (1980), and in turn, with constructivist learning theories (from classics such as Piaget, Vygotsky, and Dewey).

When developing and constructing e-textiles, electronic artefacts are created that can be wearable or that include programmable circuits or computers, which promotes learning, as a personally meaningful artefact is created (Papert & Harel, 1991). In recent years, creating digital media and learning electronics have become accessible to all audiences (Spina & Lane, 2020), making e-textiles applied to education an interesting teaching resource for STEAM education.

STEAM education with e-textiles

STEM education is based on an inclusive model that facilitates experiential learning and responds to the demands of the new millennium (Tytler, 2020; Sanders, 2009). Art was gradually integrated, in order to add a more creative and innovative perspective, thus giving rise to the term STEAM (Perignat & Katz-Buonincontro, 2019; Maeda, 2013; Yakman 2008). Among the various initiatives proposed on the basis of this educational approach, project-based learning in the context of e-textiles stands out. When considering the constructionist approach in the field of STEAM, e-textiles promise to be an important teaching resource that offers numerous possibilities for education focused on these areas (Kara & Cagiltay, 2023; Hughes & Morrison, 2018).

In this regard, among other aspects, several authors have shown that the creation of e-textile artefacts benefits the development of creative and critical thinking (Lui et al., 2019; Peppler & Wohlwend, 2018) and encourages students to learn about electrical circuit concepts in a new way (Tofel-Grehl et al., 2017). Given their characteristics, various authors argue that they represent an opportunity for the expansion of computer science learning (Jayathirtha & Kafai, 2019), including elements of circuits, design thinking, and the arts, thus blurring the traditional boundaries between disciplines (Kafai et al., 2014). This field and its applications to education are identified as a key factor for working on STEAM subjects (Fields & Kafai, 2023; Peppler, 2013) and fostering computational thinking (Wing, 2006). In particular, because the incorporation of iterative design (Fields et al., 2019) provides the learning scenario for students to acquire risk-taking skills resulting in a critical-thinking basis for computational thinking.

Following Papert (1980), the fields of learning sciences and educational technology have focused on students learning by manipulating and creating digital objects. This is reflected in the use of platforms such as, for example, TurtleStitch, which allows you to embroider what you program and create projects in textiles. The projects carried out by the community represented, among others, by Margaret Low, have demonstrated their potential for students to acquire skills in design, mathematics, art, and composition (Klimczak & Solomon, 2022). Many e-textile construction kits have emerged, offering different approaches to getting started in programming, electronics. and STEAM. The use of these kits in the classroom offers greater transparency when learning than robotics construction kits (Kafai et al., 2014). Buechley (2006) designed the LilyPad kit with the aim of broadening participation in computer science.

The LilyPad kit was designed in a similar way to the LEGO Mindstorms kit (Resnick et al., 1988) and includes a low-cost, open-source, Arduino-based programmable motherboard (Banzi, 2008), conductive thread and different sensors and actuators adapted to be easily sewable to the textile, allowing users to design and create their own e-textiles (Buechley et al., 2008). There are other similar kits such as Flora, LilyTiny or EduWear which, like LilyPad, emphasise the act of sewing the circuits and making them visible in order to give the user an understanding of programming, electronics, and circuits (Lovell et al., 2023; Schelhowe et al., 2013; Stern & Cooper, 2015). Other prefabricated kits such as i*CATch and Make Wear offer plug-and-play and are more user-friendly (Kazemitabaar et al., 2017; Ngai et al., 2013). Quilt Snaps and TeeBoard (Buechley et al., 2005; Ngai et al., 2009b) are mainly aimed at deepening the computational experience for learners. All these construction kits offer an interesting new range of tools and materials for both teachers and learners. As their educational value has been demonstrated, e-textiles have become an increasingly important competence practice, a potentially emerging field of educational research, the development of curriculum materials similar to those of educational robotics (Fields & Kafai, 2023; Hébert & Jenson, 2020) and the emergence of books with activities adapted to the American Next Generation Science Standards (NGSS), designed for teachers to bring e-textiles into the classroom (Peppler, Gresalfi et al., 2014; Peppler, Salen Tekinbas et al., 2014). Following the recent implementation of the STEAM model in the classroom and in order to improve student learning, the use of e-textiles has been gradually integrated into educational contexts through the creation of learning spaces (Peppler, 2022; Martinez & Stager, 2013). As Halverson and Sheridan point out, "the great promise of the maker movement in education is to democratise access to power discourses, so that users can produce their own artefacts, especially if these artefacts are built with 21st-century technologies" (2014, p. 502). For all these reasons, and considering the benefits that this educational resource represents in terms of scientific and technological training at an early age, it is necessary to do research into its use in education with students aged 6 to 13.

METHOD

In order to answer the research questions, a systematic literature review (SLR) of specific scientific literature (Newman & Gough, 2020) on e-textiles applied to education in the STEAM field was carried out. We used databases specific to social science research, focusing on education (Scopus, ERIC, WoS) and one specialised in computer science (ACM Digital Library), as it is of great interest as one of the reference sources for studies at the intersection of Computer Science and the Social Sciences and Humanities. The guidelines set by the PRISMA (Preferred Reporting Items for Systematic review and Meta-Analysis protocols) statement have been followed (Page et al., 2021).

Systematic literature review

The search strategy began with the selection of keywords in the three conceptual axes that make up the SLR carried out (Table 1).

Table 1

Databases, search equations, and results

Database	Search equations	Number of items found
Scopus	TITLE-ABS-KEY (("e-textiles" OR "electronic textiles" OR lilypad OR wearable*) AND (steam OR stem OR math OR science* OR technolog* OR engineering OR art*) AND ("middle school" OR "K-12" OR "primary education" OR "primary school" OR "elementary school" OR "elementary education" OR "compulsory education")))	139
WoS	TS=(("e-textiles" OR "electronic textiles" OR wearable* OR LilyPad) AND (STEAM OR STEM OR math* OR science* OR technolog* OR engineering OR art*) AND ("K-12" OR "elementary school" OR "elementary education" OR "middle school" OR "primary school" OR "primary education" OR "compulsory education")))	86
ERIC	("e-textiles" OR "electronic textiles" OR lilypad OR wearable*) AND (steam OR stem OR math* OR science* OR technolog* OR engineering OR art*) AND ("middle school" OR "K-12" OR "primary education" OR "primary school" OR "elementary school" OR "elementary education" OR "compulsory education")	36
ACM Digital Library	AND [[All: "e-textiles"] OR [All: "electronic textiles"] OR [All: wearabl*] OR [All: lilypad]]] AND [[All: steam] OR [All: stem] OR [All: math*] OR [All: science*] OR [All: technolog*] OR [All: engineering] OR [All: art*]]] AND [[All: "compulsory education"] OR [All: "middle school"] OR [All: "primary school"] OR [All: "elementary school"]]]	448

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We used reputable databases which host impact publications in order to ensure that the studies meet the standards of the scientific community, focusing on publications with full-text availability. We considered 2006 as the starting year for the systematic review due to the publication of the paper by Buechley et al. (2006) which refers to the potential of e-textiles in education. The languages of publication included were English and Spanish, two of the majority languages in the Academy.

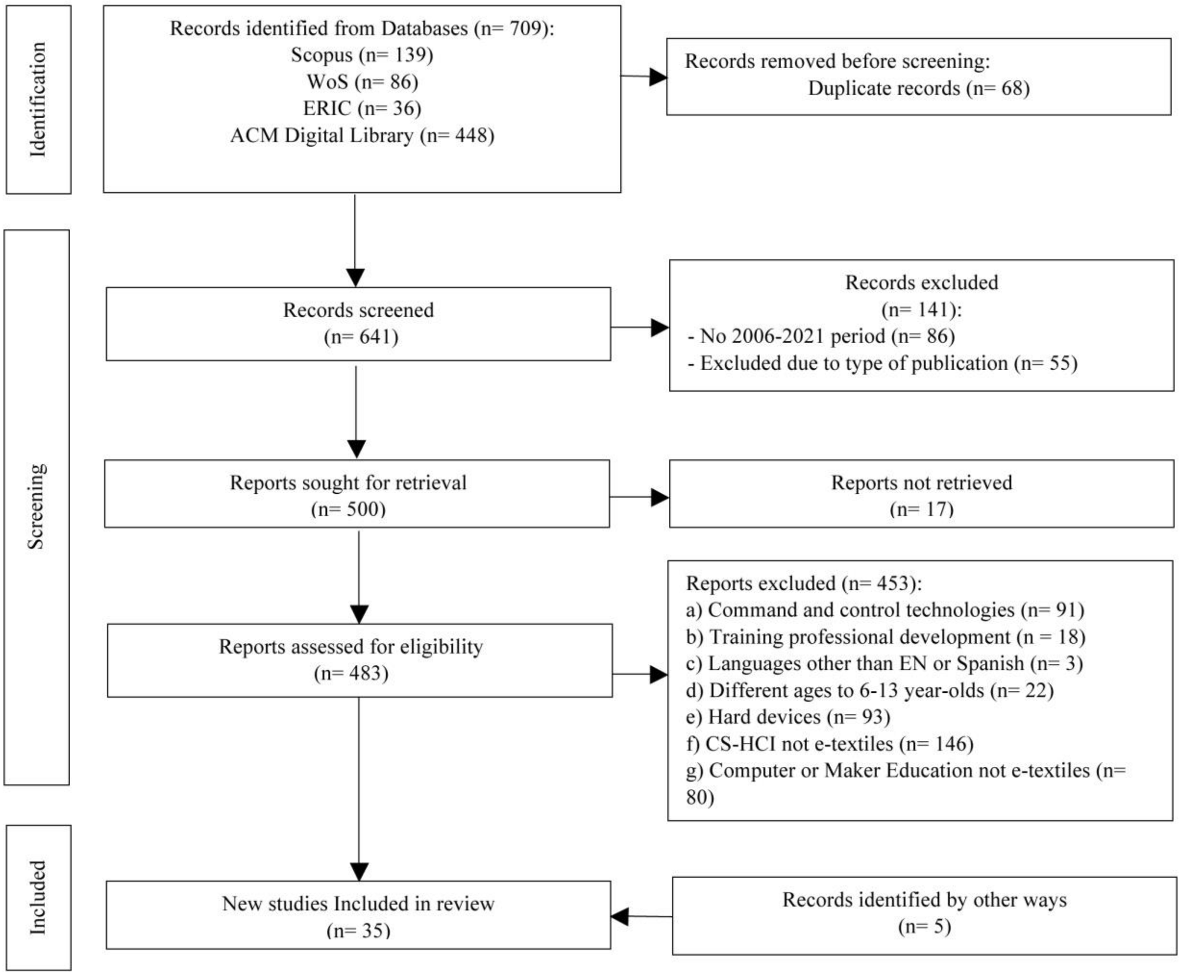
The bibliographic records resulting from the searches of each database were exported to an Excel document. The list of articles was managed on this software, with a tab for the record of each of the databases and a tab with the global list of publications, where duplicates were manually eliminated, resulting in a total of 641 records. The selection process was based on a review of the titles and abstracts of the registered documents. According to the eligibility criteria (Table 2), research in English addressing the use of e-textiles for STEAM learning in our study range was included; articles published outside the established period (2006-2021) were excluded. The full text was then checked for accessibility. At this point 17 papers were excluded (Figure 1).

Table 2
SLR inclusion/exclusion criteria

Inclusion criteria	Exclusion criteria
(a) Published between 2006-2021	(a) Publications in which the term "e-textiles" or "wearable" is mentioned as command and control devices for user monitoring, not as learning media or contexts.
(b) Full text available.	(b) Used in vocational training or continuing professional development (e.g. teacher training).
(c) Papers published in Scopus, WoS, ERIC and ACM databases.	(c) Languages other than English or Spanish.
(d) Journal paper, conference, or book chapter.	(d) Research that does not include 6 to 13 year-olds.
	(e) Studies where the term "wearable" refers to hard devices.
	(f) Studies in the field of Computer Science (CS) - HCI - that do not focus on "e-textiles" or "wearables".
	(g) Studies on computer or maker education that do not focus on "e-textiles" or "wearables".

The papers selected on the basis of the eligibility criteria were screened in the second screening stage, which removed publications where e-textiles are used as command and control technologies (e.g. smart watches, brain readers etc.), research focused on professional development and those related to e-textiles that do not focus on e-textiles. Papers that did not address e-textiles in the learning of students in the stated age range were excluded. In this stage 453 papers were excluded, resulting in 30 publications that meet the previously defined inclusion/exclusion criteria. To these, 5 papers included in a book-compilation of references in the field of e-textiles (Buechley et al., 2013) were incorporated as grey literature, resulting in 35 papers selected for content analysis (Figure 1). The papers found were reviewed by two researchers: the first author reviewed all the results, while the rest of the authors independently reviewed one third of the papers each, subsequently pooling all the assessments of each member of the research team. For those documents that raised doubts among the researchers, the analysis process was repeated.

Figure 1
PRISMA 2020 Flowchart (Haddaway et al., 2022)



Data mining and content analysis

The selected documents were analysed according to the three axes of the study: digital technology (e-textiles as a resource), methodological approach, and educational context, using the critical content analysis method (Newman & Gough, 2020). Firstly, a bibliometric analysis of the scientific production included in the SLR was carried out. This analysis shows the list of authors, their geographical distribution, their year of publication, and the characteristics of research in the field of e-textiles for learning in primary education. In a second stage, the research questions generated a series of categories of analysis, including information on the hardware, software, methodology, project, educational context, and ages involved. Two individual researchers hand-coded all studies in accordance with the categories of analysis. In case of discrepancies between the researchers, coding was established through double analysis by the other researchers.

RESULTS

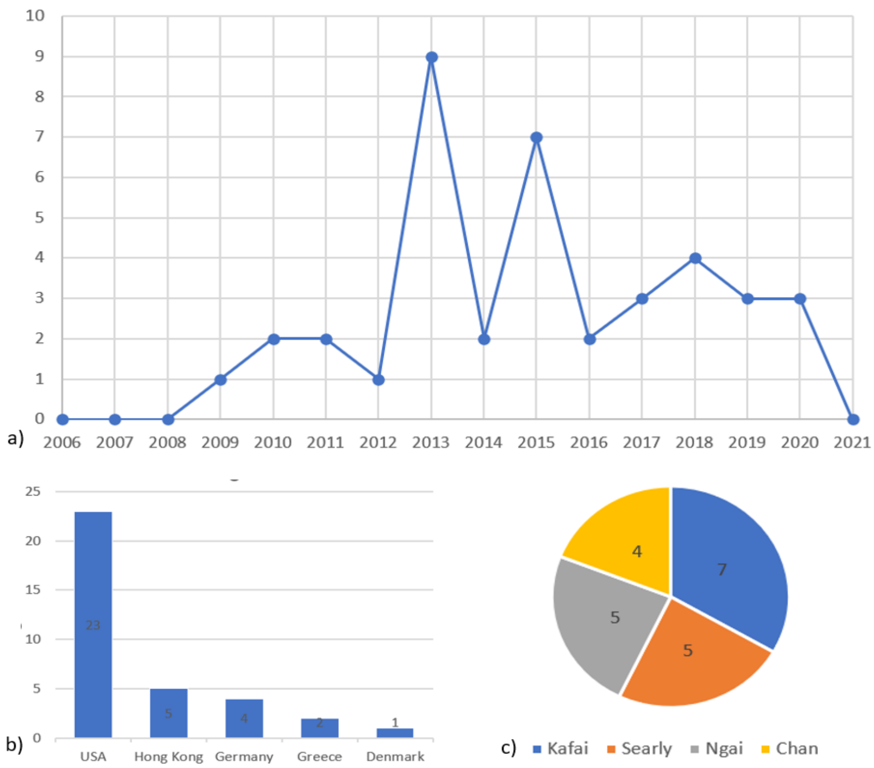
This section presents the results obtained from the in-depth analysis of the 35 documents included in the SLR, organised in terms of the research questions proposed.

Bibliometric analysis

The 35 scientific texts that constitute the sample of studies in the systematic review show that the year 2013 was the time when literature on e-textiles in the field of education first emerged (Figure 2a). The first paper dates from 2009, but it is from 2013 onwards that there is evidence of more regular annual publication on this topic. The data show that the United States is the country with the highest production (Figure 2b), with Kafai, Searle and Ngai being the authors with the highest production (Figure 2c). In terms of authorship, women dominate (55.1%): in 29 of the 35 papers, the main author is a woman, which shows that the subject is an area of growth in which the studies are made up of teams led by women.

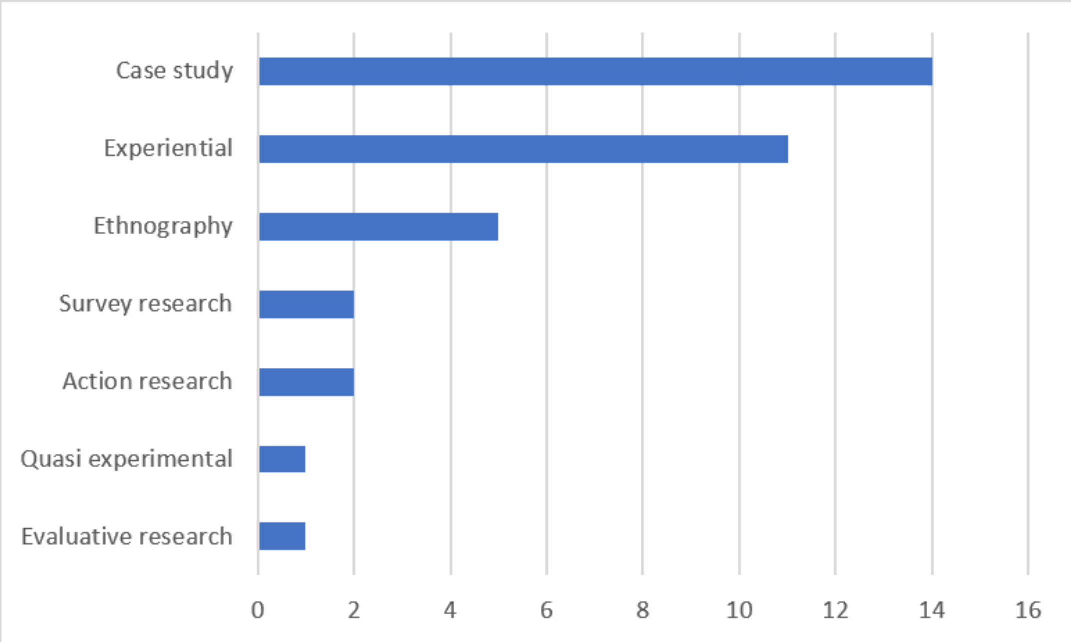
Figure 2

a) Years of publication. b) Countries of reference of the educational projects with e-textiles. c) Main authors



In terms of methodological design, research on e-textiles in education is mainly approached through qualitative designs (61.8%), predominantly through case studies (Figure 3). It is worth noting the high number of experiences shared at conferences.

Figure 3
Methodological design of research production research on e-textiles for learning



STEAM areas and technologies for working with e-textiles in primary education

The SLR shows that 75% of the projects discussed in the publications reviewed were created with an e-textile kit using a programmable board (Table 3). Of these, the LilyPad kit is the preferred kit for experiences in this field (77.8%). Drawing on the cross-referenced data derived from the meta-synthesis, such a kit is presented as an alternative to teaching educational robotics and breaks down gender or ethnic stereotypes around tools and the design of digital artefacts (Jayathirtha & Kafai, 2020). A number of the studies reviewed conclude that it helps to close the gender gap (Buechley 2010; Buechley et al., 2013; Erete et al., 2016; Keshwani et al., 2016; Lau et al., 2009; Nugent et al., 2019; Rigden et al., 2019; Kafai et al., 2014; Searle & Kafai, 2015b; Weibert et al., 2014) and to increase minority representation (Richard et al., 2018; Searle & Kafai, 2015a) in science and technology fields. The studies show that work with e-textiles in primary education favours block programming language, which is present in two thirds of the publications reviewed, especially in the last levels of primary education, mostly involving pupils aged 11 to 13 (Table 3). This result coincides with the majority of the studies reviewed in the meta-synthesis (87%) involving students aged 11 to 18.

Table 3
Ratio of technology used, e-resources and age group

Authors and year of publication	Board	Software	Language	Materials and components electronics	Ages
Ananthanarayan and Boll (2020)	Calliope	calliope.cc	blocks	Actuators and battery	8-9
Ball et al. (2017)	LilyPad	Arduino	blocks	Copper tape, conductive thread, battery, sensors, and actuators	11-18
Buechley (2010)	LilyPad	Arduino	blocks	Conductive thread, battery, sensors, and actuators	11-18
Buechley (2013)	LilyPad	Arduino	blocks	Conductive thread, battery, sensors, and actuators	10-19
Del Valle-Morales et al. (2020)	-	-	-	Conductive fabric and thread, conductive play dough, battery, actuators	10-13
Erete et al. (2016)	-	-	-	Paper prototypes (circuit design)	11-13
Guler and Rule (2013)	-	-	-	Conductor thread, actuators, battery, thermochromic textile, glow-in-the-dark tape	10-13
Kafai et al. (2011)	LilyPad	Arduino	blocks	Fabric and conductive thread, battery, sensors, and actuators	12 & 14
Kafai et al. (2014)	LilyPad	Modkit	blocks	Conductor thread, battery, sensors, and actuators	12-15
Kafai and Vasudevan (2015)	Makey Makey	Scratch	blocks	Conductive fabric and crocodile clips	11-14
Keshwani et al. (2016)	LilyPad	Arduino	blocks	Conductive thread, battery, sensors, and actuators	9-12
Koushik et al. (2017)	LilyPad	Arduino	code	Conductive thread, battery, sensors, and actuators	11-13
Kuznetsov et al. (2011)	LilyPad	Arduino	code	Conductive thread, battery, sensors, and actuators	10-12
Lau et al., (2009)	LilyPad (Teaboard)	Bricklayer	blocks	Conductive fabric, battery, sensors, and actuators	11-16
Lo et al. (2013)	-	i*Chameleon	blocks	Actuators	10
Markvicka et al. (2018)	Arduino Leonardo	Arduino	code	Conductive tape and fabric	12-15
Merkouris et al. (2017)	LilyPad	Modkit	blocks	Conductive thread and battery	11-12

Authors and year of publication	**Board**	**Software**	**Language**	**Materials and components electronics**	**Ages**
Ngai et al. (2009a)	LilyPad (Teeboard)	Bricklayer	blocks	Conductive fabric, battery, sensors, and actuators	10-16
Ngai, Chan, Leong et al. (2013)	Arduino (i*CATch)	i*CATch	blocks and code	Battery, sensors, and actuators	11-16
Ngai, Chan and Ng (2013)	Arduino (i*CATch)	i*CATch	blocks and code	Battery, sensors, and actuators	6-16
Norooz et al. (2015)	LilyPad (Body Vis)	-	-	Interactive T-shirt	4-11
Nugent et al. (2019)	LilyPad/ LilyTiny	Arduino	code	Conductor thread, battery, sensors, and actuators	9-12
Palaigeorgiou et al. (2019)	-	Arduino		El-wires	11-12
Pedersen et al. (2020)	CPX	Make Code	blocks	Conductive thread, battery, sensors, and actuators	10-12
Peppler and Glosson (2013)	LilyPad	Arduino	code	Conductive thread, battery, and actuators	7-12
Peppler and Danish (2013)	LilyPad (BeeSim)	-	-	Interactive pet	6-8
Richard et al. (2018)	LilyPad and Makey Makey	Modkit and Scratch	blocks	Conductive thread, battery, sensors, and actuators	10-13
Rigden et al. (2019)	Flora	Arduino	code	Conductive thread, battery, sensors, and actuators	11-17
Rode et al. (2015)	LilyPad	Ardublock	blocks	Conductive thread, battery, sensors, and actuators	8-10
Searle and Kafai (2015a)	LilyPad	Arduino and Modkit	blocks and code	Conductive thread and fabric, battery, sensors, and actuators	12-14
Searle and Kafai (2015b)	LilyPad	Arduino and Modkit	blocks and code	Conductive thread, battery, sensors, and actuators	12-14
Schelhowe et al. (2013)	LilyPad (Eduwear)	Amici	blocks	Conductive thread, battery, sensors, and actuators	9-15
Trappe (2012)	Arduino	GUI-prototype	blocks	Battery, actuators, and sensors	9-10
Vasudevan et al. (2015)	Makey Makey	Scratch	blocks	Conductive fabric and crocodile clips	11-13
Weibert et al. (2014)	LilyPad	Arduino	blocks	Conductive fabric and thread, battery, actuators, and sensors	8-12

Several studies discuss the potential of other platforms, both commercial and non-commercial, for the creation of e-textiles. Guler and Rule (2013) explore the potential of the Invent-abling kit to build analogue circuits to address gender inequality in STEM learning tools. Ananthanarayan and Boll (2020) conclude that the use of Calliope enables the creation of learning situations that foster the creative process as well as initiation into programming environments. In addition, different authors explore the educational use of plug-and-play kits that do not require sewing. These kits are designed for rapid prototyping of e-textiles and encourage iterative and exploratory learning. Koushik et al. (2017) explore the educational potential of the Snappable Sensors kit that allows for an approach to arithmetic and data analysis. Ngai et al. (2009a) design the i*CATch kit with the aim of enabling students to explore computational concepts in less time and concludes that this kit can be used at a wide range of academic levels. Schelhowe et al. (2013) present the EduWear e-textile construction kit, which proved to enable students to become more confident in dealing with technology as they were able to connect their own creations to the technologies in their environment.

The use of kits that allow the incorporation of flexible and conductive materials with the aim of designing video games and wearable controllers is also highlighted. Kafai and Vasudevan (2015) and Vasudevan et al. (2015) investigate the use of the Makey Makey kit, concluding that it offers new opportunities for learning about computational concepts and develops creative and self-expression skills. Markvicka et al. (2018) examine a low-cost kit created from commercial materials and conclude that it allows students to get started in the field of e-textiles, while offering the opportunity to use their artistic creativity within a technical context. Along these lines, we would also like to highlight the research by Lo et al. (2013), who examine the use of the educational software I*Chameleon as a multimodal interface to create e-textile projects, something that is especially interesting for the age range contemplated in this SLR. E-textiles are also used to create new learning resources - educational resources with which students can interact to promote understanding of complex concepts (Norooz et al., 2015; Peppler & Danish, 2013).

To conclude this section, we consider it necessary to look at the challenges of the 21st century, which are connected to the challenges that students in our age range will face. The studies analysed show that working with e-textiles using block programming language, applying principles of engineering, circuits, and design, enhances the skills aspects of learning. STEAM subjects facilitate commitment between situations of equity, critical and responsible use of digital culture, and the appreciation of cultural diversity through the creative processes inherent in e-textiles.

Methodological approaches to integrating e-textiles in primary education

The studies reviewed show three approaches to the educational methodology used in the teaching and learning process with e-textiles (Table 4). Firstly, there are publications describing innovative experiences that awaken students' interests in scientific and technological subjects or workshops focused on following the step-by-step instructions or guides typical of *Do it Yourself* learning, where the result is projects that are all the same or similar because they are customised by the members of these courses (44%). This is the majority trend.

In some cases, worksheet templates are encouraged (Searle & Kafai, 2015a, 2015b) to motivate and initiate students and get them interested in carrying out personally relevant projects. Then there are options that use active methodologies (36%). Finally, there are works at an intermediate point of the continuum, which use a mixed methodology. In these, there is a first stage of an activity, with step-by-step instructions, prototypes, models, tutorials, and templates that guide the process. In some cases, even prefabricated modules are provided (Ngai et al, 2009a; Ngai, Chan, Leong et al., 2013; Ngai, Chan & Ng, 2013). Then, in a second training stage, they offer spaces for the free creation and customisation of artefacts.

Table 4

Methodological approaches to projects involving e-textiles

Educational methodology		Publications
Guided learning	Instructions. Exercises	Ball et al. (2017); Nugent et al. (2019); Richard et al. (2018); Rode et al. (2015); Weibert et al. (2014)
	Step-by-step guide	Del Valle-Morales et al. (2020); Erete et al. (2016); Markvicka et al. (2018); Pedersen et al. (2020); Peppler and Glosson (2013); Searle and Kafai (2015a); Searle and Kafai (2015b)
Mixed	Instructions and own creation	Guler and Rule (2013); Kuznetsov et al. (2011); Lau et al. (2009); Ngai et al. (2009a); Ngai et al. (2009b); Ngai, Chan, Leong et al. (2013); Ngai, Chan and Ng (2013)
Active methodologies	Design-Based Learning	Buechley et al. (2013); Buechley (2010); Schelhowe et al. (2013); Kafai et al. (2011); Kafai et al. (2014); Kafai and Vasudevann (2015); Vasudevan et al. (2015)
	Discovery learning	Ananthanarayan and Boll (2020); Lo et al. (2013); Trappe (2012)

Looking at the artefacts built by the students in terms of the methodological approach, most of the creations based on guided projects focused on luminous bracelets (Ball et al., 2017; Del Valle-Morales et al., 2020; Erete et al., 2016; Nugent et al., 2019; Peppler & Glosson, 2013) and interactive soft toys (Kuznetsov et al., 2011; Pedersen et al., 2020; Rode et al., 2015; Weibert et al., 2014). By contrast, projects based on active methodologies were more diverse, including mainly textile video game controllers (Kafai & Vasudevan, 2015; Lo et al., 2013; Vasudevan et al., 2015) and multiple designs of sensor, musical, and light wearables (Ananthanarayan & Boll, 2020; Buechley, 2013; Kafai et al., 2014; Schelhowe et al., 2013; Trappe, 2012).

Educational context in which e-textiles learning is approached in primary education

The results show a variety of educational ecosystems (Table 5), with non-formal education being the most recurrent in the projects analysed (71.4%). We found a large number of non-formal education studies that, despite being intentional and planned, were carried out outside the scope of compulsory schooling. After-school activities and computer clubs (44%) as well as workshops (40%) were the main contexts for non-formal educational spaces that address e-textiles with students aged 6 to 13.

If we analyse the selected papers that refer to a formal setting, there are different perspectives for their inclusion in schools. Some propose adapting e-textiles to US educational standards (Ball et al., 2017), as they support meaningful learning and facilitate the understanding of complex and abstract science concepts. Others are committed to including them within optional subjects or history and culture subjects, in a transdisciplinary way, to encourage the inclusion and participation of minorities who are less engaged with computer science. This interdisciplinary approach helps to foster a more holistic view of the world around them (Kafai et al., 2014; Nugent et al., 2019; Rigden et al., 2019; Searle & Kafai, 2015a, 2015b). Along these lines, Rigden et al. (2019) with the Femineer ™ program, and Nugent et al. (2019) with the Nebraska WearTec program, propose e-textiles as teaching resources that serve as an alternative or supplement to educational robotics with the goal of inspiring and empowering learners, and in particular girls and minorities, to pursue STEM careers.

Table 5

Learning context of e-textile practices

Education	Context	Research
Non-formal	After-school classes/ Computer Club	Ananthanarayan and Boll (2020); Erete et al. (2016); Merkouris et al. (2017); Palaigeorgiou et al. (2019); Richard et al. (2018); Trappe (2012); Pedersen et al. (2020); Rode et al. (2015); Peppler and Glosson (2013); Weibert et al. (2014)
	Workshop	Buechley (2010); Buechley (2013); Kafai et al. (2011); Kafai et al. (2014); Koushik et al. (2017); Kuznetsov et al. (2011); Markvicka et al. (2018); Ngai, Chan, Leong et al. (2013); Ngai, Chan and Ng (2013); Norooz et al. (2015); Schelhowe et al. (2013)
	Museum/Art Gallery	Guler and Rule (2013)
	Makerspace	Del Valle-Morales et al. (2020)
	Summer camp/ Course	Lau et al. (2009); Ngai et al. (2009a)
Formal	Classroom	Ball et al. (2017); Kafai and Vasudevan (2015); Peppler and Danish (2013); Rigden et al. (2019); Searle and Kafai (2015a); Searle and Kafai (2015b); Vasudevan et al. (2015)
Formal and Non-formal	Classroom/Workshop	Kafai et al. (2014)
	Classroom / After-school	Nugent et al. (2019)

DISCUSSION AND CONCLUSIONS

This document provides specific information on the work carried out with students aged 6 to 13 years that uses e-textiles as an action element in activities that seek to cultivate STEAM knowledge, skills, and abilities. The study shows that practices with e-textiles for primary education have been most prevalent in the United States (63.9%), where the maker movement and the concept of STEAM education emerged. The results show that e-textile practices have been integrated into the educational environment, in formal contexts, but particularly in non-formal contexts. As Halverson and Sheridan (2014) point out, this has great potential and opens up new opportunities for educational research. Publications on the subject warn that the diversity of learners, especially in terms of gender and ethnicity, should be taken into account, and accessible alternatives have been incorporated, both in economic and ethical terms, favouring open source technology.

To answer the first research question (Which STEAM areas are worked on through e-textiles and with which technologies?), the results of the review show that they have been used effectively across all STEAM areas, as the creation of these projects involves all disciplines of computer science, engineering, and the arts. In most studies, students explore the three interconnected fields of coding, production, and circuitry. As in educational robotics, this is beneficial for the development of computational thinking (Rich et al., 2022). In any case, e-textiles provide particularly compelling examples of transparent and high-quality learning tools, as they make technology visible to learners (Kafai & Peppler, 2014). The analysis of the selected publications shows that all STEAM areas are worked on, with the LilyPad kit being the preferred tool for experiences in this field (77.8%). In this regard, the importance of this kit has also been demonstrated in the field of fine arts, where there are also promising studies that show that it is a tool that allows artists and designers to explore new forms of artistic expression through the fusion of art and technology (Peppler et al., 2013).

With regard to the second research question, which focuses on the methodological approaches used to integrate e-textiles in primary education, studies using guided learning predominate. The aim of the studies analysed focuses mainly on students designing and building, through instruction and/or discovery, a textile project in which they include a circuit, sometimes programming it, and making it work. One of the most challenging aspects of teaching computation is the interaction of the multiplicity of elements that interconnect to make a system work. This points to the need to implement the design of new strategies and to promote the ongoing training of teachers, both pedagogically and technologically in its instrumental and methodological dimension, from skills-based approaches that allow the integration of e-textiles in primary education classrooms through the promotion of student participation and learning by doing (Valente & Blikstein, 2019). In this regard, it should be noted that the predominant learning situation, while relying on the use of guides, allows for the use of unusual and unfamiliar materials and resources, such as wires, encouraging tinkering (Timotheou & Ioannou, 2019). All this ensures that the innovative activity takes place in a motivating and playful environment where collaboration, trial-and-error learning, creativity, and artistic expression are encouraged. In the words of Resnick and Rosenbaum (2013), the mere fact of the transparency offered by e-textiles and working with this type of material allows students to "see the process" and "see the result" of their work, receiving "immediate feedback" on what they are doing, which facilitates meaningful learning.

To answer the third research question (In which contexts does e-textile take place?), the results show that non-formal learning environments predominate. These results can be justified by arguing that the learning process that takes place when making an e-textile focuses on the process of creating, designing, and building physical electronic or programmable objects, and this goes beyond the learning process offered by the most widespread model of teaching (Halverson & Sheridan, 2014). However, studies that do address the formal context show encouraging results for the use of e-textiles as a teaching resource with the aim of fostering integrated competence education, the development of skills in curricular areas, and the promotion of inclusive and equitable STEAM education.

In short, the results of the systematic review show that the field of e-textiles is a promising area for STEAM-integrated teaching and offers new directions in teaching with educational technology from a competence and integrative approach. Faced with the need for scientific training at early ages, we consider this domain as a promising line of research, but we find limitations arising from the small number of countries that have implemented these educational approaches and research. Another aspect to highlight is that although the trend in the field of research and experimentation with e-textiles emphasises the potential of these resources to work on STEAM within the formal setting, there is limited scientific literature, to date, in this respect. It should also be pointed out that the field of e-textiles became open to education only relatively recently. Finally, we conclude the investigation by considering that the scientific community would benefit from studies focusing on issues related to the gender perspective and equity with e-textiles within this age range.

NOTES

1. To incorporate all the research carried out in the English-speaking world, we included students between the ages of 6 and 13 (Primary and Middle School).

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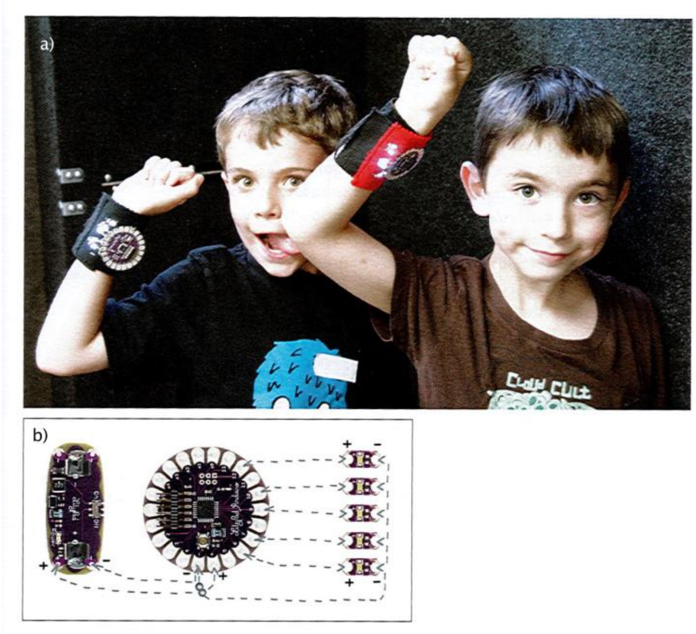
APPENDIX

Figure 1

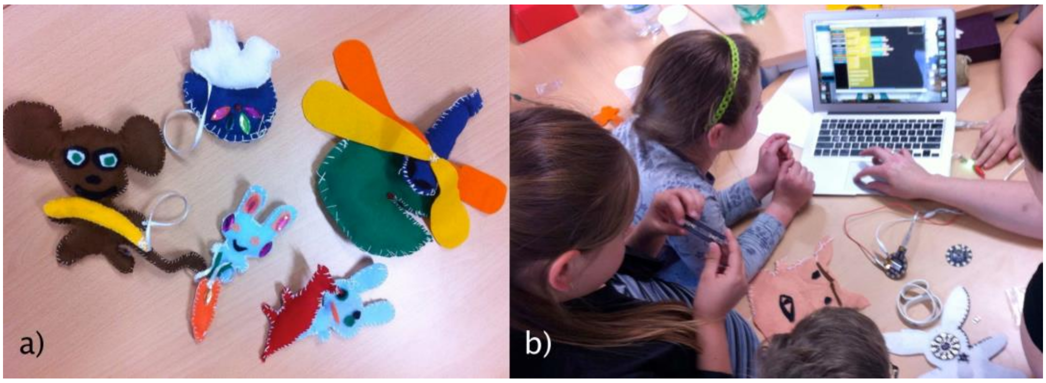
a) Light-up bracelets created with the LilyPad kit. b) Connection diagram that shows the different components of the circuit and indicates how to connect them with the conductive thread



This image shows two students showing off their glow bracelet with the Persistence of Vision (POV) effect created with the LilyPad kit. By carrying out this project they learned basic concepts of circuit theory such as polarity, voltage, and the difference between connecting a circuit in parallel and in series.

Note: Taken from the book *Textile Messages: Dispatches From the World of E-Textiles and Education*. (p.77), by Buechley et al., 2013. Peter Lang Publishing.

Figure 2
a) Examples of e-textiles projects b) Students collaborating and programming their e-textiles projects



The image on the left shows several e-textile projects, all of them created with the Bright Bunny kit, and on the right, several students collaborating and programming their projects in blocks.

Note: Taken from the article *From computational thinking to computational making*. (p.242 and p.243), Rode et al., 2015.

Figure 3
Interactive t-shirt created using the LilyPad kit

This image shows a t-shirt that enables the teacher to help the student visualise and understand body data that helps them learn about the human body.

Note: Taken from the article *BodyVis: A new approach to body learning through wearable sensing and visualization*. (p. 6), by Norooz et al., 2015.

Figure 4

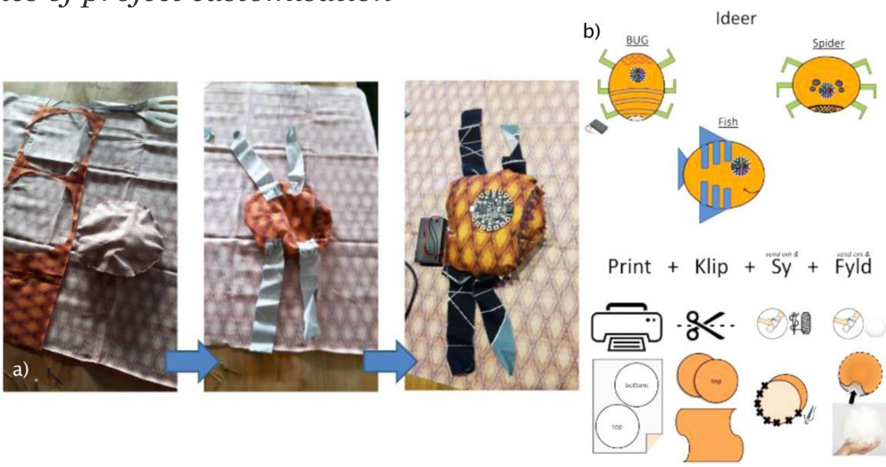
*Interactive t-shirt created with the low-cost pre-made i*CATch kit*

This image shows an e-textiles project created with a kit that offers a plug-and-play system designed to introduce students to computational concepts in a friendly way.

Note: Taken from the article *Designing i* CATch: A multipurpose, education-friendly construction kit for physical and wearable computing*. (p.10), by Ngai et al., 2013.

Figure 5

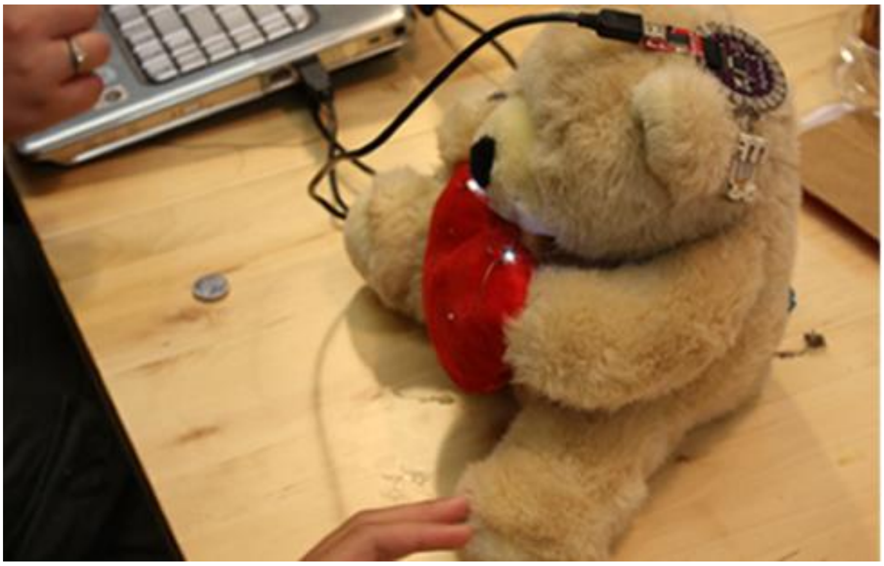
a) Step-by-step documentation for creating an interactive textile pet b) *DIY tutorial and examples of project customisation*



This image shows step-by-step images and the guide used by boys and girls to learn how to build and customize their e-textiles project

Note: Taken from the article *Fabric robotics-lessons learned introducing soft robotics in a computational thinking course for children*. (p.9), by Pedersen et al., 2020.

Figure 6
Light-up Teddy Bear created with the LilyPad kit



This image shows a light-up teddy bear in which the student has sewn a circuit using conductors and programmed several LEDs with the goal of creating a personally meaningful project.

Note: Taken from the article *Breaking boundaries: strategies for mentoring through textile computing workshops*. (p.2962), by Kuznetsov et al., 2011.

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