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Technological management for teacher improvement in education 4.0: a review of emerging technologies and digital skills

Gestión tecnológica para el perfeccionamiento docente en la educación 4.0: una revisión de tecnologías emergentes y competencias digitales

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Abstract: This research is situated at the intersection of management and education and analyzes the role of technology management in teacher professional development within the framework of Education 4.0. Its purpose is to conduct a literature review of technology management for teacher professional development. It begins by highlighting the integration of technology management, which has become a fundamental foundation for educational quality and pedagogical innovation within Education 4.0. It highlights the teacher's role as a mentor, guide, and facilitator who must be proficient in digital technology tools such as blockchain, data analytics, generative artificial intelligence, and extended reality (XR), among others, which aim to improve academic planning and the personalization of learning. Furthermore, for teacher professional development, models such as Universal Design for Learning (UDL) and TPACK (Technological Pedagogical Content Knowledge) are used, focusing on pedagogical intent and the pursuit of inclusion in the classroom. The methodology employed was a literature review conducted between January and May 2026 through searches in Scopus, ScienceDirect, and Web of Science. Combinations of terms related to "artificial intelligence," "Education 4.0," "teacher professional development," "technology management," "digital competence," and "TPACK" were used. Publications from 2020 to 2026 were considered, specifically peer-reviewed articles in Spanish and English that were directly related to technology management applied to teacher professional development. After eliminating duplicates and reviewing the titles, abstracts, and text of the articles, the studies most relevant to the topics of interest were selected for subsequent qualitative analysis.

Keywords: education 4.0, generative artificial intelligence, TPACK, digital teaching competence, educational management, pedagogical innovation.

Resumen: Esta investigación se ubica en la intersección entre gestión y educación, analiza el papel de la gestión tecnológica en el perfeccionamiento docente dentro del marco de la Educación 4.0. Tiene como propósito de hacer una revisión de la literatura de la gestión tecnológica para el perfeccionamiento docente. Inicialmente da a conocer la integración de la gestión tecnológica, que se ha convertido en una base fundamental para la calidad educativa y la innovación pedagógica que se encuentra dentro de la Educación 4.0. Se denota el papel del profesor como un mentor, orientador y facilitador el cual debe estar preparado en herramientas de tecnologías digitales tales como: el blockchain, la analítica de datos la inteligencia artificial generativa, la realidad extendida (XR); entre otras que buscan una mejor planeación académica y personalización del aprendizaje. Por otro lado, para el perfeccionamiento docente se utilizan modelos como el diseño universal para el aprendizaje (DUA) y TPACK (conocimiento tecnológico pedagógico del contenido) enfocados en la intencionalidad pedagógica y búsqueda de la inclusión en el aula. La metodología que se empleó fue de una revisión bibliográfica en el periodo entre enero y mayo de 2026 por medio de consultas en Scopus, ScienceDirect y Web of Science. Se utilizaron combinaciones de términos afines con 'artificial intelligence', 'Education 4.0', 'teacher professional development', 'technology management', 'digital competence', y 'TPACK'. Se tuvieron en cuenta publicaciones entre 2020 y 2026, con documentos directamente relacionados con la gestión tecnológica aplicada al perfeccionamiento docente artículos y revisados por pares en español e inglés. Después de eliminar duplicados, revisar títulos, resúmenes y el texto de los artículos, se seleccionaron las investigaciones con mayor pertinencia de los temas de interés para posteriormente realizar el análisis cualitativo.

Palabras clave: educación 4.0, inteligencia artificial generativa, TPACK, competencia digital docente, gestión educacional, innovación pedagógica.

1. INTRODUCTION

Education 4.0 began as a direct consequence of the fourth industrial revolution characterized by the fusion of digital, physical, and biological systems with automation [1]. Digital competence is currently recognised as a key component in teaching and learning processes [2]. In this way, the term Education 4.0 not only involves the use of technological tools, but also requires teachers to take ownership of planning, teaching, and evaluation processes in education [2], [3]. This is where technology plays a fundamental role for teachers to support themselves because they must respond to a more informed community that uses digital platforms for the construction of knowledge [3].

The management of technology in education has become an essential basis for quality in education and innovation in pedagogy [4]. The integration of technology is not limited to the use of digital tools, but involves articulating it with the needs of students and learning objectives [5]. In addition, technological management goes beyond acquiring tools, it has to be strategically articulated with learning objectives to achieve educational quality [6], [7]. Therefore, quality is achieved through a continuous institutional effort to fulfil both teaching and research functions in digitalised environments [8].

Within the latest trends in technology management, the execution of adaptive teaching is based on technology. This methodology uses formative assessment as a pillar to track student progress and make changes in real time [9]. In order for management to be more profitable, it must be directed in two stages: the first is macro adaptations, which are activities that are projected with preliminary knowledge on the part of the students; and secondly, micro-adaptations that provide personalized support through intelligent tutoring system technologies [9].

It has been proven that the effectiveness of these systems in various areas materializes when there is a good adaptation in the process of imparting knowledge to students [9]. But the management of these tools requires the teacher to be digitally literate and have the ability to relate technological tools to a certain content [10].

The emergence of generative artificial intelligence has reconfigured technological management in educational contexts by expanding the possibilities of content creation, personalization of learning, and support for teacher planning. With the introduction of Generative Artificial Intelligence, a new way of evaluating technology management in the faculty has been achieved. The use of ChatGPT for content creation allows a better way to experience learning, which with personalization projects generates autonomy in students, aligning professional aspirations with current challenges [11].

With the approach of teacher management, Generative Artificial Intelligence changes the role of the teacher from an emitter of knowledge to a counselor and facilitator of teaching-learning, in addition to being an ethical mentor [12]. Therefore, Artificial Intelligence (AI) must be handled in a technical way, observing the human side; that is, not to be biased by the use of AI alone, but to resort to critical thinking with their students [13]. The autonomy of the student would guarantee the success of their learning, and the role of the teacher is to guide the appropriate use of technologies [12].

Technology management also encompasses the architecture of the systems that support teaching. The use of cloud platforms for the management of educational information results in faster and more accurate administration compared to the manual process [12]. To perfect the systems, data mining techniques and Q-learning algorithms are used, which help predict learning behaviors and systematize the allocation of resources in search of improving institutional processes [13]. In particular, data mining facilitates the discovery of patterns related to academic performance, predicting risks and optimizing curricula.

In these times, transparency and data security are very important within management. For example, blockchain is a technology that stores data and has a decentralized architecture that provides privacy security for users and protects academic records through intertwined blocks of data [14]. It also offers disruptive potential through the creation of unalterable and decentralized registries, such as smart contracts that allow the self-execution of agreements without intermediaries, streamlining academic and administrative certification processes [15].

As mentioned above, technology management has many strengths, but it presents some barriers, especially in emerging economies, where there is a digital divide and resources are scarce, limiting education [16]. Therefore, the way to approach this technology in these scenarios will depend on the type of subject or area of knowledge and the experience of the teacher [16].

Finally, it is glimpsed that the management of technology in teacher teaching must have a character of intentionality and reflection. It is not only a matter of incorporating innovation, it is also important to use specific pedagogical functions, such as the Community of Inquiry or the LoGeT (location-generalization-transfer) model, which ensure that technology acts as a structure that seeks human well-being and the development of training competencies [17].

2. TECHNOLOGICAL MANAGEMENT FOR TEACHING IMPROVEMENT IN TECHNOLOGIES

Teacher training is the basis for the effective use of ICTs. The teacher is a creator of innovative curriculum proposals and not a simple transmitter of information. That is why you must use data analytics to perform searches and deep analysis with its subsequent interpretation for both students and teachers [18]. For data analysis to be effective, it is imperative to pre-process data with a particular domain focus and ensure the consistency and quality of information from diverse heterogeneous sources [19].

Teacher improvement is also the pillar of technological transformation where the role of the teacher has to evolve from being a transmitter of information to a mediator of learning; in addition, to integrate technologies with ethical and pedagogical criteria [6]. This implies developing competencies to adapt to global needs in a school environment [7].

The theoretical foundation that guides teacher improvement is developed by the TPACK model (pedagogical technological knowledge of content) that focuses on the integration with results of technology and that requires an articulation between digital tools, pedagogy and content management [20]. Lately, research suggests that this model has changed to more detailed variants such as AI-TPACK that trains teachers to change pedagogical models using Artificial Intelligence to facilitate the tasks and methodologies to be used [21]. When seeking teacher training, it should focus on practical methods and reflection to avoid theoretical training,

instead seeking to represent reality in classrooms that use technology [22].

It is also important to use immersive technology such as Virtual Reality (VR), it is a tool that allows the training of teachers. VR enables real-life scenarios and inclusive classroom management for children with autism by making environments safe and controlled [3]. With this, it is intended to bring classroom practice and academic theory closer together, helping the transfer of knowledge in a more effective way [23].

Likewise, the integration of methodologies such as Universal Design for Learning (UDL), which is based on neuroscience, must be flexible in the pace and style of learning when making use of digital tools to improve teacher improvement in search of educational equity and inclusion [24]. UDL is also essential to ensure that the technology is affordable and not a barrier. Currently, some people with functional diversity can take advantage of adapted devices and access assistive technologies [24]. In the same way, the promotion of computational thinking in childhood can establish a new digital literacy to be able to successfully handle technology 4.0 [25].

It has been observed that there are many advances in teacher improvement that is established as a cornerstone of the transformation. The role of the teacher evolves from being a transmitter of information to a mediator of learning capable of integrating technologies with pedagogical and ethical criteria. There are cases where teachers use technological knowledge but to a lesser extent pedagogical and disciplinary integration, which results in a superficial adoption of educational technology [26]. In addition, obstacles such as the digital divide, resistance to change in older teachers and lack of technical infrastructure are related [23]. Therefore, in order to achieve teacher improvement, continuous technical training, a culture or habits of innovation in institutions and support from educational entities are required [27].

It can be concluded that the learning process supported by the application of technologies constitutes a great contribution to the development of education and in turn it is necessary for the teacher to have new competencies in his or her role as a counselor [28]. Emerging technologies along with artificial intelligence could never replace the teacher; on the contrary, it becomes a strategic ally because it manages to improve the teaching-learning process [28]. Consequently, teacher improvement in the use of technology becomes a long-term learning process and it is appreciated that technology is a means to achieve equitable and integral development [29].

3. EMERGING TECHNOLOGIES FOR EDUCATION 4.0

As has been stated, technological integration is not restricted to the use of tools, but allows for a broad restructuring of pedagogical models that are directed towards Education 4.0 [1].

Below are the main thinking approaches derived from the sources:

- Artificial Intelligence (AI) and Learning Personalization

Artificial Intelligence allows us to transcend a paradigm that provides homogeneity in education and that has transformed the new realities of teaching. It also facilitates the design of new learning experiences due to its ability to analyze large volumes of data to generate different interests and specific learning rhythms in each individual [30]. This helps to be able to detect early the various difficulties in the teaching-learning process and generate rapid feedback; in addition, the realization of intelligent tutorials [29]. On the other hand, it allows enriching the pedagogical ecosystem by generating content and educational material such as chatbots, texts and audiovisual resources [3].

With Learning, Knowledge Technologies (TAC) and Artificial Intelligence, the automation of administrative tasks has been achieved, reducing the workload by 40%; in addition, it involves the personalization of the teaching-learning process [23]. It is important that in this highly advanced model of education, there is responsibility and ethics in the use of AI, because there is a risk of dehumanization of pedagogy [28]. Therefore, teacher improvement with the use of technologies must involve literacy not only of data but also of ethics. Therefore, teachers must be collaborators and facilitators when using AI, deploying creativity and humanization in school environments [23].

- Extended reality (XR) and immersive technologies

Augmented Reality (AR, Mixed Reality (MR) and Virtual Reality (VR) technologies favor the redefinition of the teaching-learning process

because they resort to science and technology, facilitating understanding, visualization of complex definitions and three-dimensional spatial perception [30], it is also used in the repetitive and safe practice of fields such as architecture and engineering, allowing simulations of practical activities before their actual execution. reducing the gap between theory and professional practice [31]. Additionally, they have a motivational impact because they act as a stimulus for the student, significantly improving their attention, motivation, and attitudes towards areas such as science and mathematics [32].

- Synergy of active methodologies and technology

It functions as alternatives and strategies for teacher improvement that manages to integrate methodological frameworks for the appropriate use of technologies. Among these are: Project-based learning (PBL), which is positioned as a highly effective strategy to develop pedagogical digital competence in future teachers, allowing them to internalize technological tools through authentic and collaborative tasks [33]. STEM (science, technology, engineering and maths) is used in educational management, which is the use of technologies such as digital twins or the creation of laser prototypes, with this type of STEM projects critical thinking and real-world problem solving are encouraged [34].

- Digital Competencies for Teacher Improvement

The teacher becomes a facilitator and mediator of learning in digital and hybrid environments and not as a transmitter of information [3]; Here it can be seen that this teacher must have continuous training, bridging the gap between pedagogical digital competence and familiarity with everyday applications [32]. In the same sense, it generates other ways of evaluating with specific and automated methodologies in order to observe and analyze the dissertation in the classes, achieving a more reliable and accurate feedback of their own exercise [35].

- Infrastructure and ethics

Although there are many advantages to the use of different technologies, there are also barriers and in a certain sense they are structural such as: Infrastructure, when there is limited access to devices, the internet connection is not stable and there are high costs due to the use of technologies, which increases the gaps in education [31], [36]. On the other hand, humanization and ethics, where human interaction must be had in the teaching-learning processes and also ethical regulations must be determined so that there are guarantees of data privacy [3].

4. DIGITAL TRANSFORMATION TECHNOLOGIES

Digital technologies applied in teaching seek the modernization of educational institutions through transformation towards digital and that in the end translates into continuous improvement of the educational process. The COVID-19 pandemic event quickly and significantly boosted the development of new technologies such as video learning, virtual environments, and artificial intelligence [36] where teachers had to learn new and better digital skills. One of them is the Teaching Digital Competence (CDD**),** which involves the ability to select and integrate technology into different pedagogical aspects and the technical knowledge of the tools in the design of curricula [30]. Here are some digital transformation tools:

4.1. Digital competence and integration models:

- The **Digital Teaching Agency** is the teacher's ability to reflect, act and transform with good judgment in order to empower teachers and students in the development of the learning process through the use of technology [30]. There is also the aforementioned TPACK

4.2. Emerging technologies and their application:

- **Big data and learning analytics:** It analyzes student behavior in real time, allows personalization, development of teaching methods and has information on low performance or possible dropout of students [32]. As already mentioned, there is also the use of AI as an educational assistant.

- **Learning Analytics:** The use of algorithms such as *Random Forest* allows massive data to be analyzed to predict student performance and the risk of dropout, facilitating early warning systems [3].

- **Immersive environments (VR/AR/3D):** Virtual worlds and augmented reality make it possible to transform pedagogical practices, offering interactive experiences that can overcome spatial barriers and foster deep learning [33]. There

is also extended reality (XR), which has already been exposed.

- **Educational robotics and programming:** Robotics is used as an educational practice where robots are designed, built and programmed, this allows the development of computational thinking that can be used for any discipline, especially in STEM areas [37].

It is important to achieve the integration of emerging technologies because it generates an impact of intervention of robotics and visual programming by blocks; in addition, it has fundamental concepts of machine learning (ML) in which teachers must be trained and it is also used for initial education (primary grades) [38].

In education, Machine Learning is an essential tool for personalizing learning and making strategic decisions [1]. With the above, it is necessary to integrate AI capabilities, decision-making using algorithms, and computational thinking in education processes [38]. Implementing these tools allows participants to acquire basic computational concepts such as sequences, loops, and conditionals, as well as understand the machine learning workflow (data preparation, model training, and interpretation) [37].

Table 1 shows in a comparative way the emerging technologies, models of technological integration, digital competencies or main findings reported in the literature.

Table 1: *Comparison of emerging technologies, integration models and digital competences in Education 4.0*

Technology / Model	Application in teacher training	Digital skills required	Main findings reported in the literature
Generative Artificial Intelligence (ChatGPT,)	Lesson planning, material design, automatic feedback, and personalization of learning	Critical Thinking AI Literacy, Digital Ethics, and AI-Generated Content Evaluation	It increases teacher productivity and facilitates the personalization of learning; it needs supervision to avoid bias and technological dependence.
Learning Analytics	Early identification of dropout risk, monitoring of student performance and decision support	Statistical analysis, data interpretation and information management	It allows pedagogical decision-making, timely interventions, and improves educational management through evidence.
Educational Date	Massive management of institutional and academic information	Digital literacy, information analysis and data management	It helps in the prediction of academic performance and the continuous improvement of institutional processes.
Extended Reality (XR: VR, AR and MR)	Practical training, development of skills and simulation of scenarios.	Design of digital experiences and management of immersive environments	Increases understanding of the conceptualization, motivation, and transfer of learning
Blockchain	Document management, academic certification, and protection of educational records	Information Management, Digital Citizenship, and Digital Security	Increases transparency, traceability and information security through unalterable records.
Machine Learning and Educational Robotics	Computational thinking and programming development	Basic programming, computational thinking, and problem-solving	It helps to acquire STEM skills and reinforces the understanding of algorithms and AI at an early age.
TPACK	Balanced integration between pedagogy, technology and disciplinary content,	Pedagogical, disciplinary and technological competence.	It is the model that is most used to guide the effective integration of technologies in instruction
AI-TPACK	Integration of AI tools within disciplinary and pedagogical knowledge.	Instructional design and critical evaluation with the responsible use of AI,	Develop the TPACK model by bringing together specific skills for the educational use of AI.
Universal Design for Learning (UDL)	Designing inclusive experiences through digital technologies	Accessibility, curricular adaptation and digital inclusion.	It allows multiple forms of representation, participation and evaluation, favoring educational equity.
Digital Teaching Competence (CDD)	Ongoing professional development of teachers	Content creation, digital literacy, collaboration, security, and problem-solving	Digital competence is the main factor in generating sustainable and effective technological integration in Education 4.0.

Source: *Authors' elaboration based on the literature*

5. CHALLENGES AND BARRIERS IDENTIFIED

- Digital, economic, and skills gaps persist that hinder the equitable implementation of these technologies [39].
- There is resistance to change on the part of some educators and a lack of adequate infrastructure in certain regions, underscoring the need for continuous and specialized teacher training [39].
- There is a risk of techno-anxiety and information overload (infoxication) if technology is not adopted progressively and with a clear pedagogical intention [39].

6. CONCLUSIONS

The analysis that was carried out on the literature shows that the management of technology in education 4.0 goes beyond having a physical or digital infrastructure, but that there must be a strategic alignment with the pedagogical model of the institutions so that it allows a positive impact on the quality of education. Its main contribution is that with the use of emerging technologies, it can strengthen the teaching and learning processes in such a way that the educational transformation does not depend at all on new technological tools but that the institutional vision is prioritized, and that this can be articulated with the pedagogical objectives, to later incorporate the development of teachers' digital competencies. innovation and thus seek continuous improvement of quality in education.

On the other hand, alignment can lead to the creation of more inclusive, flexible, and student-centered learning contexts; it can also promote a culture of innovation based on critical reflection, evidence-based decision-making, and adaptation to the demands of an increasingly digitized society. Therefore, technology management must be understood as a strategic process of organizational transformation that requires institutional leadership, continuous teacher training, and policies that are aimed at guaranteeing an ethical, reflective, sustainable, and effective integration of technology in education.

Generative Artificial Intelligence, Extended Reality and Blockchain are dynamizers that can simulate training practices, personalize learning, and strengthen administrative transparency. However, its effectiveness lies in the continuous teaching improvement under epistemological frameworks such as TPACK and DUA, which allow transforming the role of the educator from being a passive sender to an ethical guide and mediator in school environments. However, the evidence found allows us to infer that the incidence of these technologies does not depend exclusively on the availability of digital infrastructure or sophistication, but on the capacity of educational institutions to integrate them with the pedagogical project that is coherent and oriented towards meaningful learning. In this regard, the risk of assuming technological innovation as an end could generate simplistic digitalization processes without achieving substantial transformations in teaching.

Continuous teacher development is the main factor that determines the value of emerging technologies education. Teacher training must evolve from the use of digital tools as an instrument to favor the development of competencies that allow adapting, selecting, and critically evaluating technological resources based on curricular objectives, student characteristics, and context. Likewise, the incorporation of these technologies can broadly redefine the role of the educator, in such a way that it must increase the ability to exercise pedagogical judgment, interpret information, promote critical thinking and accompany the integral development of students. Then the teacher ceases to be a transmitter of information to become a mediator of knowledge, a designer of learning experiences, and an ethical reference in the responsible use of algorithms, data and artificial intelligence. This transformation requires the strengthening of critical information evaluation skills, digital literacy, and mitigation of algorithmic biases. protection of privacy and the promotion of values related to responsible digital citizenship.

Finally, the research shows that the effective incorporation of Extended Reality, Generative Artificial Intelligence and Blockchain requires a systemic vision of educational transformation, so that permanent training policies, institutional leadership, investment in infrastructure and an organizational culture aimed at pedagogical innovation converge. With this articulation, it will be possible to guarantee that technological development helps to improve equity, educational quality, and the formation of citizens capable of developing in an ethical, critical, and competent way in the digital environments of Education 4.0.

As future trends and lines of research, the need to study the longitudinal incidence of hybrid methodological variants in the reduction of academic dropout through predictive analytics is

identified. Also, the most relevant challenges for developing economies are not restricted to reducing the digital divide, but require instructing and legislating on the governance of ethical data literacy and AI to balance the risks of pedagogical dehumanization, and thus ensure that technological evolution always places human well-being at the center of the educational process.

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