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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.

INTRODUCTION

Education 4.0 begins 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 now recognized as a key component in teaching and learning processes[2]. Thus, the term Education 4.0 not only involves the use of technological tools, but also requires teachers to take ownership of planning, teaching and assessment processes in education[2],[3]. This is where technology plays a fundamental role in supporting the teacher, because it must respond to a better-informed community that uses digital platforms for the construction of knowledge[3].

Technology management in teaching has become an essential foundation for educational quality and pedagogical innovation [4]. The integration of technology is not limited to the use of digital tools, but implies articulating it with the needs of students and the learning objectives [5]. Moreover, technology management goes beyond acquiring tools; it must be strategically articulated with learning objectives to achieve educational quality [6], [7]. Quality is therefore achieved through a continuous institutional effort so that it fulfills both teaching and research functions in digitalized environments [8].

Among the latest trends in technology management, the implementation of adaptive teaching is based on technology. This methodology uses formative assessment as a pillar to monitor student progress and make changes in real time[9]. For management to be better leveraged, it must be directed along two stages: the first is macro adaptations, which are activities planned with prior knowledge on the part of the students; and second, micro adaptations, which provide personalized support through intelligent tutoring system technologies[9].

The effectiveness of these systems in various areas has been shown to materialize when there is good adaptation in the process of imparting knowledge to students[9]. However, managing these tools requires the teacher to be digitally literate and to have the ability to relate technological tools to a specific content[10].

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

Under the teaching management approach, Generative Artificial Intelligence changes the teacher's role from a transmitter of knowledge to a guide and facilitator of teaching-learning, as well as an ethical mentor[12]. Artificial Intelligence (AI) must therefore be handled technically while observing the human side; that is, not biasing oneself with the use of AI alone, but rather resorting to critical thinking with one's students[13]. Student autonomy would guarantee the success of their learning, and the teacher's role 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 educational information management has an impact on faster and more accurate administration compared with the manual process[12]. To improve the systems, data mining techniques and Q-learning algorithms are used, which help predict learning behaviors and systematize resource allocation in pursuit of improving institutional processes[13]. In particular, data mining facilitates the discovery of patterns related to academic performance by predicting risks and optimizing curricula.

In these times, data transparency and 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 by means of interlinked data blocks[14]. It also offers disruptive potential through the creation of unalterable and decentralized records, as is the case with 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 presents some barriers, especially in emerging economies, where there is a digital divide and resources are scarce, limiting education[16]. Therefore, the way of approaching this technology in these scenarios will depend on the type of subject or area of knowledge and the teacher's experience[16].

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

TECHNOLOGY MANAGEMENT FOR TEACHER PROFESSIONAL DEVELOPMENT IN TECHNOLOGIES

Teacher professional development is the foundation that allows ICT to be used effectively. The teacher is a creator of innovative curriculum proposals and not a mere transmitter of information. This is why the teacher must use data analytics to carry out searches and in-depth analysis with its subsequent interpretation for both students and teachers[18]. For a data analysis to be

effective, it is imperative to carry out data pre-processing with a particular domain focus that guarantees the consistency and quality of the information from various heterogeneous sources[19].

Teacher professional development is also the pillar of technological transformation, in which the teacher's role must evolve from being a transmitter of information to a mediator of learning; in addition, it must 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 professional development is developed by the TPACK model (Technological Pedagogical Content Knowledge), which focuses on integration with technology outcomes and requires an articulation among digital tools, pedagogy and content management [20]. Recently, research suggests that this model has shifted to more detailed variants such as AI-TPACK, which enables teachers to change pedagogical models by using Artificial Intelligence to facilitate the tasks and methodologies to be used [21]. When seeking teacher professional development, the focus should be on practical and reflective methods to avoid theoretical training; instead, the aim is to represent the reality of classrooms that use technology [22].

The use of immersive technology such as Virtual Reality (VR) is also important; it is a tool that allows teacher training. VR enables real-life scenarios and the management of inclusive classrooms for children with autism, turning environments into safe and controlled ones[3]. With this, the aim is to bring classroom practice and academic theory closer together, helping knowledge transfer 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 learning pace and style when using digital tools to improve teacher professional development in pursuit of educational equity and inclusion[24]. UDL is also essential to ensure that 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, fostering computational thinking in childhood can establish a new digital literacy to successfully manage 4.0 technology[25].

It has been observed that there are many advances in teacher professional development, which is established as the cornerstone of transformation. The teacher's role evolves from being a transmitter of information to a mediator of learning capable of integrating technologies with pedagogical and ethical criteria. There are cases in which 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 among older teachers and a lack of technical infrastructure are related[23]. Therefore, achieving teacher professional development requires continuous technical training, a culture or habits of innovation in institutions and support from educational entities[27].

It can be concluded that the learning process supported by the application of technologies makes a great contribution to the development of education and, in turn, that teachers need new competencies in their role as guide[28]. Emerging technologies together with artificial intelligence could never replace the teacher; on the contrary, the teacher becomes a strategic ally because they improve the teaching-learning process[28]. Consequently, teacher professional development in the use of technology becomes a long-term learning process, and technology is seen as a means to achieve equitable and comprehensive development[29].

EMERGING TECHNOLOGIES FOR EDUCATION 4.0

As has been stated, technological integration is not restricted to the use of tools; rather, it enables a broad restructuring of pedagogical models that move toward Education 4.0[1].

The main lines of thinking derived from the sources are presented below:

- Artificial intelligence (AI) and personalization of learning

Artificial intelligence makes it possible to move beyond 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 through its capacity to analyze large volumes of data to generate different interests and learning rhythms specific to each individual[30]. This helps to detect the various difficulties in the teaching-learning process early and to generate rapid feedback, in addition to the implementation of intelligent tutoring[29]. It also enriches the pedagogical ecosystem by generating content and educational material such as chatbots, texts and audiovisual resources[3].

With Learning and Knowledge Technologies (TAC) and artificial intelligence, administrative tasks have been automated, noticeably reducing the workload by 40%; this also involves the personalization of the teaching-learning process[23]. In this highly advanced education model, it is important to have responsibility and ethics in the use of AI, because there is a risk of dehumanization of pedagogy[28]. Teacher professional development with the use of technologies must therefore involve

literacy not only in data but also in ethics. Teachers must then 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 draw on science and technique, facilitating understanding, the visualization of complex definitions and three-dimensional spatial perception [30]; they are also used in repetitive and safe practice in fields such as architecture and engineering, enabling simulations of practical activities before their real 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 toward areas such as science and mathematics [32].

- Synergy of active methodologies and technology

They function as alternatives and strategies for teacher professional development that manage to integrate methodological frameworks for the appropriate use of technologies. These include: Project-based learning (PBL), which is positioned as a highly effective strategy for developing pedagogical digital competence in future teachers, allowing them to internalize technological tools through authentic and collaborative tasks[33]. In educational management, STEM (science, technology, engineering and maths) is used, that is, the use of technologies such as digital twins or laser prototyping; this type of STEM project fosters critical thinking and real-world problem solving[34].

- Digital skills for teacher professional development

The teacher becomes a facilitator and mediator of learning in digital and hybrid environments and not a transmitter of information[3]; here it can be seen that said teacher must have continuous training, narrowing the gap between pedagogical digital skills and familiarity with everyday applications[32]. In the same sense, it generates other ways of assessing with specific and automated methodologies in order to observe and analyze the dissertation in classes, achieving more reliable and precise feedback on their own practice[35].

- infrastructure and ethics

Although there are many advantages to using the different technologies, barriers also arise 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 for the use of technologies, thereby increasing gaps in education[31],[36]. On the other hand, humanization and ethics where there must be human interaction in the teaching-learning processes and also ethical regulations must be determined so that there are guarantees regarding data privacy[3].

DIGITAL TRANSFORMATION TECHNOLOGIES

Digital technologies applied to teaching seek the modernization of educational institutions through the transformation toward the digital, which ultimately translates into continuous improvement of the educational process. The COVID-19 pandemic event rapidly and significantly drove the development of new technologies such as video learning, virtual environments and artificial intelligence [36], in which teachers had to learn new and better digital skills. One of these is Digital Teaching Competence (DTC), which involves the ability to select and integrate technology into different pedagogical aspects and the technical knowledge of tools in curriculum design[30]. Some digital transformation tools are mentioned below:

Models of digital competence and integration

- The Digital Teaching Agency is the teacher's capacity 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]. The TPACK model mentioned above is also found.

Emerging technologies and their application

- Big data and learning analytics: These analyze student behavior in real time, enable personalization and the development of teaching methods, and provide information on low performance or possible student dropout[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 analyzing massive data to predict student performance and dropout risk, facilitating early warning systems[3].
- Immersive environments (VR/AR/3D): Virtual worlds and augmented reality allow transforming 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 discussed.
- Educational robotics and programming: Robotics is used as an educational practice in which robots are designed, built and programmed; this allows developing computational thinking that is useful for any discipline, especially in STEM areas[37].

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

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

Table 1 shows, in a comparative form, the emerging technologies, technology integration models, digital skills, and main findings reported in the literature.

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

Technology / Model	Application in teacher professional development	Required digital skills	Main findings reported in the literature
Generative Artificial Intelligence (ChatGPT,)	Class planning, material design, automatic feedback, and personalization of learning	Critical thinking, AI literacy, digital ethics, and evaluation of AI-generated content	It increases teacher productivity and facilitates the personalization of learning; it requires supervision to avoid biases and technological dependence.
Learning analytics	Early identification of dropout risk, monitoring of student performance, and support for decision-making	Statistical analysis, data interpretation, and information management	It enables pedagogical decision-making and timely interventions, and improves educational management through evidence.
Educational Data	Massive management of institutional and academic information	Digital literacy, information analysis and data management	Helps predict academic performance and drive continuous improvement of institutional processes.
Extended Reality (XR: VR, AR and MR)	Practical training, skills development and scenario simulation.	Design of digital experiences and management of immersive environments	Increases understanding of conceptualization, motivation, and learning transfer
Blockchain	Document management, academic certification, and protection of educational records	Information management, digital citizenship and digital security	Increases the transparency, traceability and security of information through immutable records.
Machine Learning and educational Robotics	Development of computational thinking and programming	Basic programming, computational thinking and problem solving	It helps to acquire STEM competencies and reinforces the understanding of algorithms and AI at early ages.
TPACK	Balanced integration of pedagogy, technology and disciplinary content,	Pedagogical, disciplinary and technological competence.	It is the model 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 assessment with the responsible use of AI,	It develops the TPACK model by bringing together specific competencies for the educational use of AI.
Universal Design for Learning (UDL)	Design of inclusive experiences through digital technologies	Accessibility, curricular adaptation and digital inclusion.	It allows multiple forms of representation, participation and assessment, favoring educational equity.
Digital Teaching Competence (DTC)	Continuous professional development of teachers	Content creation, digital literacy, collaboration, safety and problem solving	Digital competence is the main factor for generating sustainable and effective technological integration in Education 4.0.

Source: own elaboration based on the literature

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, which underscores 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].

CONCLUSIONS

The literature analysis shows that technology management in Education 4.0 goes beyond having a physical or digital infrastructure; it also requires strategic alignment with the institutions' pedagogical model so that it can have a positive impact on the quality of education. Its main contribution is that the use of emerging technologies can strengthen teaching and learning processes in such a way that educational transformation does not depend at all on new technological tools but instead prioritizes the institutional vision, and that this vision can be articulated with the pedagogical objectives, in order to subsequently incorporate the development of teachers' digital skills and innovation and thus pursue continuous improvement of the quality of education.

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

Generative Artificial Intelligence, Extended Reality and Blockchain are drivers that can simulate training practices, personalize learning, and strengthen administrative transparency. But their effectiveness lies in continuous teacher professional development

under epistemological frameworks such as TPACK and UDL, which allow transforming the role of the educator from a passive transmitter to an ethical guide and mediator in school environments. . However, the evidence found allows inferring that the impact 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 a coherent pedagogical project oriented toward meaningful learning. In this regard, the risk of assuming technological innovation as an end in itself could generate simplistic digitalization processes without achieving substantial transformations in teaching.

Continuous teacher professional development is the main factor determining the value of emerging technologies in education. Teacher training must evolve from using digital tools as an instrument toward fostering the development of competencies that allow teachers to adapt, select, and critically evaluate technological resources based on curricular objectives, the characteristics of students and of the context. Likewise, the incorporation of these technologies can broadly redefine the educator's role, such that the capacity to exercise pedagogical judgment, interpret information, promote critical thinking and accompany the comprehensive development of students must increase. The teacher thus ceases to be a transmitter of information and becomes a mediator of knowledge, a designer of learning experiences, and an ethical reference for the responsible use of algorithms, data and artificial intelligence. This transformation requires strengthening competencies in critical evaluation of information, digital literacy, 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 continuing training policies, institutional leadership, investment in infrastructure and an organizational culture aimed at pedagogical innovation converge. With this articulation it will be possible to ensure that technological development contributes to improving equity, educational quality, and the training of citizens capable of developing ethically, critically, and competently in the digital environments of Education 4.0.

As future trends and lines of research, there is a need to study the longitudinal incidence of hybrid methodological variants in reducing academic dropout through predictive analytics. Likewise, the most relevant challenges for developing economies are not restricted to narrowing the digital divide; it is also necessary to educate and legislate on the governance of ethical data literacy and artificial intelligence in order 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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