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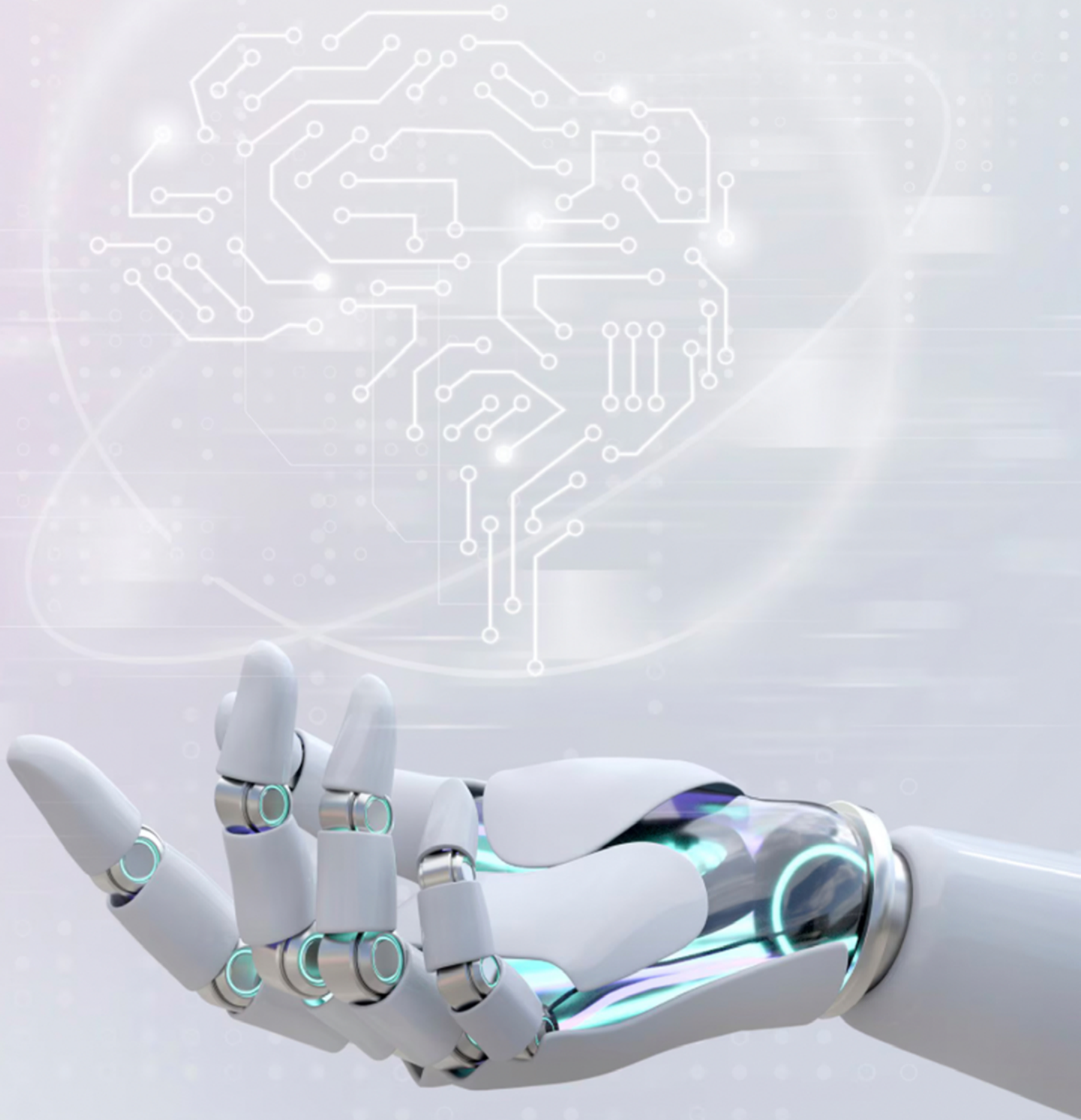


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ACADEMIA

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INTEGRATION OF ARTIFICIAL INTELLIGENCE (AI) IN SECONDARY CHEMISTRY EDUCATION: PROPOSAL FOR AN APPLIED GUIDE

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Abstract. The implementation of artificial intelligence (AI)-based technologies within the Costa Rican educational context presents several challenges, including technological infrastructure, education policies in this area, and teacher training. This study is grounded in the integration of AI into the development of chemistry teaching at the secondary education level. A mixed-methods approach was employed, where the data collected—corroborated through documentary review—offered clear evidence of the current reality faced by teachers when incorporating new technological alternatives in their professional practice. The findings reflect a prevailing sense of uncertainty among the teaching population, fluctuating between recognizing the potential benefits of implementation and the lack of equitable resources and policies for responsible use. As a result,

a didactic guide was developed focused on chemistry teaching, aiming to provide teachers with tools that facilitate both content creation and effective evaluation, thereby allowing the human factor to concentrate more fully on the pedagogical process.

Keywords. Artificial Intelligence, Chemistry Education, Secondary Education, Didactic Guide, Education Policy, Technological Infrastructure, Teacher Training.

INTEGRACIÓN DE LA INTELIGENCIA ARTIFICIAL (IA) EN LA EDUCACIÓN SECUNDARIA DE QUÍMICA: PROPUESTA DE UNA GUÍA APLICADA

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Resumen. La implementación de tecnologías basadas en inteligencia artificial (IA) en el contexto educativo costarricense presenta diversos desafíos, como la infraestructura tecnológica, las políticas educativas en este ámbito y la formación docente. Este estudio se basa en la integración de la IA en el desarrollo de la enseñanza de la química en la educación secundaria. Se empleó un enfoque de métodos mixtos, donde los datos recopilados, corroborados mediante revisión documental, ofrecieron evidencia clara de la realidad actual que enfrentan los docentes al incorporar nuevas alternativas tecnológicas en su práctica profesional. Los hallazgos reflejan una sensación de incertidumbre prevaleciente entre el profesorado, que oscila entre reconocer los beneficios potenciales de la implementación y la falta de recursos equitativos y políticas para su uso responsable. Como resultado, se desarrolló una guía didáctica centrada en la enseñanza de la química, con el objetivo de proporcionar a los docentes herramientas que faciliten tanto la creación de contenidos como la evaluación efectiva, permitiendo así que el factor humano se concentre más plenamente en el proceso pedagógico.

Palabras clave. Inteligencia Artificial, Enseñanza de la Química, Educación Secundaria, Guía Didáctica, Política Educativa, Infraestructura Tecnológica, Formación Docente.

1. INTRODUCTION

Context of Artificial Intelligence (AI)

Far from being a modern or fictional concept, artificial intelligence (AI) is a field grounded in the simulation of human cognitive development and the result of an extensive evolution in computer science. Escolano et al. (2003) define AI as “the science that incorporates knowledge into processes or activities, so they succeed,” emphasizing its role as a catalyst for efficiency and effectiveness in various domains. Russell and Norvig (2004) classify AI as systems that think or act like humans, highlighting rational decision-making as a foundation for continuous improvement in understanding intelligent agents. This concept is reinforced by McCorduck (2004), who traces AI’s origins back to pioneers like Alan Turing and its consolidation as a scientific discipline at the Dartmouth Conference in 1956. While AI has traditionally been applied to computing, today it permeates areas such as communication, transportation, and education—bringing significant added value. Nevertheless, technological progress must be aligned with human-centered principles that promote equity and social ethics.

Current State of AI in Costa Rica

The global rise of AI has also reached Costa Rica. Although its integration into the national education system remains

at an early stage, the country has taken initial steps toward ethical and responsible adoption. The National Artificial Intelligence Strategy 2024–2027, led by the Ministry of Science, Innovation, Technology and Telecommunications (MICITT), presents Costa Rica as a pioneering country in Central America (Murillo, 2024). Supported by international entities such as UNESCO, which view it favorably (Álvarez, 2003), this strategy aims to ensure technological development focused on human well-being, social inclusion, and equal access. However, obstacles remain, including unequal distribution of technological infrastructure among educational institutions and insufficient teacher training, as documented by the Ministry of Public Education (2024). Although pilot projects and self-directed training initiatives have been launched in technical high schools (MEP, 2022), the digital divide persists as the greatest challenge. Additionally, the lack of a specific legal framework regulating AI use in schools hinders implementation, although bills seeking ethical, cross-cutting regulation have been proposed (Gutiérrez Guillén, 2025). Achieving alignment between AI development and public education in Costa Rica requires strengthening infrastructure, ensuring teacher preparedness, and establishing a clear regulatory framework based on equity, transparency, and human development.

National and International Background

Integrating AI into pedagogical practice is a complex goal and a central focus of this research. At the national level, effective implementation in the education sector is still limited by unequal access to technology, absence of clear guidelines, and insufficient teacher training—factors identified as the main obstacles. Nevertheless, according to Álvarez (2023), both public and private sectors have made efforts to incorporate AI as a strategic focus. A noteworthy example is the joint initiative by MICITT and Intel, positioning Costa Rica as a regional benchmark through a national strategy for ethical AI use. The MEP has promoted programs through its digital platforms encouraging self-directed and specialized training in technical schools (MEP, 2022; 2024), but these efforts are not yet enough to ensure widespread and effective teacher adoption.

Academic research provides evidence of both perceptions and challenges related to AI. Obando et al. (2025) conducted a study with students from the University of Costa Rica, revealing significant gaps. The study showed that platforms such as ChatGPT and Grammarly are increasingly used for academic work; however, it also raised concerns about over-reliance on technology, the potential displacement of teachers in critical educational processes, and the need to preserve critical thinking. Similarly, Campos

Madrigal (2024) argues that the use of generative AI (GenAI) must be accompanied by clear regulation. His proposal advocates for the creation of an interdisciplinary committee linking public and private sectors to supervise AI's educational development. Cervantes Hidalgo (2021) emphasizes the importance of protecting data privacy and promoting ethical, pedagogically grounded technological development.

Internationally, AI integration in education is more advanced. López-Altamirano et al. (2024) demonstrate its use in chemistry, particularly in molecular energy calculations. While the results show efficiency and problem-solving potential, ethical use depends on the teacher's ability to clearly define the input data and interpret outcomes. Likewise, Blonder et al. (2024) caution against biased results when prompts are poorly formulated. Meanwhile, Yildirim and Akcan (2024) underscore the importance of professional development for teachers. Their Professional Development Model (PDM) focused on ethics and effective use of AI, eliminating errors and misunderstandings caused by undertrained systems.

In short, AI integration is not only viable when supported by policy and professional ethics, but it also offers real potential to improve educational outcomes without displacing the essential human element.

Purpose and Scope

Given the background and current realities of the Costa Rican education system, this study aims to link emerging AI technologies with the need for better adapted, scalable teaching content across subjects. Chemistry was chosen due to its instructional complexity, which demands both memorization and hands-on application. CINDEA Escazú was selected as the site of study due to its instructional system and large teaching population, which made it suitable for the proposed methodological approach.

The main objective was to design a didactic guide incorporating GenAI tools, virtual labs and simulations, adaptive platforms, and AI systems tailored to the teaching and research needs of chemistry educators.

Given the increasing pervasiveness of AI in daily life, identifying spaces for its ethical and effective use must be a priority, ensuring that educators are equipped with both the tools and training necessary to transmit knowledge confidently and responsibly.

2. MATERIALS AND METHODS

Considering the faculty of CINDEA Escazú as the study population, the research adopted a mixed-methods approach that incorporated teachers' experiences, challenges, and expectations regarding these technologies in quantifiable terms. Based on a literature

review of publications, books, and national and international academic work related to AI in education, a participant profile was designed to guide an interview that would integrate teaching responsibilities with knowledge of this technology. As a result, an information systems engineer was chosen as the interviewer.

With these two methods implemented, the scope of analysis for the target population was expanded. The survey was structured to explore relevant dimensions, aiming to characterize participants by age and teaching experience, inquire into their knowledge of AI tools (usage, functions, platforms), and evaluate their understanding of AI's benefits for teaching (administrative management, content creation, assessment, etc.), as well as their awareness of challenges and national-level concerns (infrastructure, policies, ethics). The platform used for administering the survey was Google Forms. Although the survey analysis was comprehensive due to the number of participants, some individuals were unable to participate due to a lack of technological infrastructure or unfamiliarity with the platform.

3. RESULTS AND ANALYSIS

To include the widest possible range of relevant aspects for extending this study to other subjects, the survey was structured to identify five key areas for analysis of the

study population. These were:

1. Challenges in teacher training on technology and AI.
2. Gaps in access to technological resources.
3. Use of AI as a complementary—not replacement—tool.
4. Ethical barriers and the need for digital ethics training.
5. The need for clear guidelines and policies for AI usage.

These topics were discussed with Engineer Henry Ferrero Cano, who pointed out the disparity within the national education system, stating during the interview:

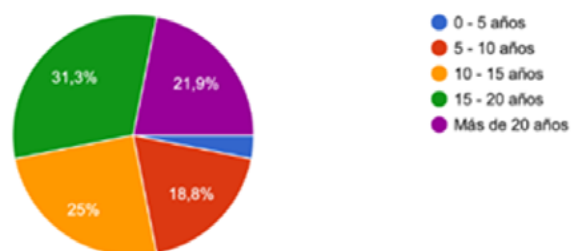
“A nationwide education policy would have to be developed—something mandatory—which is very complicated.”

In the case of CINDEA Escazú—the institution chosen for this study due to the versatility of its educational model and diverse teaching staff—the survey implemented via Google Forms explored not only these five topics but also broader aspects such as awareness of AI tools, perceived efficiency and effectiveness of integrating such technologies into teaching practices, and the risks involved if ethical education is not prioritized.

The survey (see Annex 2) was completed by thirty-two teachers aged between 20 and 60. Approximately 85% were between 30 and 50

years old, and over 75% (Figure 1) had more than 10 years of teaching experience.

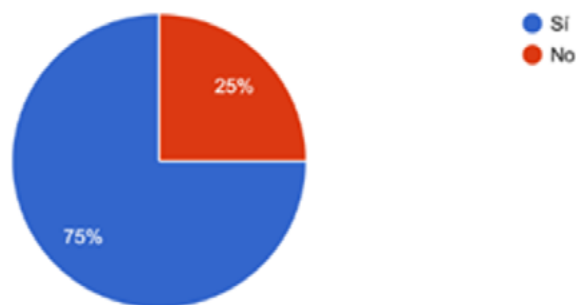
Figure 1. *Years of experience among surveyed teachers from CINDEA Escazú.*



Source: Own elaboration (2025)

The next group of questions focused on knowledge: familiarity with the technology, its use in their teaching practice, and commonly used platforms. Given their age range and technological exposure, high engagement was expected, even with limited formal training. Only 25% of respondents (Figure 2) reported not having used AI in their work, which may be linked to adherence to traditional pedagogical methods.

Figure 2. *Percentage of teachers from CINDEA Escazú who have used AI in their teaching.*



Source: Own elaboration (2025)

Another important result related to the platforms used. Although thousands of specific AI tools exist today, social and professional networks tend to create biases and limitations in choosing the most suitable ones. In this case, generative AIs (GenAI) were the most frequently cited, especially ChatGPT, Copilot, and Gemini. These were followed by automated evaluation systems and adaptive learning platforms.

The following section explored perceived benefits of AI, particularly in terms of how it could positively impact students.

Figure 3. *Opinions from CINDEA Escazú teachers on workload reduction through AI.*



Source: Own elaboration (2025)

Unanimously, as seen in Figure 3, teachers believe that their workload would be significantly reduced. Automation of certain administrative tasks, faster grading, and improved quality of content were identified as key benefits. Additionally, AI could enhance extracurricular tutoring and student support, provided that ethical use is emphasized, and AI is treated as a complement to classroom

instruction.

One of the most notable concerns raised was the lack of teacher training, followed by ethical issues such as algorithmic bias and fears of overdependence by both teachers and students. Another implicit concern was the possible replacement of teachers due to the rapid advancement of technology, without adequate technical support for educators.

Lastly, the survey asked whether respondents were aware of any policies or guidelines regulating AI use in education. Over 95% indicated they did not know whether such policies existed or were implemented by the education system.

AI is a constantly evolving field in all sectors. In this study, a guide was developed to assist chemistry teachers by integrating key AI tools. While GenAI systems are particularly useful for generating educational content, simulations, and virtual labs, adaptive platforms and subject-specific tools not only enhance conceptual understanding but also increase student success and engagement in STEM (Science, Technology, Engineering, and Mathematics) disciplines.

Discussion

1. Relation to the Study Objectives

The guiding purpose of this project was to achieve the main objective:

“To develop a basic educational guide

that enables secondary school teachers to maximize the benefits of artificial intelligence (AI) as a technological tool.”

Based on the data collected through instruments applied to teachers at CINDEA Escazú, this objective was successfully met. The initial characterization of the study population revealed a heterogeneous group in terms of experience and prior exposure to emerging technological tools. This finding is particularly useful, as the level of AI knowledge is directly related to the willingness to use it in the classroom. Although many teachers reported limited prior experience with AI, overall, there was an openness to exploring its applications—provided ethical justifications were in place.

International organizations such as UNESCO emphasize AI’s potential to personalize learning, automate administrative tasks, and produce adaptive content. Similarly, the literature reviewed indicates that these benefits can only be fully realized when teachers and students receive ethical guidance and proper training.

The findings also reveal that AI is not yet fully embedded in the institutional culture of the school. Therefore, the contrast between teachers’ willingness to adopt AI and the lack of structural conditions to support its use highlights a critical area for educational authorities to address.

In other words, the results validate the relevance of this study, particularly by justifying the creation of a didactic guide as a support resource for teachers. This guide not only introduces technological tools into chemistry education, but also addresses a broader need for foundational training, ethical guidelines, and context-specific methodologies tailored to the Costa Rican reality.

2. Analysis of Identified Barriers and Limitations

One of the main findings was the identification of multiple barriers that hinder the proper integration of AI into teaching practice. The most significant concern expressed by teachers was the lack of specific training in AI applications within the educational context.

Many respondents indicated that they lacked sufficient technical knowledge to understand how these tools work, which limits their autonomy and critical thinking when applying them pedagogically. This problem is exacerbated by the scarcity of institutional training programs focused on advanced digital competencies—a concern echoed in national studies.

Teachers also expressed high levels of anxiety regarding AI’s potential to alter the essence of the teaching process, particularly the fear of dehumanizing education and over-relying on automated systems. This concern was echoed

in the interview with Engineer Henry Ferrero, who emphasized that AI should be treated as a complementary tool that enhances—but does not replace—the teacher’s role and human interaction in the classroom.

Another key issue was the availability of technological resources in educational centers, including devices, stable internet connections, and equal access to digital platforms. The technological divide continues to be a major impediment within CINDEA institutions. Additionally, there is a notable absence of clear educational policies regarding AI use. Although the MICITT has launched recent initiatives and legislative bills (such as Bills No. 23771, 23919, and 24494) propose AI regulation, no concrete mechanisms have been established to ensure responsible use in educational settings.

As a result, teachers are not fully aware of the boundaries for AI use, and no effective measures exist to safeguard students’ personal data. AI implementation in classrooms currently exists in a legal vacuum. These findings underscore the urgent need to promote responsible and equitable AI adoption supported by a structured and enforceable policy framework.

3. Complementary Role of Artificial Intelligence in Teaching

The data collected contributes to the broader discussion of how teachers perceive AI’s role

in education. Despite expressing concerns about automation, many respondents agreed that AI is being developed to support—not replace—human educators.

The perceived benefits include more efficient lesson planning, customized learning materials, automated content generation, and real-time feedback in assessments. Teachers recognized that these tools could be adapted to students’ individual schedules, learning styles, and needs. This is particularly relevant at CINDEA Escazú, given the diverse student body in terms of age, prior knowledge, skills, and previous educational experience.

Virtual assistants, adaptive learning platforms, intelligent text editors, and predictive analytics systems were identified as accessible AI tools that could be gradually integrated into classroom dynamics. However, teachers emphasized that the effective use of such tools depends on the educator’s pedagogical expertise. Thus, AI is not seen as an autonomous entity that will replace teachers, but rather as a means of enhancing didactic decision-making and freeing time for more meaningful instructional activities. This perspective was reaffirmed by the interviewed professional, who emphasized that AI’s true value lies in its ability to manage technical and routine tasks efficiently, thereby allowing teachers to focus on personalized guidance, pedagogical mediation, and values education.

AI was thus recognized as an enabling rather

than a limiting tool—capable of offering specialized support without undermining the teacher’s authority in the educational process. These findings suggest that the success of AI integration in education depends not only on access to technology but also on cultivating a teaching culture that can critically evaluate and utilize AI as a pedagogical ally.

4. The Need for Ethical Training and AI Regulation in Education

Regarding the use of AI tools and systems, teachers demonstrated a general ethical awareness, and a basic understanding needed to make informed and critical decisions. However, based on the literature review, AI integration in education must be grounded in transparency and algorithmic accountability. The study found that most of the teachers surveyed lacked the disciplinary knowledge required in these areas.

One of the most frequently expressed concerns was the absence of training and institutional policies regulating the ethical and responsible use of such tools in classrooms. Teachers were especially concerned about student privacy, biased outcomes, and overdependence on algorithm-driven services. These concerns point to the immediate need for continuous national training programs focused on AI tools and their ethical implications.

Additionally, the study revealed a regulatory gap in Costa Rican educational policy

concerning AI. While some national progress has been made through initiatives led by MICITT and pending legislation, there are no specific or binding proposals for the education sector.

As a result, institutional decision-making is hampered by an ambiguous legal framework, leaving the implementation of AI to the discretion of individual teachers. This highlights the urgent need for national authorities to develop a regulatory policy for AI in education—one that adheres to general ethical principles, is culturally relevant, and provides clear guidelines for teachers.

5. Pedagogical Value of the Proposed Guide

This study proposes a didactic guide for teaching chemistry that includes AI-based tools. The design of this guide is informed by professional experience in the field and the results of the applied research instruments, which show a strong interest among teachers in new technologies and a lack of structured resources to implement them effectively in the classroom.

The guide constitutes a context-specific pedagogical proposal tailored to the everyday realities of Costa Rican education. Functionally, it serves as a practical companion to help teachers integrate AI gradually, safely, and in alignment with their instructional goals.

It includes specific recommendations

on accessible platforms, class planning suggestions, sample activities that incorporate AI, and tech-assisted assessment strategies. Nonetheless, the guide reaffirms that the teacher must remain the central figure in the educational process, with AI merely supporting instructional delivery.

Another key strength of the guide is its flexibility and adaptability. It can be applied across various educational levels and student populations, thereby supporting educational equity in programs such as CINDEA. The focus on active learning from a student-centered perspective enables technology to serve as a vehicle for grasping abstract concepts, promoting virtual experimentation, and encouraging continuous feedback.

From a broader perspective, the guide can be replicated in other educational contexts and scientific disciplines, particularly those—like chemistry—that tend to pose instructional challenges. Given that technology is now employed in nearly all teaching fields, this evidence-based and context-sensitive guide represents a high-value pedagogical tool.

4. CONCLUSIONS

This research has provided a critical analysis of both the opportunities and challenges associated with introducing artificial intelligence (AI) into secondary chemistry education in Costa Rica, with a specific

focus on the reality of the CINDEA Escazú institution. The findings from the instruments applied indicate that although AI is still in an early phase of adoption within the teaching culture, there is a genuine interest among educators in exploring its pedagogical potential.

The results reflect a broad recognition of AI's potential to improve curriculum design, lesson planning, student assessment, and learning processes tailored to individual rhythms and abilities. However, the challenges identified in this study—such as structural and training barriers—negatively affect AI implementation. These include limited technical training, inadequate digital infrastructure, lack of clear institutional guidelines, and ethical concerns centered around data privacy and the dehumanization of teaching. Consequently, there is a need to approach this issue with a gradual, context-specific, and values-based strategy.

In this regard, educational institutions must implement ongoing professional development programs aimed at equipping teachers with the technical skills required to use diverse AI platforms in teaching and learning contexts. Furthermore, there is an urgent need to establish a specific regulatory framework in Costa Rica that ensures AI is used in alignment with ethical principles such as equity, transparency, and accountability.

As a concrete outcome, this study proposes

a specialized didactic guide for chemistry education—the most significant academic contribution to the author’s professional field. This guide, grounded in both empirical evidence and pedagogical principles, could be replicated in other teaching settings and scientific disciplines.

In conclusion, AI should not be viewed as an adversary to the teaching profession but rather as a powerful ally—if used responsibly—to enhance pedagogical mediation, expand learning opportunities, and revitalize educational practices in response to today’s challenges.

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