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Methodology to Integrate Artificial Intelligence into Mining, Metallurgy and Geology Formation at the University of Moa

Metodología para integrar la Inteligencia Artificial en la formación geólogo minero metalúrgica de la Universidad de Moa

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Abstract: This proposal presents a methodology for developing an institutional project at the University of Moa focused on integrating artificial intelligence as a didactic resource into the educational processes of the core specialty programs —mining, metallurgy and geology— as well as into postgraduate studies. To this end, an analysis was conducted on the teaching staff competencies and significant research and results at the institution that involve AI applications in undergraduate and postgraduate educative processes, including curricula, curricular strategies, scientific publications, theses, and projects directed towards digital transformation of research management. The project is framed within Technology Readiness Levels (TRL) 3 and 4. As a result, an integrative methodology was developed in four stages: diagnosis, planning, development and implementation, followed by an evaluation stage to assess the impact of AI, through which AI is mainstreamed into the training processes. This methodology provides a pathway to prepare future professionals for a changing and

technologically advanced work environment, where the mining industry as a whole is undergoing an unprecedented technological revolution known as Mining 4.0

Keywords: technical and vocational education, higher science education, engineering education, digital transformation

Resumen: La propuesta constituye la metodología para desarrollar un proyecto institucional en la Universidad de Moa para integrar la inteligencia artificial como recurso didáctico en los procesos formativos de las carreras rectoras del perfil geólogo-minero metalúrgico y programas de posgrado. Para ello se realizó el análisis de las competencias del claustro y de la investigaciones y resultados significativos en la Universidad de Moa con aplicaciones de IA en el proceso de formación de pregrado y de posgrado, tales como planes de estudio, estrategias curriculares, publicaciones científicas, tesis y proyectos dirigidos a la transformación digital de la gestión del proceso de investigación. Se empleó la escala TRL 3 y 4 (Madurez Tecnológica o Technology Readiness Level), en la cual se enmarca el proyecto. Como resultado se obtuvo una metodología integradora desarrollada en cuatro etapas; diagnóstico, planificación, desarrollo e implementación, y una etapa de evaluación del impacto de la IA, mediante la cual se realiza la transversalización de la IA en los procesos formativos. Esta metodología constituye una vía para preparar a los futuros profesionales ante un entorno laboral cambiante y tecnológicamente avanzado, donde la industria minera en general se encuentra en medio de una revolución tecnológica sin precedentes, conocida como Minería 4.0.

Palabras claves: enseñanza técnica y profesional, enseñanza científica superior, formación de ingenieros, transformación digital

1. Introduction

Artificial intelligence (AI) integrated into educative processes as a tool to improve and facilitate the teaching process and the continuous updating of curricula, both in undergraduate and postgraduate education, is a reality that demonstrates its widespread use in the education sector (Incio Flores *et al.,* 2022; Vera, 2023; Payró *et al.,* 2025; Rodríguez Flores, 2025). According to Jara and Ochoa (2020), González and Bonilla (2022), Supelano Londoño (2021), and Villafuente *et al.* (2025), AI has fostered improvements in different areas of this sector such as administration, teaching, and student learning. An analysis of the academic sources selected for the study (Arana, 2021; Supelano Londoño, 2021; Artavia and Castro, 2021)

showed that AI has been applied by educational institutions in several ways. In higher education, the potential of AI tools use for various administrative and teaching purposes has been demonstrated (Parra-Sánchez, 2022; Salmerón *et al*., 2023; Perdomo & González, 2025). Numerous countries like China, Spain, Belgium, Chile, Uruguay, and Colombia, and others, count on national strategies to develop it (Díaz, 2021; García Benítez & Ruvalcaba, 2021; Filgueira, 2023).

The Cuban Digital Transformation Policy (Ministerio de Comunicaciones, 2024) guides, through its strategic axes, objectives, and actions, the implementation of digital technologies with an ethical and innovative approach as a curricular strategy in programs and curricula at all educational levels, as well as the promotion of teaching methods that foster the development of digital competencies in educational centers.

In turn, the Strategy for the Development of Artificial Intelligence in Cuba (Ministerio de Comunicaciones, 2024) establishes the following specific objectives:

-Updating the curricula in all selected undergraduate and postgraduate programs, integrating the study of AI transversally, with an emphasis in its ethical use, in order to enable the development of digital competencies for the adoption of these technologies in the educational process.

-Implementing professional development and specific AI training programs aimed at educators, teachers, and all professionals involved into the educational process.

The current potentialities demonstrate the vital role of AI, which has as an important precedent the Sector Program "Cuban Software Industry and Informatization of Society" promoted by the Ministry of Communications, which approved the project "Strategy for the Development of Artificial Intelligence in Cuba," developed between 2022 and 2023. This project was coordinated by the University of Camagüey, with the participation of other institutions such as the Center for Advanced Technology Applications (CENATAV, in Spanish acronym), the Ministry of Higher Education (MES, in Spanish acronym), the Ministry of Public Health (MINSAP, in Spanish acronym), the University of Havana (UH), the University of Informatics Sciences (UCI, in Spanish acronym), the Technological University of Havana (CUJAE, in Spanish acronym), the Central University Marta Abreu de Las Villas (UCLV, in Spanish abbreviation), and the University of Oriente (UO) (Caballero Mota *et al*., 2024).

In this sense, the introduction of AI allows teachers to perform their functions more effectively and efficiently. These technological innovations have also permeated other academic sectors, fostering effectiveness and efficiency (Troncoso Heredia, 2023). Another foundation is provided by Jara and Ochoa (2020), who state that AI has improved efficiency in administrative task performance, such as reviewing student papers, grading, and providing feedback on assignments through automation using web-based platforms or computer programs.

Through AI it is possible to design different friendly and interactive virtual platforms that facilitate educational processes for students, teachers, and administrators; consequently, some institutions are adopting alternatives based on instructional design, Learning Management Systems (LMS), and artificial intelligence to interact synchronously and asynchronously with students (Marrufo & Espina, 2021; Giró & Sancho, 2022).

The above statements justify the existence of projects using AI in educational processes. This research took into consideration the results of a diagnosis which showed that, in the recent evaluation of the implementation of the curricula of the three core specialties at the University of Moa Mining —Engineering, Geological Engineering, and Metallurgical and Materials Engineering— that AI is not integrated transversally as a didactic tool, nor does it appear in the methodological guidelines of these specialties' disciplines.

The impact of the quality and updating of these programs' educational processes is of national and international relevance and influences traditional practices in the extraction and processing of natural resources. These programs train and educate geoscience professionals in the country and have a long-standing tradition of undergraduate and post-graduate alumni from more than 50 countries.

Of particular uniqueness is the unprecedented technological revolution in geology, mining, and metallurgy towards Industry 4.0, which is based on the digitalization and automation of production processes and is characterized by the use of technologies such as the Internet of Things (IoT), AI, big data, robotics, machine learning, and augmented reality. According to a report by the International Mining Association (IMA), it was estimated that 70% of mining companies would have implemented digital transformation solutions in their operations by 2025 (Santos Rodríguez, 2023).

Therefore, the research is formulated at a time when Cuba is emphasizing the need to apply AI. Consequently, it is necessary to improve the curriculum of undergraduate and postgraduate programs within the geological-mining-metallurgical profile, with a perspective of sustainable development and mainstreaming AI into the corresponding elements of these professionals' modes of action of in order to guarantee the country's progress toward digital transformation and sustainability. Its purpose is to implement a proposed methodology as part of an institutional project aimed at integrating artificial intelligence (AI) as a didactic resource into undergraduate educational processes of the geological-mining-metallurgical profile programs and the postgraduate programs at the University of Moa.

This integrative methodology is developed into four stages: a diagnosis and planning stage, two development and implementation stages, and a stage for evaluating the impact of AI on educational processes. Through this methodology, AI is mainstreamed into educational processes, knowledge gaps in the curriculum are identified, the curriculum is updated, and these professionals' modes of action are expanded. This methodology provides a pathway to prepare future professionals for a changing and technologically advanced work environment, while contributing, at the same time, to increasing social relevance, highlighting the leading role of undergraduate and postgraduate education, and improving the professional educational process in the core specialties and related programs from an approach based on updating, humanism, and sustainability.

2. Materials y methods

The proposed methodology is integrative. The main scientific research methods employed were interviews with professors from the selected programs and the Computer Science program; compilation to gather and systematize information through review and analysis of the teaching staff competencies, research, and significant results at the University of Moa involving AI applications in undergraduate and postgraduate training processes, such as curricula, curricular strategies, scientific publications, grade, master's and, doctoral theses, as well as projects aimed at the digital transformation of research management. As the project is framed within Technology Readiness Levels, the TRL scales 3 and 4 were used. The procedure established in the current Manual for Managing the System of Science, Technology, and Innovation Programs and Projects (CITMA, 2025) was used to formulate the project.

3. Results and discussion

3.1 Methodology for integrating AI as a didactic resource within undergraduate and postgraduate educational processes

The proposed methodology enables the integration of AI as a didactic resource within the undergraduate educational processes of the geological, mining, and metallurgical profile programs and postgraduate programs at the University of Moa, in order to update their curriculum, expand these professionals' modes of action, and promote sustainable development. Figure 1 shows the four stages of the methodology.

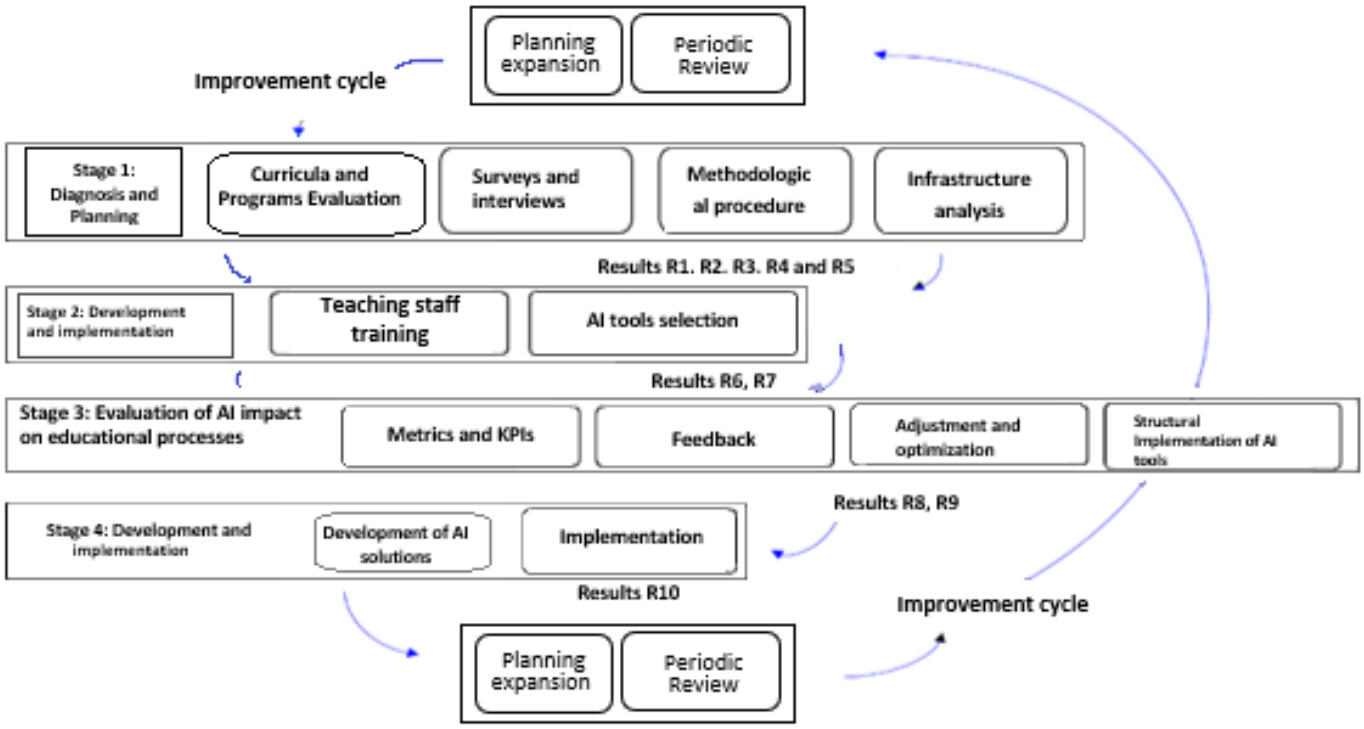

Figure 1. Methodology for integrating AI into educational processes.

R1. Procedure for mainstreaming AI into the educational processes of Geological Engineering, Mining Engineering, and Metallurgical, Materials Engineering programs, as well as into the following academic programs: Master's degree in Mining, Master's degree in Mining Surveying, Master's degree in Geology, Master's degree in Electromechanical Engineering, Master's degree in Metallurgy, Master's degree in Higher Education, Master's degree in Sustainable Development within Mining and Metallurgical Activity, and Master's degree in Cleaner professional mode of action and technical-scientific advances, respectively.

R2. Updated curricular strategies for the programs.

R3. Designed and implemented optional educational program mainstreaming the use of artificial intelligence (AI) within the selected undergraduate and postgraduate programs.

R4. Map by discipline, subject, and courses in postgraduate programs addressing AI topics according to professional modes of action.

R5. Strategies developed for the implementation of AI in the selected master's programs.

R6. Virtual teaching-learning environments, digital platforms, and other educational resources using AI that have improved the teaching-learning process.

R7. System of postgraduate courses designed for the professional development of teachers, cadres and administrative staff, on AI-related topics.

R8. Key indicators established to evaluate transformations at the institutional, curriculum, and program level related to the use of AI.

R9. Research lines on AI included into the research groups at the University of Moa and its study centers.

R10. Collaboration actions developed with the University of Camagüey, DRUEIDA Network, and mining companies to exchange AI-related knowledge and technologies.

R11. Workshops, forums, conferences, and events developed on topics related to AI within educational processes and curricula.

R12. Creation of educational materials such as guides, tutorials, videos, and a tool such as a Science and Innovation Management System (abbreviated SGCI in Spanish) that classifies the results of science at the University of Moa according to their generalization levels and identifies knowledge gaps.

The methodology's stages integrate the following aspects:

Stage 1. Diagnosis and Planning: this stage is proposed to evaluate the current state of the curricula and to mainstream AI tools as required by the professional modes of action and the technical-scientific advances in the geological-mining-metallurgical field, as well as to improve the teaching-learning process through the use of advanced AI systems, in order to develop personalized educational pathways adapted to each student´s individual needs, skills, and learning paces. This yield results R1, R2, R3, R4, and R5. Surveys and interviews are conducted with students, teachers, and administrative staff to identify areas where AI could be beneficial and where knowledge gaps exist. Needs and opportunities

for AI implementation are identified, and the existing technological infrastructure, installed capacities, and staff skills are reviewed to determine the available resources and the improvements needed.

Stage 2. Development and Implementation: professional development programs on AI and teaching methods and pedagogical models that facilitate their integration are designed and implemented for teachers, researchers, and professionals involved in educational processes, according to their specialty's professional modes of action. The most appropriate AI tools and platforms for the defined objectives are explored and selected, leading to results R6 and R7.

Stage 3. Evaluation of AI impact on educational processes and continuous improvements are implemented: metrics and KPIs (key performance indicators) are established to measure AI impact on learning and teaching. Feedback is obtained from students, teachers, and other stakeholders on their experience with the new tools and processes. Based on the evaluation results and feedback, adjustments are made to the implemented tools and processes to optimize their effectiveness, as well as to plan the expansion of successful solutions to other programs or departments within the university, ensuring that quality is maintained and lessons learned are addressed. A periodic review process is established to continuously evaluate the use of AI in education and get to adapt to new technologies or changes in educational needs.

This methodological approach allows for a structured and reflective implementation of AI within educational processes, ensuring that both the opportunities and challenges arising along the way are addressed, leading to results R8 and R9.

Stage 4. Development of selected AI solutions and their implementation in educational processes, leading to result R10.

The expansion of AI implementation to other undergraduate and postgraduate programs (Figure 2), as well as monitoring and review represent the institutional generalization phase, where the methodologies, tools, and pedagogical approaches validated in the core specialty programs of the geological-mining-metallurgical profile are adapted and transferred. This transfer process ensures that the integration of artificial intelligence is consolidated as a cross-cutting pillar in academic education (Celik *et al.*, 2022). At the same time, a formal periodic review cycle is established to reassure the long-term sustainability and relevance of the program through continuous impact evaluation, technological updating in the face of rapid AI advances (Bozkurt, 2023), and curriculum adjustments based on technical-scientific changes such as the progress toward Mining 4.0, and feedback from the university community and employers. This way this initiative is transformed into a permanent and evolving component of the university´s educational excellence.

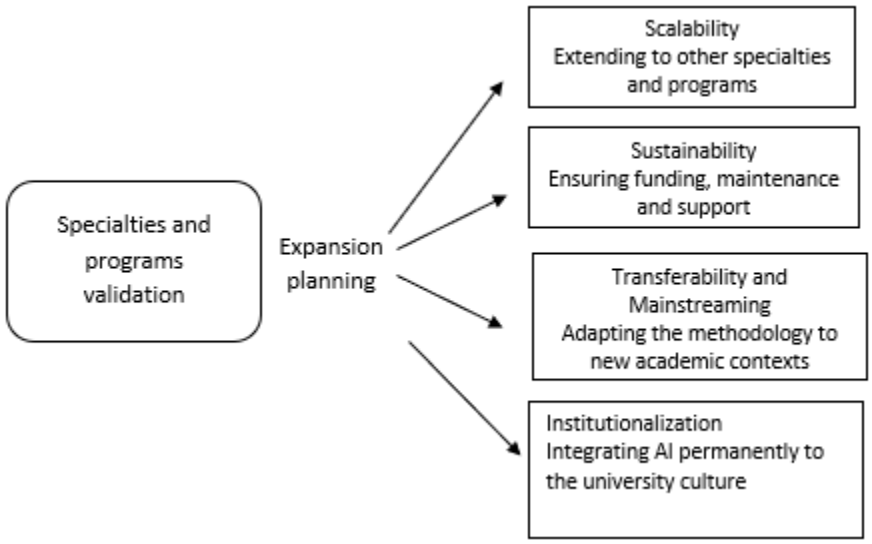

Figure 2. Aspects of project expansion or generalization.

3.2 Expected impacts

The methodology favors AI mainstreaming into the educational process of Geological Engineering, Mining Engineering, Metallurgy and Materials Engineering specialty programs and the selected academic programs, as required by the professional modes of action and technical-scientific advances. The tool Science and Innovation Management System (SGCI), with the use of AI, will classify scientific results generated at the University of Moa, according to their generalization levels, and will identify knowledge gaps, which facilitates the organization of science at the institution and allows for the establishment of accurate research lines of national and international importance.

The economic impact is evidenced by the increase in teaching work efficiency achieved, as it allows effective use of time when teachers integrate AI as a didactic resource. They develop a combination of technical, pedagogical, and ethical skills, while also creating personalized teaching strategies and improving the quality indicators of these processes. Likewise, it contributes to the economic and sustainable development of mining companies by increasing professional competencies and promoting action aligned with the current and future standards of the industry. For instance, the use of intelligent simulators eliminates the need for expensive materials or in situ practices without compromising learning quality.

The social impact is equally relevant, as it will foster the education of professionals more qualified to face the current challenges set by the extractive and metallurgical sector. By facilitating access to cutting-edge technological tools, the technological gap is reduced and greater equity in access to

knowledge is promoted, benefiting both the academic community and professionals; this strengthens university-company ties and promotes social changes in favor of the environment.

From an environmental perspective, AI plays a crucial role when educating engineers to consider sustainability as a fundamental pillar. Through simulations and predictive analyses selected in the project, students can learn to minimize the environmental impacts of extractive and metallurgical activities. This includes optimizing the use of natural resources, reducing pollutant emissions, and efficiently managing waste.

Summing up, the development of the proposed methodology in undergraduate and postgraduate educational processes has the potential to improve the management of higher education quality and to prepare students to face the labor market challenges, where technology plays a crucial role, through pertinent mainstreaming strategies related to their professional mode of action, continuous content updating, studying cases related to their professional profile, as well as transforming the learning experience by providing a personalized experience and improving efficiency to achieve a quality education(SDG 4) that is inclusive and equitable to achieve sustainable development and sustainable lifestyles.

3.3. Knowledge valorization

With the purpose of accelerating the application, dissemination, use, and exploitation of the results obtained with the methodology that form part of the institutional project, the initial diagnosis was designed to raise awareness among the involved university community to identify the results achieved at the University of Moa and the knowledge gaps regarding the implementation of AI in the selected undergraduate and postgraduate programs. To achieve and valorize the expected results, a multidisciplinary team was formed by expert professors in the field of computer science and AI applications, as well as in geological, mining, and metallurgical processes. The following planned actions were included:

Promotion of the use of AI through strategic planning at the University of Moa by using specific goals and indicators. This will ensure that knowledge remains alive and is applied on a daily basis.

Utilization of the University of Moa's university press, which publishes three journals indexed in prestigious international databases, including a Group II journal (Minería & Geología).

Application of strategies for intellectual property management (copyright and industrial property) such as CENDA (Andean Communication and Development Center) registration.

Establishment of connections with other educational institutions and organizations working on integrating AI into education through network creation. This can facilitate knowledge and resources exchange.

Creation of educational materials (guides, tutorials, videos) that incorporate the knowledge acquired during the project. These resources can be used by other teachers and students.

Establishment of mechanisms to evaluate the impact of the methodology on the training processes and obtain feedback from students and teachers for continuous improvement.

Establishment of alliances with companies to apply the acquired knowledge in real-world contexts, which can also open up internship or employment opportunities for students.

Implementing these actions will not only help valorize the knowledge obtained but also contribute to an institutional culture that promotes innovation and continuous learning regarding the use of AI for educating.

4. Conclusions

The diagnosis conducted showed that, in the core programs and postgraduate courses, AI is not effectively mainstreamed as a didactic tool, nor does it appear in the disciplines´ methodological guidelines.

The proposed methodology allows for the integration of AI into the educational processes of the geological, mining, and metallurgical specialty programs and postgraduate programs at the University of Moa. It leads to curricula improvement and favors continuous improvement toward the excellence of university specialties and programs.

The University of Moa consolidates itself as a key agent of change with the development of an institutional project of great relevance and impact.

For the development of the institutional project, within the University of Moa's context, institutional mechanisms, national articulation with the Economic and Social Development Plan up to 2030, inter-institutional coordination, the regulatory framework, information management, and the active participation of the different stakeholders are involved, in strategic alliance with other Higher Education Institutions.

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Author's Contribution according to CRediT Taxonomy

Maday Cartaya Pire: Conceptualization/Investigation/Formal analysis/Methodology/Writing – review & editing/Visualization
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Lourdes García Pujadas: Supervision/Investigation/Writing – review & editing
Yurisley Valdés Mariño: Investigation/Conceptualization/Project administration
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