Prioritization of Educational Strategies in Metallurgy and Materials for Pedagogical Innovation through the Régnier's Abacus

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Abstract: Pedagogical innovation in the teaching of metallurgy and materials is essential to improve educational quality and respond to the industrial and academic sectors. The implementation of effective educational strategies requires methodologies that promote active learning, the incorporation of information and communication technologies, and curricular updating. This work makes an approach to the prioritization of educational strategies in metallurgy and materials using a literature review, semi-structured interviews, and the application of the Régnier's abacus as a way of evaluating and reaching a consensus.
The results highlighted the need to incorporate active methodologies such as project-based learning and collaborative learning in virtual environments; this need also led to the conclusion of the need for teacher training and the integration of digital tools such as computer simulations and virtual laboratories, as well as the urgency to update metallurgy and materials curricula. While this work can provide information to the educational system for decision-making, it is clear that further research is needed to address the impact of these strategies or how they can be incorporated into different training contexts.

Keywords: educational innovation, pedagogical strategies, engineering education, active methodologies, Régnier’s abacus.

1. Introduction

The teaching of metallurgy and materials has followed a process of expansion, accompanied by the increase in the level of demand defined by the industrial world and the academic world (Ralph et al., 2022). The literature emphasizes the need to introduce innovative procedures for the training of engineers, promoting didactic forms for creativity, problem-based learning, or various integrated disciplines (Gajdzik & Wolniak, 2022); in this way, the teaching of metallurgy and materials gives priority to student participation, which is crucial to improve educational quality and knowledge transfer in the area (Matinde, 2018).
One of the innovative methodological tools in education is the Régnier’s abacus, based on its ability to evaluate and prioritize strategies with the visual representation of preferences (Brodeur et al., 2022).

Despite its high potential to improve pedagogical decision-making or to offer a systematic approach to educational innovation, the use of the Régnier's abacus is not usually a common element in the teaching of metallurgy and materials. On the other hand, educational strategies in materials engineering have also moved towards other methodologies that foster critical thinking and innovation, among which project-based learning (PBL) or gamification have been studied to improve teaching in this subject (Varun & Krishnan, 2021).

Similarly, digitalization and hybrid learning have also changed the order in which the contents of materials engineering teaching are presented, increasing interactivity and, at the same time, also allowing more attention to be paid to the personalization of the teaching process through active learning regarding the content (Sanjuan et al., 2021). Studies, such as that of Gajdzik & Wolniak (2022), suggest that creativity and innovation in the activity corresponding to the metallurgical sector are decidedly influenced by the academic offer; while the work carried out by Matinde (2018) suggests that the inclusion of entrepreneurship modules in the materials engineering curriculum could lead to increasing the capacity of students to carry out innovative solutions.

Despite the existence of active teaching methodologies, the selection of appropriate teaching strategies within metallurgy and materials turns out to be a challenge. Furthermore, the lack of criteria by which pedagogical approaches can be evaluated and prioritized results in the application of methodologies without their respective analytical framework (Gao et al., 2022). In this sense, it is necessary to have tools that make it possible to systematize decision-making and favor teaching.

The Régnier's abacus is an alternative to address this issue, as it allows for structuring the opinion of experts and facilitates the choice of teaching strategies based on their degree of importance or application (Godet, 2001). However, the use of this methodology in metallurgy and materials education has been very little researched, which highlights the need to develop research focused on the applicability of the Régnier's abacus.

Therefore, the present study aims to investigate the possibility that the Régnier's abacus method contributes to the prioritization of educational strategies in metallurgy and materials. The research will help to gain new knowledge about the application of the Régnier's abacus method, providing a methodological framework as a way to carry out the prioritization of pedagogical strategies in metallurgy and materials. In addition, this research aims to help identify the most effective educational strategies to facilitate their subsequent introduction into educational plans and, thus, reinforce a more structured and dynamic learning in tune with the needs of the industrial and educational sectors.

2. Methodology

This work is a qualitative study with an exploratory and descriptive design. It is exploratory because its purpose is to generate initial knowledge about innovative educational strategies that encompass the teaching of metallurgy and materials, a field that is still conceptually and theoretically under development (Saengboon, 2016). Due to its descriptive nature, this work attempts to characterize these strategies once interviews with experts have been conducted, as well as an exhaustive review of documents (Creswell & Poth, 2016).

The choice of a qualitative approach is relevant because it allows for an in-depth understanding of the complexity of the phenomenon studied, as it favors the evaluation of the perceptions and experiences of experts on how to prioritize educational strategies (Patton, 2014). This design facilitates detailing the pedagogical dynamics, as well as the various factors that come together in the teaching of metallurgy and materials.

The sample consisted of ten experts in the context of teaching metallurgy and materials. Purposive sampling or convenience sampling was used, since the objective was to be able to contact people who had specialized knowledge on the subject addressed (Etikan et al., 2016). This technique ensures that the participants are people with significant professional and academic experience, thus guaranteeing the quality and relevance of the type of information collected. A sample of ten experts is adequate in qualitative studies to obtain different perspectives and achieve theoretical saturation (Morse, 2000). Likewise, the selection of experts has the virtue of guaranteeing a complete analysis of educational strategies, based on the experience and knowledge of the participants.

Regarding the development of the research, it was carried out in two distinct phases. First, a systematic investigation was carried out by searching academic databases such as Google Scholar and Scopus, using the search strings "educational strategies in metallurgy", "pedagogical innovation in engineering",

"Régnier's abacus in education", and "strategies prioritization in materials science". The documentary review allowed the phenomenon to be contextualized adequately, in addition to providing the basis for the design of the interview guide (Okoli & Schabram, 2015).
The Régnier's abacus technique was then applied to evaluate and prioritize the educational strategies. This technique allows the collection of structured forms of expert opinions in order to assign a score to the strategies according to their weight and their possibilities of implementation. The semi-structured interviews were guided according to a previously designed questionnaire, which was subjected to a pilot test with three participants outside the final sample. An adapted version of Régnier's abacus with scoring scales (Table 1) was used to evaluate the importance of the strategies for teaching metallurgy and materials.

Table 1. Régnier's abacus scale

Dark green	5	Very high priority
Light green	4	High priority
Yellow	3	Moderate priority
Fuchsia	2	Low priority
Red	1	Very low priority
White	0	No response

Source: Authors

Each statement was evaluated with the numerical scale associated with colors that allow for visualizing the consensus among the evaluator population. The color scale has been used to collect nuances in the perception of the experts following the Régnier's abacus methodology.
The main limitations of the research are linked to the sample size, since, although 10 participants are sufficient in qualitative research, a few can condition the generalization of the results (Etikan et al., 2016). However, the purpose of the research is not to make a statistical generalization but to try to understand what the strategies allow. Another limitation is the subjectivity of the qualitative analysis; interpretations can be influenced by experts and/or researchers. To prevent this bias, triangulation between documentary sources and interviews has been used (Denzin, 2017).
Finally, the Régnier's abacus technique requires that the definition of evaluation criteria must be clearly defined and that the experts must be fully active in the research; to ensure the applicability of this technique, a protocol was generated to facilitate the understanding of the instrument by the participants and to facilitate its use.

3. Results

Based on the documentary review and the application of the Régnier's abacus technique, a set of key educational strategies in the teaching of metallurgy and materials were identified and prioritized. These strategies were classified into three categories, representing different approaches to pedagogical innovation:
Innovative methodological strategies. Pedagogical strategies that encourage active learning and problem-solving in real situations, such as PBL and collaborative learning. Strategies for the use of technological and experimental tools: advanced technological tools are introduced in the teaching of metallurgy and materials, such as computer simulators, virtual laboratories, and 3D modeling. Educational policies for pedagogical innovation: incorporation of standards for curricular improvement, teacher training in active methodologies, and the creation of synergies between academia and the industrial sector.
The prioritization of these strategies was carried out using Régnier's abacus, which allows for an evaluation based on the perceptions of experts regarding their application and/or adaptation to the teaching of metallurgy and materials.
Identification and evaluation of educational strategies
The identified strategies were evaluated in terms of importance and feasibility by the experts using the Régnier's abacus technique. Each established strategy was given a score using a color scale, in order to make visible the experts' perception regarding the importance of its impact on the teaching of metallurgy and materials.

Table 2. Educational strategies in metallurgy and materials

Code	Strategy	Description
E1	Curricular update in metallurgy and materials	Review and modification of the study programs to include content aligned with the industry's current needs and sustainability.
E2	Collaborative learning in virtual environments	Use of digital platforms to encourage teamwork and discussion of problems in teaching materials.
E3	Computational simulation applied to materials	Implementation of simulation software to visualize metallurgical processes and evaluate the behavior of materials in different contexts.
E4	Teacher training in active methodologies	Training of teaching staff in innovative teaching approaches, promoting adaptation to new pedagogical models.
E5	3D modeling and additive manufacturing	Incorporation of technologies such as 3D printing to facilitate the analysis and understanding of structures and properties of materials.
E6	Project-based learning (PBL)	Methodology in which students solve real problems applied to metallurgy and materials, promoting autonomy and critical thinking.
E7	Use of virtual laboratories	Application of interactive virtual environments that allow experimentation with materials and metallurgical processes without requiring physical laboratories.
E8	Creation of collaboration networks between universities and industry	Establishment of strategic alliances with companies to facilitate the transfer of knowledge and the integration of teaching with the productive sector.

Source: Prepared by the authors based on expert evaluation.

Evaluation of strategies using Régnier's abacus

The Régnier's abacus technique allowed the prioritization of strategies to be visually represented through a chromatic scale, assigned based on the degree of agreement between the experts. The strategies were structured in a matrix where the rows corresponded to the strategies evaluated and the columns for each expert. Table 3 shows the distribution of responses in terms of colors according to the participants' evaluation, reflecting the levels of consensus reached.

Table 3. Prioritization of educational strategies according to expert evaluation

E6	Project-based learning (PBL)										
E3	Computational simulation applied to materials										
E7	Use of virtual laboratories										
E5	3D modeling and additive manufacturing										
E2	Collaborative learning in virtual environments										
E4	Teacher training in active methodologies										
E1	Curricular update in metallurgy and materials										
E8	Creation of collaboration networks between universities and industry										

Source: Prepared by the authors based on expert evaluation.

The results show that the most prioritized strategies are related to the implementation of active methodologies and the use of technological tools in the teaching of metallurgy and materials. PBL obtained the highest priority, with a strong consensus among experts on its effectiveness in improving students' practical learning.

Experts highly valued computer simulations and virtual laboratories, as they allow metallurgical processes to be replicated without the costs and risks associated with physical experiments. On the other hand, 3D modeling and additive manufacturing were highly agreed upon, however, some experts indicated that they need a greater infrastructure to be implemented. Collaborative learning in virtual environments was also highly valued, although some experts indicated that its applicability depends on the levels of interaction between students and the availability of technological tools.

On the other hand, experts considered that teacher training and curricular updating are necessary, but they also warn that their impact depends on the willingness of higher education institutions to give rise to more dynamic training models. Finally, the creation of collaboration networks with industry was the strategy with the least consensus, given that its viability is subject to the existence of companies willing to participate in academic training.

4. Discussions

The results of this study have determined the priority educational strategies for teaching metallurgy and materials. Within this framework, those that combine active methodologies, technological tools, and educational policies for the innovation of the educational system stand out above the others. The use of Régnier's abacus has proven to be an effective technique to systematize and give structure to the prioritization of strategies since it allows for having a certain vision about the degree of consensus and the discrepancies between the participating experts.

One of the most relevant conclusions that could be drawn from this study is the fact that above all the other educational strategies used to teach metallurgy and materials, PBL is clearly the preferred one. This would align with the work of other authors, in which it has been shown that PBL helps to make learning meaningful since it allows for posing problematic situations, performing the required tasks, and developing problem-solving skills, in an authentic context (Kolmos et al., 2016).
Similarly, the high valuation of collaborative learning in virtual situations shows the need to use digital tools to improve interaction and co-construction of knowledge in engineering education. The literature highlights that collaborative spaces promote the understanding of complex concepts and group work in the teaching of metallurgy and materials (Bilyatdinova et al., 2016).
On the other hand, the use of cutting-edge technologies has also been one of the educational strategies chosen when evaluating the teaching of metallurgy and materials. Computer simulation applied to materials, virtual laboratories, 3D modeling, and additive manufacturing have been indicated as highly preferred, so the use of this educational strategy can be extended to the digitalization and virtualization of metallurgy teaching.
Previous work has shown that these technologies facilitate students' better understanding of metallurgical processes and material characterization, without the cost and safety limitations associated with the use of traditional laboratories (Muthusamy et al., 2005). Similarly, three-dimensional modeling and 3D printing are effective tools for representing complex structures and enriching teaching in the context of materials science (Edgar & Tint, 2015). Despite their high rating, some experts pointed out that the use of these technologies holds some problems such as access to infrastructure and teacher training for their implementation. These comments align with studies such as the one carried out by Velychko et. al (2022) who emphasize that teacher training is what is needed to help these types of tools be effectively integrated into the classroom.
The need for the teaching curriculum of materials metallurgy to be continuously updated by revising the curriculum in order to integrate new trends such as the adoption of sustainable materials or manufacturing techniques was also highlighted, since in this way engineering teaching is adapted to the needs of the sector, allowing it to keep pace with its evolution (Sanjuan et al., 2021).
Finally, the creation of collaborative networks between universities and industries, one of the strategies that led to a diversity of opinions among experts since while some of them accept the importance of alliances between universities and industry to help better train students, for others the logistical difficulties and the lack of incentives in the industry are perceived as obstacles to its implementation. These findings are consistent with previous research indicating that collaboration between academia and industry continues to be a challenge in the training of engineers, despite its potential to increase the employability of graduates (Bédard et al., 2012).
This study has certain limitations that are considered when interpreting the results. Firstly, the number of experts consulted, although sufficient for theoretical saturation, can be expanded in future research, thus increasing the diversity of points of view. Furthermore, the prioritization of strategies based on Régnier's abacus depends on the clarity with which the evaluation criteria are stated, which entails a possible need for subsequent validations in other educational contexts.
For future research, it is recommended to explore the impact of the implementation of these strategies on the academic performance of students and their applicability at different educational levels. Likewise, it would be useful to analyze the impact of the incorporation of emerging technologies, such as artificial intelligence and augmented reality, in the teaching of metallurgy and materials.

5. Conclusions

In conclusion, the findings of this study have allowed for identifying priority strategies for teaching metallurgy and materials, highlighting the importance of active methodologies, the use of advanced technologies, and curricular updating. The application of Régnier's abacus has been a valid tool to shape decision-making in improving pedagogical innovation, as well as in future implementations in the educational context.
The teaching of metallurgy and materials is evolving, and the results of this study can serve as a reference for improving metallurgy and materials engineering programs. However, its success will depend on the capacity of educational institutions to assimilate the strategies and adapt them appropriately, thus guaranteeing the quality of teaching, meeting the requirements demanded both in the sectorial and educational spheres.

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