Application of Engineering Processes in Educational Scenarios: a literature review

Aplicación de Procesos de Ingeniería en Escenarios Educativos: una revisión de literatura

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RESUMEN

Este documento, en su primera parte, aborda el contexto en que se desarrolla la ingeniería pedagógica o instruccional. Posteriormente afronta la conceptualización teórica de cómo la ingeniería ha sido empleada en procesos educacionales y las diferentes formas de aplicación en dicho contexto educativo. Revisa la metodología de revisión bibliográfica utilizada: bola de nieve. Finaliza con un recorrido por distintas experiencias de aplicación de la Ingeniería pedagógica o instruccional.

Palabras Clave: *Ingeniería educative; diseño instruccional; pedagogía; educación; tecnología.*

ABSTRACT

The first part of this document addresses the context in which engineering pedagogy or instructional engineering is developed. Subsequently, this work addresses the theoretical conceptualization of how engineering has been used in educational processes and the different ways of applying it in the context of education. Review the literature review methodology used: snowball. The paper concludes with an overview of different experiences in the application of engineering pedagogy and instructional engineering.

Keywords: *Educational Engineering; Instructional ; Design; Pedagogy; Education; Technology.*

1. INTRODUCTION

Technology-mediated learning has reached a moment of maturity characterized by defined standards that have been assumed by universities, industry, and technological tool suppliers. Similarly, there is an evident commitment to the quality of computer platforms and the production of content for education. Additionally, the achievements obtained with information and communication technology (ICT) -mediated learning are related to the way that this approach fits into learning environments and the expectations regarding its contributions in virtual scenarios.

However, the development of learning approaches such as e-learning, m-learning or, more recently, u-learning has revealed problems associated with teaching and learning processes. Regarding obtaining complete and complex representations, it is necessary to have effective and efficient technological mediation, to determine the limits of the control of instructional sequences of activities and to merely fulfill proposals and curricular plans [1].

These issues imply that the design for a learning process should also consider the importance of collective construction actions, derived from the interactions both between learners and between learners and digital content. Therefore, the combination of good pedagogical modeling and an optimal structure in notation, representation, and communication, aimed at configuring virtual or mixed education scenarios, can facilitate the fulfillment of learning goals.

This document review of literature introduces the reader to current teaching and learning approaches that aim to extract the best practices from processes in the field of engineering to be applied in complex educational environments.

2. LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

Engineering has permeated various fields of our daily life, and studies [2] argue that this dynamic exemplifies the impact of engineering in important areas such as education.

Applying engineering steps and methodology to educational sciences, three levels of action can be analyzed: macro (social engineering), meso (training engineering), and micro (engineering of pedagogical processes) [3].

Based on this analysis, three tendencies can be distinguished. First, social engineering, a concept taken from political science, refers to strategic or political planning by governments or private groups to influence attitudes and social behavior on a large scale.

Second, training engineering considers the organizational, economic, methodological, technical, pedagogical and didactic dimensions of a training activity [4]. In this regard, Hynes recounts the experience of teachers from six secondary schools who applied the process of engineering design in their classrooms [5].

Finally, engineering pedagogy focuses on educational media and instructional resources inherent to teaching and learning processes [3]. This approach aims to guarantee quality and relevance at different stages of training by using all teaching methods and possible tools to achieve knowledge transfer. It is framed from macro planning (educational technology) to the micro dimension (instructional design).

Recently, the use of social networks such as Twitter and Facebook as tools for education was analyzed in [6] and [7]. Furthermore, other studies [8] emphasize that the key elements of engineering are the systematic perception of the elements of processes and their couplings, the goals aimed at the objectives of the process and the need for feedback measurements to successfully achieve these goals.

Table 1 - Relationship between pedagogical concepts and terms used in engineering.

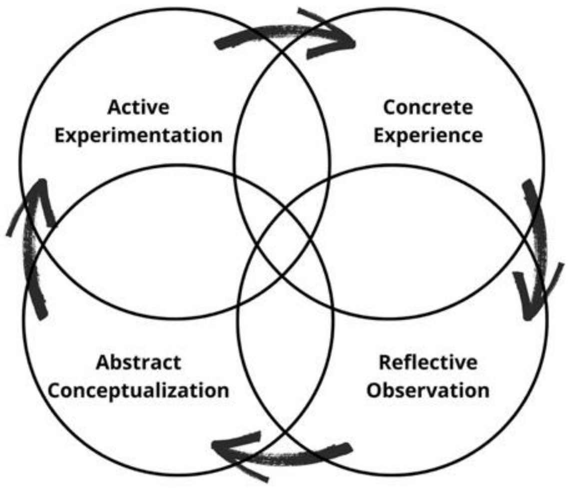
Pedagogical concepts	**Terms associated with engineering**
Learning objectives	Goal-oriented objectives Control reference signals Regulating
Formative and summative assessment	Measurements Comments
Learning is a dynamic process in general	Dynamic systems

Source: prepared by the authors

Table 1 presents a relationship between concepts and terms from pedagogy and engineering. This information also suggests a correlation of activities between the two fields and could allow us to find common ground to explore a joint evolution of both aspects.

In summary, pedagogical processes can be assessed from the point of view of engineering, given its broad theoretical framework and the diversity of tools for analyzing these processes.

Figure 1 - Kolb learning cycle. Source: prepared by the authors based on [8]



To support this claim, Kolb's experiential learning model (Figure 1) makes it evident that students should be able to immerse themselves in new experiences; demonstrate skills and make observations from multiple points of view; conceptualize these observations and experience through their integration with theories; and finally, use these theories to make decisions and solve problems. Therefore, students effectively learn four skills: concrete experience, observation, conceptualization, and active experimentation. Optimal learning occurs when an adequate balance of these four variables is developed.

These are the stages of knowledge creation based on experience [9]. Learning requires that individuals must first detect, represent, or capture knowledge and then undergo a construction phase that allows carrying out the learning process. This construction involves a transformation of knowledge comprising a mental model and knowledge experience.

Likewise, Sánchez highlights the constitutive elements of the engineering's pedagogical processes: educational technologies, instructional design and pedagogical tools [10]. The first element, according to Chadwick, involves the application of a scientific and systematic approach with associated information to improve education in all its manifestations and diverse levels [11]. Furthermore, according to Berger and Kam, instructional design refers to the creation of detailed specifications for the development, implementation, evaluation, and maintenance of situations that facilitate the learning of small and large content units at different levels of complexity and, pedagogical tools, are the set of instruments, techniques, methods or strategies for the development of a) processes of thinking and creative thinking, b) synthesis, comparison and gathering of information, c) analysis and conceptualization and d) social thinking and emotional and social intelligence [12].

3. METHODOLOGY

Initially, the interpretations of [3] [4] [8] [9] [15] and [16] were examined, who coincided on views regarding the definition of the term "Pedagogical Engineering." This type of method is known as snowballing and is characterized by finding relevant literature based on a specific set of documents, articles, and authors that address the identified themes related to the study object. Subsequently, specific inquiries are conducted on certain categories or investigative interests that have been identified [13]. [14] point out that the snowball search method can be summarized in three steps: 1) initiation of searches in key reference sources such as journals, conferences, or tracking concepts of particular authors to obtain an initial set of references of interest in the area, 2) review of reference lists and bibliographies found in the documents from step 1, and 3) identification of articles citing the articles found in the previous steps.

In this sense, a bibliographic search was carried out in books and bibliographic databases such as: Scopus, Science direct, Elsevier, among others, as well as in academic google using the descriptors: Educational Engineering, Instructional Design, Engineering Pedagogy. The records obtained were around 350.000 after the combination of the different keywords. The selection of documents was made prioritizing those that covered formal aspects regarding Educational Engineering, Instructional Design and pedagogy for engineering, as well as significant experiences in the application of technology for curricular design.

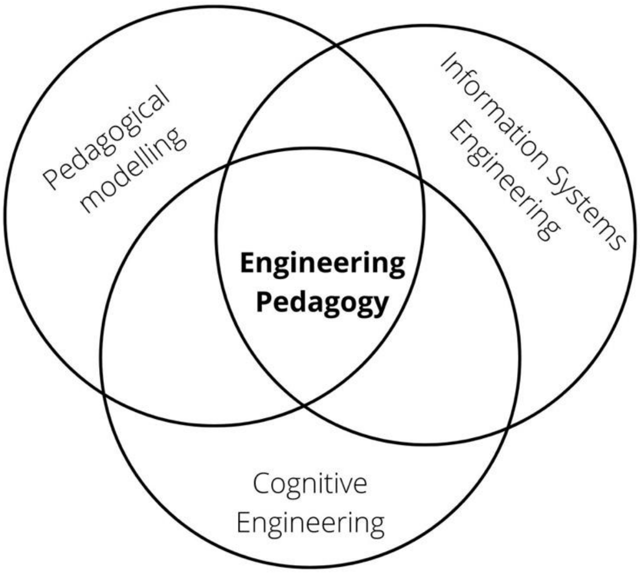
4. RESULTS AND DISCUSSION

Before proceeding with a detailed review of the uses and applications of instructional engineering, it is important to address the different definitions that allow us to conclude that both this and engineering pedagogy have the same structure and purposes and that the difference in terminology is derived from the different translations and meanings of the word "pedagogy" in English and French. In fact, the documentary references consulted and the information available in different journals, papers, databases and books validate this interpretation.

In this sense, Engineering pedagogy is a fundamental component for the transformation of education because it allows moving from disciplinary knowledge, characterized by academic rigor, homogeneity in skills and hierarchical structure, to the construction of knowledge based on interdisciplinarity, transdisciplinarity and the development of competencies [15].

Likewise, according to Paquette, engineering pedagogy involves the analysis, conception, realization and planning of learning systems and integrates the concepts, processes and principles of pedagogical modeling, software engineering (also known as information systems engineering) and cognitive engineering, as shown in Figure 2 [16].

Figure 2 - Systemic methods of engineering pedagogy design, Source: prepared by the authors based on Paquette [16]



It is evident that pedagogical design incorporates a set of theories and models that allows us to understand, improve and apply teaching methods that favor learning, such as in [17], [18] and [19]. These models have been applied to assess the commitment of students in engineering classes, the teaching of environmental sustainability and the boundaries between formal and informal education. Regarding the theories developed in the psychology of learning, pedagogical design can be seen as a form of engineering that leads to improving educational practices.

The relationship of engineering with pedagogy is analogous to that of an engineer with respect to the physical sciences or that of medicine with respect to the life sciences [16]. The result of pedagogical design is a set of plans and provisions that describe the development of learning and teaching activities. Such plans group a set of prescriptions that favor learning rather than a description of the learning processes. This approach represents a contribution, in turn, to training in the health sciences [20]. This can be useful to understand educational models in the field of engineering.

Likewise, software engineering offers some interesting solutions to satisfy the demands required by the technologies used in a Distributed Learning System (DLS) [21]. The authors consider that a learning unit and its distributed environment are part of an information system composed of a complex set of software tools, digital documents, and communication services. In this way, with the adaptation of the principles of software engineering to the principles of pedagogical modeling, instructional engineering has well-defined processes and principles that help produce the described deliverables with precision. Some of principles and tools that software engineering brings are: systematic design modeling, reusability and modularity, version control, agile methodologies, data-driven decision making, user-centered design, automated assessment and feedback, quality assurance and project management and collaboration tools [21].

Finally, cognitive engineering focuses on the identification and structuring of knowledge using a graphic representation or a symbolic language to facilitate its use by people and/or computer systems. In engineering pedagogy or instructional engineering processes, cognitive engineering is fundamental for modeling knowledge processes or workflows that guide designers in their tasks to define content and objectives and use them as an orientation for the design of educational scenarios, learning objects or educational resources, as well as the deliverables of a learning system.

In general, engineering pedagogy comprises the main steps of a systems approach to problem solving, namely, defining the problem, analyzing it, developing a solution, developing a respective action plan and evaluating the implemented proposal. Therefore, engineering pedagogy considers all global dimensions of a technology-mediated learning project.

Menéndez and Prieto, paraphrasing the IEEE committee, concluded that "instructional engineering is the application of a systematic, disciplined and quantifiable approach to the development of instructional design and, consequently, to the exploration and maintenance of digital resources for learning" [22].

Additionally, the authors highlight that instructional engineering provides solutions for areas as diverse as instructional design, the management of learning objects and the semantic search and recovery of resources based on repositories. They also note that the central objects of instructional engineering studies are teaching and learning in general, with its purpose being the evaluation and exploration of resources, technical methods and instruments to facilitate and guarantee achieving the intended results. Thus, the applicability of this strategy extends to systems such as web recommenders, performance support systems and learning management systems.

Engineering pedagogy or instructional engineering is defined as a system that aims to develop other systems: learning systems. According to Newell and Simon, it can be formulated as a complex problem-solving process that finds its definition in the cognitive sciences [23], which has been studied by authors, such as Romiszowski [24], Reigeluth [25], Tennyson [26] and Merrill [27].

In the same sense, the problems addressed by engineering pedagogy are, initially, only problems; they then become design problems (similar to architecture or mechanical engineering), pedagogical design problems and, finally, pedagogical design problems that require the didactics of one or more disciplines [16]. The study of each of these four levels of problems provides a useful reference framework for the conception of an engineering method of learning systems. According to Paquette, the general model of problem solving in cognitive sciences invites us to characterize the process of engineering pedagogy in the following terms:
1) an initial state: an approximate definition of the problem to which the learning system must respond,
2) a final state: the learning system that must be built,
3) operators, or processes, that will allow transforming the initial definition of the problem into increasingly precise descriptions until reaching the concrete realization of the process.

Based on [28], the systemic approach to solving problems guided by methodological rules is based on five phases or processes:
1) The definition of the problem,
2) The analysis of the problem to find possible paths to the development of a solution,
3) The development of a solution plan, i.e., the identification of operations, stages, phases, or means by which the current situation can be transformed to achieve the desired outcome,
4) The application or implementation of the solution plan,
5) The evaluation of the solution and the review for feedback or reuse in similar problems.

The usefulness of this method for engineering pedagogy is that it allows an analyst to decompose complex learning problems into simpler questions, where a solution can be imagined and then combined with other partial solutions. According to Paquette, the implementation of this methodology eases recognizing the development of the plan, that is, the conception of a pedagogical provision or course plan and its implementation, the choice of media support, and the integration of tools and media [16]. This methodology allows an evolution phase in which the system can be reviewed, if necessary, before implementing the learning system.

Regarding the methodologies used in instructional engineering or engineering pedagogy, there are many variants, among which we can highlight the learning systems engineering method (MISA, for its acronym in French), a methodology that helps with the design of learning systems for e-learning formats and that seeks to make its products legible and constantly evaluable in terms of quality. Its objectives are to facilitate communication between the actors involved, to organize the design without limiting creativity, to produce learning systems, to allow various uses for each learning system created and to maintain consistency and unity between the content produced.

Applications of engineering pedagogy

In assessing the effective use of engineering pedagogy or instructional engineering in previous studies, it is necessary to reiterate that because engineering pedagogy lies at the intersection of three fields of knowledge, there are many computational tools that allow us to demonstrate the presence of this discipline in processes that support learning dynamics mediated by technology.

Notably, in [16] used systemic methods for the design of educational scenarios for engineering pedagogy, pedagogical modeling, cognitive engineering, and software engineering. As part of engineering pedagogy, educational applications supported in instructional design, the pedagogical design of serious games, collaborative learning supported by technologies and the pedagogical use of networks (social, learning, among others) were included.

According to the above, the following studies detail the use of engineering pedagogy or instructional engineering concepts and tools:

Learning unit production in Télé-Université in Québec (Canada) [16]

This paper presents advances in the use of instructional engineering in a Canadian university. The authors describe a method for instructional engineering called MISA 4.0 (in French, Méthode d'ingénierie des systèmes d'apprentissage), which is a Research & Development project that began in 1992 and whose background is the ADISA system (In French: Atelier distribué d'ingénierie de systèmes d'apprentissage) elaborated by the Gilbert Paquette Research Group in 2001.

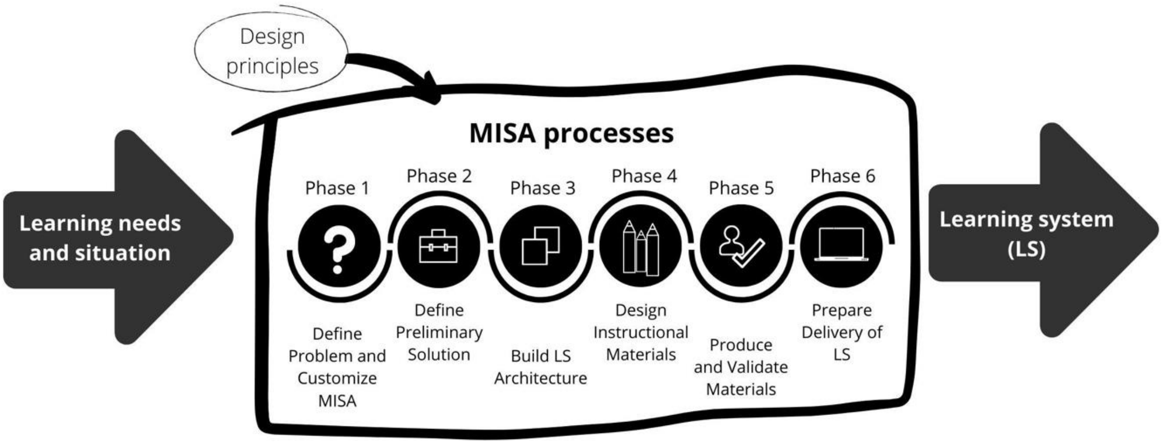
MISA supports more than 35 main tasks and processes developed by the Laboratoire d'Informatique Cognitive et d'Environnements de Formation, Télé-université, Montréal - LICEF [14]. It is based on knowledge modeling and handles all the components of a learning system.

It is supported by tools such as modeling for object types (MOT) (in French: *modélisation par objets typés*) to allow the creation of a graphical representation of knowledge in the same way as a formal representation. The following are its four main axes:

1) Content design, which allows the modeling of knowledge and skills,
2) Pedagogical design, scenarios, activities and other related topics,
3) Support for the development of new educational materials,
4) Deployment planning.

MISA is based on a problem-solving approach. The method begins with the identification of an educational problem, its context and limitations, and its general focus. It continues with the definition of the preliminary solution. Then, it passes to the construction of the architecture of the learning system (particularly the elaboration of knowledge, competencies, and teaching models) and the instructional design of educational materials. It finishes with modeling, production, and validation of the learning materials and the specification of deliverables of the learning system as well as its maintenance and quality management procedures.

Figure 3 - MISA phases, Source: prepared by the authors based on [16]



After the Global Learning Consortium – IMS (for Instructional Management System project) adopted the Educational Modeling Language (EML) as a basis for a specification standard, MISA was used to produce learning designs that could be read by any compatible learning content management system (LCMS). Hence, learning design specifications and the MISA method can complement the teaching method proposed in the previous graph. Notably, the MISA method also appears to be a promising alternative for Unified Modeling Language (UML), mainly because it is based on the theory of instructional design and has been built supported by the actions used by the human mind to achieve processes of education and training.

Integrated model for the design of operational processes of a learning system

A general approach that facilitates the modeling and exploitation of learning systems is presented in [27]. These authors establish an analogy in which systems of goods and services production (associated with systems engineering) can be applied to learning processes through the application of these three main phases: the design of a product or service and its manufacture, planning, and programming to achieve the objectives of the products or services. In this text, the modeling of a learning system is shown using methods developed to produce modeling systems such as UML.

Thus, the authors describe their modeling methods and the results obtained, in addition to some applications associating them mostly with tools adapted and developed to respond to the requirements of learning systems. These applications are focused on the definition of training paths in a planning matrix and a proposal for the programming of training courses in learning systems. All these pieces are connected to each other to create a computer-assisted integrated system to help the operational process of designing an efficient learning system.

The project was divided into two phases: it first focused on the operational process to present a detailed UML model that would facilitate the design of formative itineraries adapted to the learning expectations of system users (after consultation with them); it then focused on the planning and implementation of the courses by integrating all restrictions related to the functionality of the system.

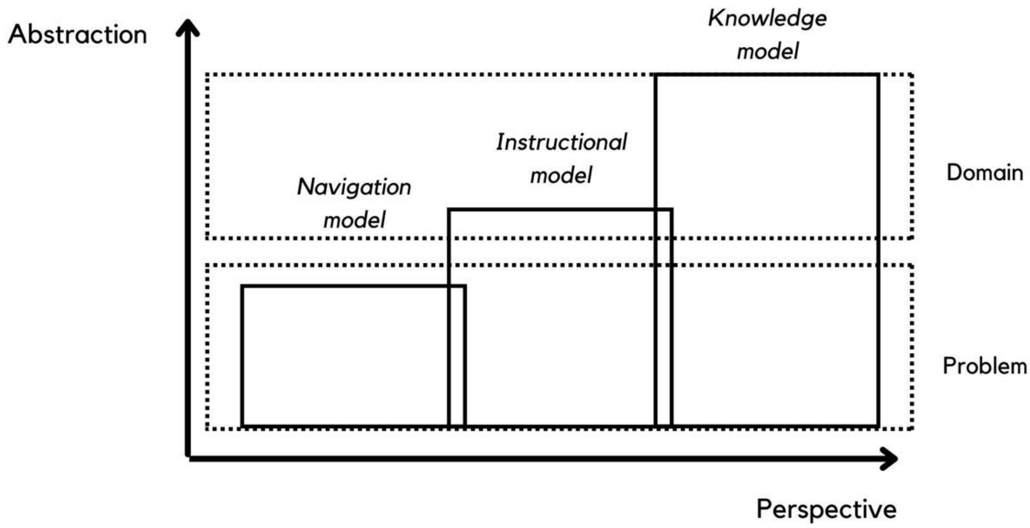
Finally, there was significant difficulty because the number of activities required to carry out the training processes was unknown. However, at each stage, they sought to adapt the computational tools to the context and to the limitations of the learning systems.

Instructional engineering analysis method

This work recognizes the analysis phase as an essential step in the development of information systems and especially in the development of software as support for learning. The diversity of capacities, needs, and interests of stakeholders must be considered to adapt it to a variety of contexts and pedagogical paradigms. This work examines two current trends in software engineering dedicated to the optimization of information systems development: aspect-oriented software development (AOSD) and model-driven architecture (MDA). It also notes that the combination of both mechanisms can facilitate the development of computer systems that support learning.

Therefore, the authors propose a method of analysis for the development of learning materials based on the mentioned software trends—AOSD and MDA. They take as a case study the processing of profiles and preferences of users from the perspective of instructional design. These profiles are an essential aspect in the design of learning systems using the navigation model, the educational model and the knowledge model. The difficulty in the analysis of learning systems is represented in Figure 2, where it is observed from different perspectives and levels of abstraction.

Figure 4 - Perspectives and levels of abstraction. Source: prepared by the authors based on Fernández, & Dodero [30]



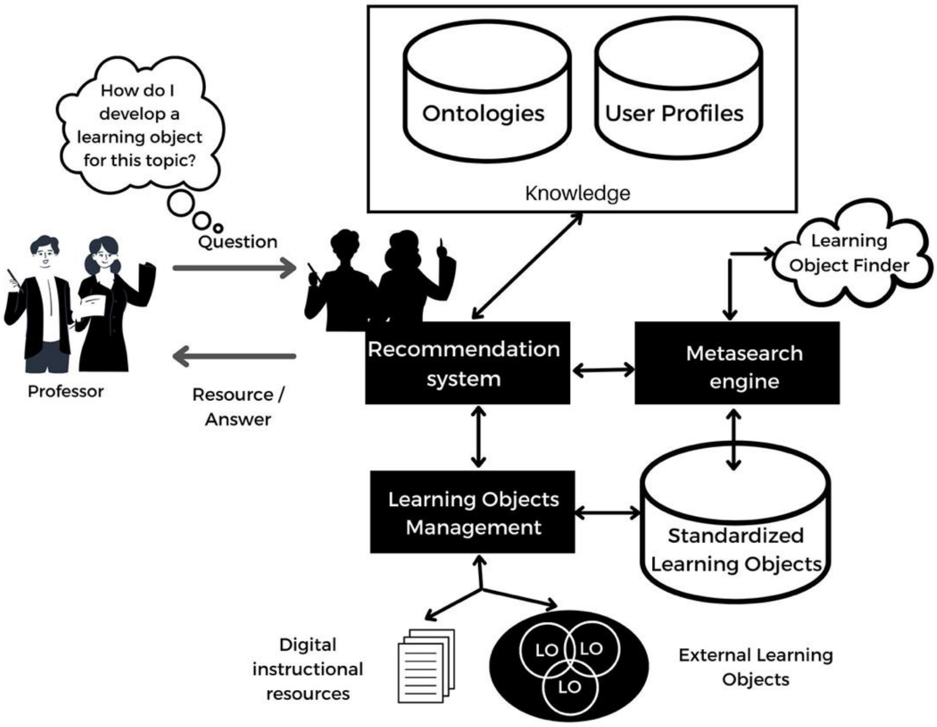
The development of the proposed system is driven by three levels of abstraction: the computation independent model (CIM), the platform independent model (PIM) and the platform specific model (PSM). This is how we propose a method of instructional engineering analysis based on the use of AOSD in the framework of MDA. Two issues are identified: independent properties (vertical stripes) and transversal properties (horizontal stripes). Based on the previous graphical representation in which the combination of the AOSD and MDA methodologies is shown, the method of analysis proposed by the authors considers the following guidelines: 1) The analysis of the learning problem is addressed at the CIM level and involves mapping the description of the problem in the system properties, 2). The functionality of the learning system takes place at the PIM level, 3). Each of these levels will be divided in turn into several perspectives based on the points of view involved in the system.

The developers of this experience conclude that the definition of instructional or engineering pedagogy methods for the analysis phase of a learning system represents an advance in creating educational materials. However, to ensure the usefulness of this improvement, it is essential to test the capability of the analysis methods for complex systems with a high degree of overlap. In fact, [30] assert that learning analysis is a method that guarantees the complexity condition based on AOSD and MDA.

AGORA platform

This platform is used to develop infrastructure for instructional design. One of the most important objectives is to provide solutions for the management of learning objects, serving as an example of the application of instructional engineering methodologies. The platform is composed of an instructional knowledge base comprising ontologies, a module for the comprehensive management of learning objects, a semantic metasearch engine specialized in e-learning resources, a method and tool for the evaluation of digital resources, and a recommendation system capable of supporting the design, search, recovery and reuse of learning resources, according to [31].

Figure 4 - AGORA platform, Source: prepared by the authors based on Prieto & Menéndez [31]



Specification of educational configuration patterns through ontologies
This proposal is inspired by the standard specification of language processes in commercial areas and considers the philosophy of patterns used in the field of software engineering. The specification developed by Rius et al.[32] proposes an open framework to formally describe generic processes that usually occur in learning environments as educational configuration patterns. The main contribution of this document is an extensible ontology for specifying processes in learning environments. This ontology aims to improve the reuse of its formal specifications regardless of the educational institutions where the processes and learning platforms that support them occur. The proposal is embodied in terms of computer-aided software engineering (CASE) to facilitate its representation.

Implementation, deployment, and evaluation of a mobile personal learning environment
Conde et al. [33] proposed a service-based approach to define personal mobile learning environments that facilitate communication with institutional learning platforms. This approach is implemented as a prototype and is evaluated through a pilot study to demonstrate which types of mobile learning platforms are feasible and can increase motivation to facilitate student learning.

Development and usability of a diagram based on the collaborative brainstorming component
Another example of the application of the fundamentals of engineering pedagogy for the improvement of learning processes is the study by Azevedo et al. [34], which develops a tool that allows effective collaboration in creating, evaluating, discussing, and revising different models for the process of knowledge creation, such as the construction of strategies, the analysis of scenarios, the analysis of cause-effect, Ishikawa diagrams and brainstorming. The approach involves a synchronic collaborative diagram editor for exchanging ideas integrated into a flexible group support system. The usability of the approach adopted is evaluated in a case study on collaborative learning.

Evaluation of open questions using a multidimensional approach for the interaction and collaboration of students in e-learning environments

Hoang & Arch-Int [35] created a multidimensional assessment (M-DA) method that achieves greater compatibility with learning. In this method, students are not limited to giving answers that are compared with the teacher response. Rather, the student is evaluated based on the activities developed and the understanding of knowledge, allowing for improved collaboration and interaction between students, which is necessary for e-learning and social learning networks. This system proposes an algorithm where students, in addition to answering teachers' questions, can comment on and interact with the responses of other students, encouraging participation. The application of this model showed better performance than a model that did not use the M-DA method.

Architecture proposal for educational environments

According to Garrido et al. [36], current technologies allow an educational environment that offers students and teachers functionality and information at any time, regardless of location and circumstances. These environments combine three notable characteristics, namely, ubiquity, sensitivity to context and collaboration, which allow us to avoid errors when performing activities. Additionally, the system architecture is defined as the first step in obtaining the proposed environment. Its design is embodied in software and hardware architecture, in which the software controls how the system distributes functionality and information in the hardware components that will be used, such as smartphones, servers, and communication elements.

From mixed learning to inclusive learning: accessibility, profiles, openness, and higher education

Finally, on [37] specified the need for studies to understand the requirements of users and identified their profiles to enhance the quality of the online teaching-learning process. In this sense, they specify that the identification of the profiles of teachers and students and their needs as users of a course management system is an important input to ensure the quality of a b-learning process, with a more complete interface, toward inclusive learning. Through 68 face-to-face interviews, four profiles of professors (focused on activities, interaction, evaluation, and collaboration) and three profiles of students (oriented toward interactive learning environments, training, and teachers' beliefs) are revealed. This study supports an inclusive, multidimensional, and holistic understanding of ICT to choose teaching-learning strategies for the improvement of accessibility and inclusion in learning environments.

5. CONCLUSIONS

The application of engineering in education allows the development of result-oriented processes. The instructional design facilitates creative thinking processes in addition to the synthesis, comparison, contrast, and analysis of information, conceptualization, social thought, and emotional intelligence.

Specifically, instructional engineering or engineering pedagogy is fundamental for transitioning from disciplinary cohorts to interdisciplinary and competency-based cohorts. Therefore, to improve educational practices by integrating pedagogical modeling, cognitive engineering, and information systems, sets of activities that promote learning, as opposed to simply describing learning processes, must be developed; that is, a problem-solving complex is required to transcend design.

Therefore, engineering pedagogy develops its potential to the extent that it seeks to improve the functioning and productivity of learning activities in varied environments (virtual and blended). The systemic approach of instructional engineering has contributed to rethinking learning processes from diverse perspectives, and models for the design of blended environments are still in development, which enables an effective articulation between face-to-face, virtual and mobile learning approaches.

In reviewing the four implementations of engineering pedagogy or instructional engineering, the importance of pedagogical modeling, the use of software engineering methodologies and the analysis of systems that tend toward cognitive engineering or knowledge stand out. This discipline allows us to articulate the theoretical and methodological positions of education and didactics with the terms of normalization and codification of processes and procedures that have been developed over several years in some branches of engineering.

Besides, the constant evolution of tools and technological platforms to support virtual learning activities demand the construction and adaptation of new educational scenarios, where interaction, viewed as collaboration among learners, is still a field of both conceptual and real application development. A process of change in design orientation can begin as soon as there is awareness that the technological tools and applications must respond to the requirements of educational design.

Finally, the MISA Model, the AGORA platform, and Instructional Engineering were presented. The MISA Model stands out for its focus on integrating technology in learning. AGORA centers on a comprehensive analysis to identify educational needs and objectives. On the other hand, Instructional Engineering encompasses the entire process of educational design and evaluation systematically. A future research study could analyze the effectiveness of the MISA Model in promoting collaboration and access to digital educational resources in higher education. Additionally, investigating how AGORA contributes to personalized learning considering different student profiles could be valuable. Moreover, exploring how Instructional Engineering enhances the quality of teaching and the achievement of educational objectives in higher education institutions would be beneficial. A comparative and qualitative analysis could provide a deeper understanding of the applicability and benefits of each model in higher education, optimizing the design of effective and student-centered learning environments.

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