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Teaching control theory: a selection of methodology based on learning styles

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Abstract
This research results from the need to establish a connection between educational methodologies and students' learning styles so that students can understand concepts with a high level of abstraction, such as control concepts. For this, definitions for learning, learning styles and active educational methodology from an engineering perspective were proposed. Then, a review of the literature on the use of learning styles in engineering, specifically in the area of systems control, is also presented. Finally, a methodology with a laboratory approach, integrating active methodologies and a learning style model, to teach control concepts was proposed.

Keywords: active methodology; control systems; engineering education; learning styles.

Enseñando teoría de control: una selección de metodología basada en estilos de aprendizaje

Resumen
El objetivo de esta investigación fue establecer una conexión entre metodologías educativas y los estilos de aprendizaje de los estudiantes, para que estos mejorarán la comprensión conceptos de alto nivel de abstracción como los conceptos de control. Para ello, se propusieron definiciones de aprendizaje, estilos de aprendizaje y metodología educativa activa desde una perspectiva de educación en ingeniería. Luego, se presenta una revisión de la literatura sobre el uso de los estilos de aprendizaje en ingeniería, específicamente en el área de control de sistemas. Finalmente, se propone una metodología con un enfoque de laboratorio para enseñar conceptos de control, integrando metodologías educativas activas y un modelo de estilos de aprendizaje.

Palabras clave: metodología educativa activa; control de sistemas; educación en ingeniería; estilos de aprendizaje.

1. Introduction

Currently, there are several educational methodologies, which are transformed according to the job skills in each profession, to teach in any subject. For example, the training of professionals in engineering careers requires methodologies that combine the teaching of theoretical concepts and practical skills [1-4]. Specifically, the topic of dynamic system control has a high level of abstraction, which complicates the understanding of concepts by students because of the diversity of the mathematical content, such as the Laplace transform, differential equations, and complex numbers, that are used to explain the concepts. Therefore, in this case, it is necessary to implement methodologies that combine theory and practice in order to facilitate correct understanding by students [5-7].

In addition, it is necessary for students to acquire not only technical skills but also soft skills in their training process. These skills, such as the skills to work in multidisciplinary teams, to communicate effectively, to understand the ethical implications of their professional performance and to develop long-term self-learning capacities, among others, will enable students to integrally practice their professions. Therefore, it is necessary to use teaching methodologies that facilitate the acquisition of human and technical skills for students [8-10].

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For this reason, an adequate educational methodology with a theoretical-practical approach, which allows students to consolidate theoretical knowledge and acquire skills to apply their knowledge in the real world, must be proposed [11]. In addition, human beings have different ways of learning, as stated by Kolb, Felder and Silverman [12,13]. Then, professors must establish a connection between educational methodologies and the different learning styles of students so that everyone can understand the concepts and develop soft skills.

Based on the above, the following question was asked: What learning styles are used in dynamic system control? This question was addressed using a large literature review of approximately two hundred studies that were classified in order to identify only the studies in the control area. The eight studies selected employ the following active educational methodologies: learning by doing, problem-based learning, project-based learning, collaborative learning, and STEM (Science, Technology, Engineering and Mathematics) [7,14-20]. In summary, the previous bibliographic review concluded on the importance of updating the didactic and methodological strategies for teaching control theory due to its high level of abstraction and suggested establishing a relationship with the learning styles of students in order to effectively connect the theory with practice and to improve the understanding of control concepts. However, there is currently no review on how to relate learning styles with active methodologies for engineering education that allows improving the teaching of control concepts.

Therefore, the present work addresses the selection of methodologies that integrate a learning style model and active methodology to improve the understanding of basic control concepts under a laboratory practice approach. In summary, the objective of this article is to demonstrate the use of learning styles in the area of control engineering and propose the construction of a methodology for teaching control theory.

This article is organized as follows. Section 2 presents the definition of the concept of learning. Section 3 presents the definition of active educational methodology and a literature review of the methodologies used in the control area. In Section 4, three learning style models are detailed: the Kolb model, the Felder and Silverman model, and the VARK (Visual, Auditory, Reading, Kinesthetic) model. In addition, the use of these models in the area of system control is explained. Section 5 presents the relationship between control concepts and laboratory control objectives using the learning styles of Felder and Silverman. Section 6 proposes a methodology based on three active educational methodologies and the Felder and Silverman learning style model to improve the teaching of control concepts. Finally, in Section 7, the conclusions are presented.

2. Learning concept in engineering education

First, it is necessary to define learning. The concept of learning is difficult to define because it is abstract. However, there are several theories and authors that explain it from different perspectives. As described in [21], there is no exact definition of learning, even in specialized books on the subject. Although learning is defined as "acquiring knowledge of something through study or experience" according to the Royal Spanish Academy [22], this definition falls short according to the specific needs of engineering training and generating a didactic strategy. Thus, it is necessary to understand learning concept from an engineering perspective.

For that, it is necessary to consider some aspects:

- What is the most relevant information?
- How is the information given?
- What is the best alternative to connect theory with the real world?

Hence, in [23] presented three definitions of learning from three psychopedagogical paradigms: behaviorism, cognitivism and constructivism. For behaviorism, learning is a change in behavior in the face of environmental stimuli; for cognitivism, learning is a change in mental processes when a link is established between the new knowledge and the prior knowledge of the individual; and for constructivism learning, learning means building lifelong knowledge over time from the development of social and cognitive skills.

However, in [24] learning is defined as “the process of acquiring a relatively long-lasting disposition to change perception or behavior as a result of an experience”. In [25] learning is defined as "a relatively permanent change in behavior generated by experience". In [12] learning is a two-step process that involves receiving and processing information. Therefore, the definition of learning has changed in accordance with the psychopedagogical trends and the needs of society. Thus, the definition of the Royal Spanish Academy is the most recent according to the literature analyzed.

Based on the definitions found in the literature and in accordance with the purposes of this work, a definition of learning is structured from a didactic approach framed in engineering education. Thus, learning is a process that consists of acquiring, processing, understanding and applying new information in a given context.

3. Active methodology to teach control systems

After learning concept was defined, it was necessary to define an active methodology. There are different educational methodologies for engineering education that have been used to improve the learning process.

An analysis of the methodologies that are used in engineering education is presented in [3]. According to the authors, it is not pertinent to use a single teaching method because engineers need to not only learn theory but also develop their practical and social skills. Thus, it is necessary to establish an educational methodology to link a methodology with the learning process. This is possible through active methodologies because they are alternatives to solve the current requirements of our society, for example leadership, critical thinking and adaptability, such as those analyzed in [1].

Then, what is an active methodology? According to the literature review conducted by [1], active methodologies are any instructional method that involves students in the learning process. Therefore, active methodologies are characterized by constant student intervention;

Table 1.
Benefits of active methodologies

Methodology	Benefits
Learning by doing	This methodology encourages the observation and application of theory based on experimentation.
Problem-based learning	This methodology encourages problem detection, frustration tolerance, and problem solving.
Project-based learning	This methodology encourages critical thinking, creativity, flexibility and innovation.
Collaborative learning	This methodology encourages group reflection, teamwork, and leadership.
STEM	This methodology encourages training in engineering areas in elementary and middle school students.

Source: The authors.

hence, they are fundamental in engineers' education. Furthermore, authors agree that more than one educational methodology should be used for engineering education to ensure that students acquire both the technical and human competencies required by an engineer today [1,3,8-10].

Among the active methodologies, the most prominent in the area of system control are project-based learning, problem-based learning, learning by doing, collaborative learning and STEM according to [7,15-20]. The benefits associated with these five active methodologies are presented in Table 1 according to [23,26-43].

4. Learning styles in control engineering

Once the learning concept is defined and what are the most common active methodologies in the area of control systems are identified, it is necessary to define learning styles.

There are different models and definitions of learning styles, such as those in [12,13,44-49]. Learning styles are the cognitive, affective and physiological traits that serve as indicators of the way in which individuals perceive, interact and respond to their learning environments [44]. [13] defines that learning styles are individual differences in learning based on a student's preference for using various phases of the learning cycle. And [49] establishes that learning styles are the methods that a person uses to learn and study.

Based on these definitions, the following definition of learning styles was structured from a didactic and engineering education perspective: an individual's preferences regarding the way in which person acquires, processes, understands and retains information.

With the definition of learning styles, it is necessary to find what learning style models are the most appropriate for system control. Therefore, the 26 learning style models described in [48] were analyzed, and a literature search was conducted with one criterion: the model must be used in control engineering. As a result, three learning style models are selected according to [7,14-20]: the Kolb model, the Felder and Silverman model, and the VARK model.

Table 2.
Activities and methodologies according to Kolb's learning styles model.

Learning Style	Activities	Methodologies
Diverging style	Experiments Simulations Conceptual maps	Learning by doing Collaborative learning
Assimilating style	Take notes Reading texts Written reports	Lecture Autonomous learning Flipped classroom
Converging style	Charts and Maps Practical projects Memorization exercises	Learning by doing Project-based learning Flipped classroom
Accommodating style	Experiments Practical demonstrations Discussion	Collaborative learning Learning by doing

Source: The authors.

4.1 Kolb model

Based on the experiential learning theory in [13,50], Kolb conceives learning as a four-stage process: concrete experience, abstract conceptualization, active experimentation and reflective observation. Kolb establishes four learning styles from the combinations of the learning cycle: diverging style, assimilating style, converging style and accommodating style.

So, Table 2 was generated by relating the needs of each Kolb's learning styles, the activities required for each learning style and an active methodology that fits with both.

4.2 VARK model

This model is based on the neurolinguistic programming model of Bandler and Grinder [45], which considers three major systems for mentally representing information: visual, auditory and kinesthetic. However, Fleming & Mills add one more system to de Bandler and Grinder model: the reading-writing system. Therefore, this VARK model consists of four learning styles: visual, auditory, reading and kinesthetic [46].

This learning style model focuses mainly on how a student receives information; thus, it is possible to establish a relationship between the sensory modality of the human body and the VARK learning styles. For sight is the visual style, hearing is the auditory style, motor skills are kinesthetic style, and sight with motor skills are reading style. Table 3 shows the activities and the most appropriate active methodologies for each VARK's learning style

Table 3.
Activities and methodologies according to the VARK learning styles model.

Learning Style	Activities	Methodologies
Visual	Charts and Maps Flowcharts Photos and videos	Learning by doing Lecture with multimedia resources.
Auditory	Exhibitions Discussion Out loud reading	Collaborative learning Lecture Seminars and forums
Reading-Writing	Take notes Reading texts Written reports	Lecture Autonomous learning Flipped classroom
Kinesthetic	Experiments Practical demonstrations Teamwork	Learning by doing Collaborative learning Problem-based learning

Source: The authors.

4.3 Felder and Silverman model

Based on Kolb's model, Felder and Silverman provide a vision of how students learn and how to generate material to easily reach each type of student in [12]. This model has four dimensions for learning: perception, input, processing, and understanding. For each dimension, two opposite categories, such as active and reflective, was established; thus, in this model, there are eight learning styles:

Perception dimension:

- Sensitive: Sensitive people are people who prefer to observe. They like practical work and activities oriented toward facts and procedures.
- Intuitive: Intuitive people are conceptual people oriented toward theories and demonstrations.
- Processing dimension:
- Reflective: Reflective people are analytical and reflective people; therefore, they require spaces to think and meditate.
- Active: Active people are people who need to apply, experiment on and conduct practical activities.

Input dimension:

- Visual: Visual people are people who better remember what they see. They prefer figures or demonstrations.
- Verbal: Verbal people are people who prefer to receive information verbally or in writing.

Understanding dimension:

- Sequential: Sequential people are people who learn incrementally.
- Global: Global people are people with a comprehensive vision of things.

Additionally, four dimensions directly related to the learning dimensions, which are content, presentation, student participation and perspective, are established for teaching. Thus, there are two opposite styles for each teaching dimension, resulting in eight teaching styles. In Fig. 1, the relationship between the dimensions of learning and teaching is shown according to [12].

Considering the learning styles of Felder and Silverman, their activities and methodologies were analyzed according to the needs of the eight learning styles, as described in Table 4.

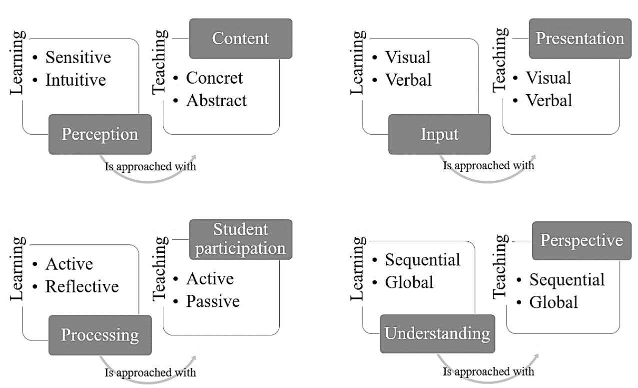

Figure 1. Learning styles and teaching styles of the Felder and Silverman model.
Source: The authors.

Table 4.
Activities and methodologies according to Felder and Silverman's learning styles model.

Learning Style	Activities	Methodologies
Sensitive	Perform experiments Simulations Observation of phenomena Memorization exercises	Learning by doing Collaborative learning Problem-based learning
Intuitive	Take notes Reading texts Written reports Thought experiments	Lecture Autonomous learning Flipped classroom
Visual	Charts and Maps Practical projects Photos and videos	Learning by doing Lecture with multimedia resources.
Verbal	Exhibitions Discussion Explain to others Out loud reading	Collaborative learning Lecture Seminars and forums
Active	Teamwork Perform experiments Discussion Practical Demonstrations	Collaborative learning Learning by doing Problem-based learning
Reflective	Individual activities Take notes Reading texts Written reports	Lecture Autonomous learning Flipped classroom
Sequential	Take notes Flow charts Simulations Lab guides	Lecture Learning by doing Problem-based learning
Global	Practical demonstrations Practical projects Conceptual maps Elaboration of conclusions	Learning by doing Project-based learning

Source: The authors.

Tables 2, 3 and 4 can be used in the design of teaching resources that integrate the learning style models since they facilitate the identification of the methodologies and activities that impact the learning styles of each model. Thus, professors can first select the learning style model and then generate teaching resources according to the activities established for each learning style.

4.4 Selection of learning styles to teach control systems

From the specific search on the use of learning styles in the area of control engineering, eight works that are described in Table 5 were found. Some investigations do not have feedback from students, as in [16-18]. In [18], only partial results are presented; [16,19-20] focus only on simulation and in theory; and [7] focuses only on the practical component. Conversely, only [14] shows the distribution of their students' learning styles.

In Table 5, the use of four learning style models, including the Kolb learning style, Felder and Silverman learning style, Gardner multiple intelligences style and VARK learning style, are shown.

Table 5.
Learning styles in control area.

Authors	Learning Style Model	Principal Objective
[16]	Kolb model	Authors design web module for teaching control using Kolb's experiential learning theory.
[17]	Kolb model Felder and Silverman model	Authors incorporate experiments with an inductive approach into a lecture to teach control system.
[19]	Authors do not mention a particular learning style	Authors include art and storytelling in form of challenges to introduce robotics concepts.
[15]	Kolb model VARK model	Authors design a control laboratory under a constructivist approach.
[7]	Kolb model. Gardner's theory of multiple intelligences.	Authors design practical activities as a didactic strategy for teaching control concepts.
[20]	Authors do not mention a particular learning style	Authors design an active learning strategy for the control and dynamic processes subject using simulation activities and collaborative learning.
[18]	Gardner's theory of multiple intelligences.	Authors develop a virtual control subject using project-based learning
[14]	Kolb model	Authors identify the learning styles of students through a robotics workshop.

Source: The authors.

Given that the objective of this work is to find a learning style model that allows proposing an educational methodology for the teaching of control theory, Gardner's multiple intelligences model cannot be framed for the teaching of control concepts since it is not possible to address all the model's learning styles, especially musical, intrapersonal, naturalistic and interpersonal intelligences.

Finally, the advantages and disadvantages of the other learning style models are analyzed. Applications of the Kolb model in teaching, such as those presented in [7,14-16], are found in the bibliography. In addition, as evidenced in Fig. 1, the Felder and Silverman model includes dimensions associated with the didactic field and a correspondence between learning style and teaching style. This allows the Felder and Silverman model to have more direct applications as an educational methodology, although thus far it has not been used as widely as the Kolb model. However, it is possible to compare both models and conclude that the Felder and Silverman model includes the dimensions proposed in the Kolb model.

Additionally, comparing the Felder and Silverman model with the VARK model shows that the VARK model focuses on a single dimension of the Felder and Silverman model: the input. There is also a disadvantage in the Kolb and VARK models that their tests are not free.

Therefore, the model that has both a cognitive and a didactic perspective is the Felder and Silverman model, which facilitates not only the design of activities but also the structuring of an educational methodology by having a direct relationship with the way it should be taught.

Hence, the learning styles model of Felder and Silverman is selected as the appropriate model for the objectives of this work.

5. Selection of the main control concepts

One of the main challenges in teaching automatic control is to provide an adequate balance between theory and practice. Theory requires a high level of abstraction on the part of students due to a large amount of required mathematical background, which makes it difficult to understand the concepts, creating a need to implement different teaching strategies and tools, such as simulations and experimental laboratories, that allow these concepts to be consolidated [51-53].

Although this work is focused on teaching the theory and practice of concepts of control systems, it is necessary to restrict the concepts to a limited number of concepts since the topics of dynamic systems control are too broad to be covered in a single study. To do this, the choice will be limited to the basic concepts of control theory.

Two factors were considered to select the control concepts for this work: a review of the literature and a review of the topics in the Input–Output Control subject of the Universidad Nacional de Colombia.

Starting from the literature search, which was limited to the basic concepts of control [7,11,21,51,54-57] are condensed into 11 control concepts, considering the concepts taught in the Input–Output Control subject.

Table 6.
Relationships between control concepts and learning styles.

Control concept	Activities	Learning style
Closed and open loop control	Select an everyday example of control loop.	Global
Transfer functions	Perform the Laplace transform of a system.	Intuitive and reflective
Block diagrams	Establish a relationship between the signals of a system. Perform block algebra	Global and visual
State space	Decompose a system into state space.	Intuitive
Linearization and operating point	Perform Taylor series linearization of a system	Intuitive and Sequential
Frequency response	Chart the bode diagram of a system	Visual
Time response	Chart the step response of a system	Visual
Stability	Calculate the Routh Hurwitz criterium	Intuitive and reflective
Feedback effects	Analyze the effects of feedback in a system	Intuitive and reflective
Effects of PID control actions	Chart and mathematically calculate the effects of PID control actions in a system	Sensitive, visual and reflective
Controller design	Design a controller for a real or simulated plant	Active, sequential and sensitive

Source: The authors.

Table 7.
Relationships between control laboratory objectives and learning styles.

Objectives of laboratory on control system	Learning style
Obtain and visualize System inputs and outputs	Sensitive, intuitive, visual and global
Connect the theory with what is observed in the lab, and identify differences between models and real systems.	Global and reflective.
Design and verify controllers to desired specifications	Active, sequential and sensitive
Implement a controller in a real plant	Active, sequential and sensitive
Identify physical system failures such as sensor noise, interference, saturation, and correct them.	Active, global and reflective
Write a laboratory report that describes the obtained results.	Intuitive and sequential

Source: The authors.

Considering the learning styles model of Felder and Silverman, relationships were established between the most important control concepts and the learning style. To address each topic, Table 4, Fig. 1, and the activities that are proposed throughout the Input–Output Control subject were considered, resulting in the relationships presented in Table 6.

Table 6 shows that the topics of control theory are beneficial to students who have visual, intuitive and reflective styles. This makes it difficult for students with other predominant learning styles to understand the concepts, especially those who learn naturally through active experiences, which agrees with [5,7]. Additionally, it is important to mention that the verbal style is present in all sessions since listening to a teacher's explanations and reading guiding material is necessary for this type of style.

For this reason, an adequate educational methodology with a theoretical-practical approach that can allow students to consolidate theoretical knowledge and acquire skills to implement the different techniques in the real world must be proposed.

To accomplish this, there are some tools that improve the appropriation of concepts by students, such as simulation and experimental practices in laboratories. Laboratories play an important role in engineering training since it is through practical experiences that students connect theory with the real world. Therefore, institutions such as ABET have proposed the inclusion of engineering laboratories in their criteria, which is also in agreement with what was described by Felder and other authors [2,8,9,58-59]. Thus, the connection between theory and practice using a working method, the laboratory, is necessary for teaching control issues by having a working method.

Table 7 shows the relationship of the Felder and Silverman learning styles with the first six learning objectives for a control laboratory presented by [11].

This relationship is established considering the activities outlined in Table 4 and Fig. 1 for each learning style.

From Table 7, it is evident that the students who would benefit from a laboratory in the control area are those with an active, global, sequential, and sensitive learning style. Now, comparing Tables 6 and 7 shows that the practical part complements learning styles that are not covered in the theoretical part, thus covering the eight learning styles proposed in the Felder and Silverman model.

Considering this analysis, there is a need to establish a methodology more in line with the other learning styles that allows the design of activities to teach the control concepts, considering the limitations of each concept.

6. Proposed methodology

Considering the conclusion of the previous section, the most appropriate option to meet these needs is a mix of active methodologies.

Due to the inclusion of the practical part of control concepts, it is necessary to select an active methodology that adapts easily to the teaching environment in the control laboratory. Regarding the educational methodologies used in the control area, in [7,15-20], the use of learning by doing, project-based learning, collaborative learning and STEM methodologies are illustrated. In this case, the STEM methodology is discarded as it is a methodology focused on K-12 education, and it is supported by learning by doing methodology; thus, the other three active educational methodologies are selected.

These three methodologies, learning by doing, project-based learning and collaborative learning, are appropriate for generating teaching material in a laboratory environment, as seen in [21,60-66]. In addition, although problem-based learning contains elements of collaborative learning, each concept was considered separately since this method allows for greater flexibility when preparing teaching materials for each particular concept, thus having the possibility of elaborating the material with one, two or all three methodologies as required.

For the selected educational methodologies, an analysis was based on the dimensions for teaching presented by Felder and Silverman according to the learning styles, as presented in Fig. 1, and the activities associated with each style described in Table 4 was conducted. The result of this analysis is shown in Fig. 2, which represents the relationships between the selected educational methodologies and the Felder and Silverman learning styles model.

The learning by doing methodology focuses on activities in which a student is the main actor and encourages self-learning through clear instructions for the student to conduct activities that can strengthen the concepts to be learned. This type of educational methodology is considered pertinent for sensitive, visual, active, and sequential learning styles.

Conversely, the problem-based learning methodology focuses more on problem solving. One of its main activities is the case study, allowing the student to analyze the problem and generate solutions. Therefore, the activities within this methodology are suitable for sensitive, intuitive, reflective and global learning styles.

The collaborative learning methodology allows for communication between students, teamwork, developing communication and reflection skills, which is ideal for active, verbal and global learning styles.

Therefore, the combined use of these three educational methodologies, combining theoretical classes with laboratories, will allow for the generation of activities that impact the eight learning styles of the Felder and Silverman

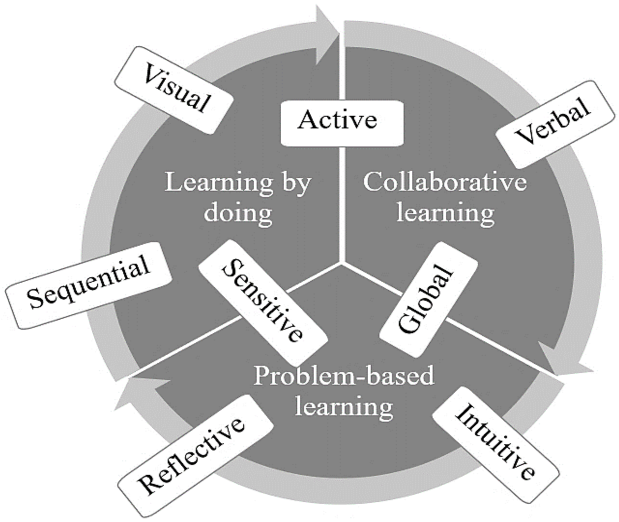

Figure 2. Learning styles and teaching styles of the Felder and Silverman model.
Source: The authors.

model. Laboratory practices favor the connection between theory and practice, that is, the association of concepts with a real case study, such as laboratory plants, allowing students to directly appropriate and apply the theoretical concepts that were taught in a lecture.

7. Conclusions

In this work, the inclusion of learning styles as a central component in designing a methodology to teach control theory and practice was addressed. To accomplish this, it was necessary to analyze how students learn in order to facilitate the acquisition of skills related to being and doing for students.

The definitions of learning, learning styles and active methodology were adapted with the aim of applying them to research in engineering education under a didactic approach. These definitions can be used in any type of engineering.

The specific characteristics of each learning style model were detailed, and then matrices in which the activities and methodology were presented according to the learning styles of each model were constructed. These tables can be used in the design of teaching resources in any engineering context as they facilitate the identification of activities that impact the different styles of each learning style model. Therefore, professors can select a learning style model and teaching resources to use according to the activities for each learning style.

In this work, the Felder and Silverman model was selected considering the practical considerations, advantages and disadvantages of each learning style model presented. This model includes dimensions associated with the didactic field and a correspondence between learning style and teaching style, which facilitated its direct application for the design of a methodology for teaching not only control system theory but also any engineering subject.

Finally, it is concluded that the proposed methodology is relevant for the teaching of control concepts and is a novel tool to address control systems topics considering the learning styles of the students.

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