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Strengthening Critical Thinking in Engineering Students through Mathematics: The Power of Attitudes

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Abstract: This study aims to strengthen critical thinking in future engineers through mathematics by stimulating their attitudes. To achieve this, a qualitative informative study will be conducted with a characteristic cut and a deductive orientation through the analysis and synthesis of contents from scientific publications specializing in the development of critical thinking. This type of thinking can be strengthened through strategies proposed by the mathematics teacher, allowing an increase in curiosity, eagerness to learn and inquire, and especially promoting and awakening curiosity in students through contexts where mathematics is formally applied in engineering. These strategies should include concrete actions that foster attitudes of critical thinking and a better ability to argue, interpret, and make judgments independently, ultimately acquiring a set of skills, especially in problem-solving. The results show that an engineering student as a critical thinker must have a critical attitude, which is evidenced through dispositions, habits, and character traits, which, when stimulated through mathematics, would contribute to their professional formation.

Keywords: disposition, education, habit, problem-solving.

通过数学加强工科学生的批判性思维：态度的力量

摘要：这项研究旨在通过数学激发未来工程师的态度，从而加强他们的批判性思维。为了实现这一目标，将通过分析和综合专门从事批判性思维发展的科学出版物的内容，以特色剪切和演绎为导向，进行定性信息研究。这种思维可以通过数学老师提出的策略来加强，从而增加好奇心、学习和探究的渴望，特别是通过数学在工程中的正式应用的背景来促进和唤醒学生的好奇心。这些策略应包括具体行动，培养批判性思维的态度以及更好的独立辩论、解释和判断的能力，最终获得一套技能，特别是解决问题的技能。结果表明，作为批判性思考者的工科学生必须具有批判性态度，这通过性格、习惯和性格特征得到证明，当数学激发这些态度时，将有助于他们的专业形成。

关键词：性格、教育、习惯、解决问题的能力。

1. Introduction

Some international accreditors of engineering programs, such as ABET (Accreditation Board for Engineering and Technology) and EUR-ACE (European Quality Seal in Engineering), include Learning Outcomes aimed at developing skills in solving complex difficulties, studying design and innovation, conducting research, and basic competencies that view engineers as integral beings in areas such as communication, ethics, morals in professional practice, collaborative work, and continuous lifelong learning [1]. Therefore, engineering students require certain skills to use concepts from Sciences and Mathematics in Engineering, for analyzing, using, and interpreting information through experimentation, and thus identifying, understanding, presenting, and solving engineering problems immersed in a social environment, using the necessary skills, tools, and modern instruments required for such purposes. This involves proposing a system, device, idea, or process that allows for achieving specific goals, considering responsibility, professional ethics, and effective communication, both for achievements and implications.

The teaching of any subject in an engineering program must include, among other knowledge, the development of skills and the aim of cultivating reflective thinking with attitudes and habits of critical thinking so that students have the disposition to strengthen their attitudes and become good critical thinkers when necessary [2].

The above-mentioned skills could be enriched if accompanied by critical thinking (CT). To achieve this, a close articulation between specific technical subjects on critical thinking and engineering subjects is initially required, and finally, an active work with teachers in the Basic Sciences area is required to allow academic spaces (such as Basic Mathematics, Linear Algebra, Differential and Integral Calculus, Numerical Methods, Statistics, and Differential Equations) where critical thinking can evolve and be put into practice, involving pedagogical aspects. These courses provide the necessary tools and instruments through algorithmic techniques and mathematical models for the necessary understanding of the behavior of engineering processes and/or phenomena and problem-solving (P-S hereafter) that could not be solved without their help.

In the same line of thought, [3] discuss how during their academic training, students in engineering, when reading and writing technical texts, will benefit from CT in providing support and structure to argue and justify their decisions and positions, considering social, economic, and environmental aspects. In addition, [4] present a case study regarding teaching strategies to be considered for the development of critical thinking in future engineering professionals.

1.1. Theoretical Framework

It is important to highlight the difficulty that some engineering students face when using previous concepts that will allow them to explain and understand phenomena and/or processes in their daily experiences [5]. Despite being well-prepared in their scientific field, they hesitate when critiquing nonscientific claims in their everyday life. Some studies have shown the connection and importance between previous concepts in mathematics and CT, as exposed by [5], and a descriptive study demonstrated that students who are just starting engineering programs do so with a low level of CT [6].

Therefore, it is significant to promote and reinforce CT in engineering students so that they can face future challenges imposed by society with a positive attitude. Furthermore, it is essential to highlight the role of mathematics and its value as an instrument to promote CT [7]. In the context of attitudes toward mathematics, [8] is noteworthy because it considers cognitive, affective, and behavioral components to achieve success based on the pedagogical strategy used. Similarly, studies have shown the importance of the relationship between mathematical understanding and CT [9].

Mathematics allows engineering students to analyze, abstract, construct, evaluate, infer, induce, deduce, estimate, compare, contrast, interpret, pose, and handle the premises of mathematical arguments. Based on this, they can communicate, conjecture, generalize, specialize, classify, categorize, describe, visualize, sequence, order, predict, validate, test, generate hypotheses, relate, and model their conclusions, patterns, or best decisions and results rationally through disciplined and organized activities that contribute to problem-solving. This may involve procedures such as graphing functions or analyzing data tables with their constants and essential parameters, optimization (as an application of calculus), a specific numerical method in the absence of mathematical linearity (which occurs in reality), or solving a differential equation that models a phenomenon or process [10].

The ability to identify and solve the above-mentioned processes contributes to the construction of well-founded reasoning and, from there, to make judgments and concepts, some of which are supported mathematically.

The aim is for engineering students to acquire new knowledge (the necessary knowledge) and be able to sustain a debate with rigorous and appropriate arguments (using techniques such as informal logic related to analysis, proof, and error investigation in language). In this way, through creative and reflective

CT, they contribute to the resolution or formulation of a problem, and they can also make judgments from a technical, legal, regulatory, financial, environmental, moral, and ethical perspective.

Critical thinking in engineering education occurs today primarily in a focused context directed toward achieving one of several learning outcomes, as in the case of ABET [11]. CT involves much more than conventional engineering practices, estimating and linking assumptions in P-S, choosing appropriate hypotheses and instruments for experiments, and structuring open design problems. It is essential to mention that P-S, especially in mathematical modeling under a STEM approach (Science, Technology, Engineering, and Mathematics), has contributed to cognitive CT ability [12]. ABET, among other accrediting bodies, requires that engineering students learn CT skills, and for that, it is necessary to foster some attitudes that can be promoted and stimulated by their teachers to shape more competent engineering professionals. In this regard, [13] highlights the need to apply and design strategies to enhance critical thinking in engineering students for the development of skills related to reading, text analysis, etc.

1.2. Research Problem

Given the above, it is necessary and important to stimulate and promote the use of critical thinking as a skill that contributes to the education and professional development of engineering students, starting from mathematics courses (in the area of Basic Sciences). Therefore, the following question arises: how can critical thinking be strengthened in future engineering professionals through mathematics by stimulating their attitudes?

2. Methodology

This work has consisted of methods of analysis and synthesis of the contents of scientific and methodological publications on the development of attitudes, habits, and traits related to CT. The study follows a qualitative documentary approach with a descriptive and deductive focus, which allows for characterizing the results of attitudes that may arise in engineering students, according to [14] and [15]. The information under study, identified through a literature review, includes scientific articles, classic books, and academic event proceedings. The inquiry was conducted using the Google Scholar search engine with the keywords: Critical Thinking, Engineering, Attitude, and Mathematics in May 2023, covering the period from 1980 to 2023. In total, 38 sources of information were found, excluding duplicates.

The organization of the information was done according to the type of source, as concentrated in Table 1; the language of publication is presented in Table 2, and the distribution over time is shown in Table 3.

Table 1 The source distribution (Developed by the authors)

Document Type	Quantity	Percentage %
Scientific Article	27	71.1
Specialized Book	7	18.4
Conference	4	10.5
Total	**38**	**100**

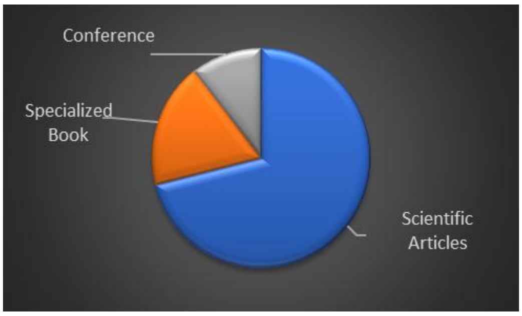

Fig. 1 The source distribution (Developed by the authors)

Table 2 The publication languages (Developed by the authors)

Language	Quantity	Percentage %
Spanish	27	71.1
English	11	28.9
Total	**38**	**100**

Fig. 2 The publication languages (Developed by the authors)

Table 3 The time intervals (Developed by the authors)

Publication Interval	Quantity	Percentage %
1980 - 1994	05	13.2
1995 - 2009	07	18.4
2010 - 2023	**26**	**68.4**

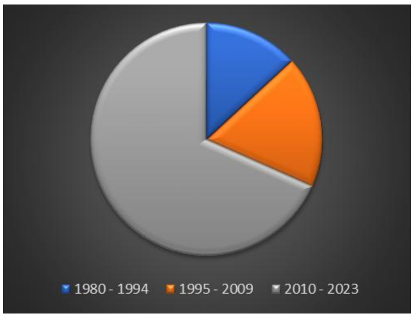

Fig. 3 The time intervals (Developed by the authors)

3. Results

Initially, the main classical definitions of CT presented in the literature are stated. Subsequently, different attitudes toward CT, as recommended by respective theorists, are considered. Finally, based on teaching experience, it is evident how attitudes toward CT can be stimulated through mathematics courses, allowing future engineers to acquire increasingly better skills grounded in CT, especially in problem-solving processes.

3.1. Critical Thinking: Definitions

Throughout the last century, numerous definitions of CT have been proposed, but among the most cited ones with a focus on engineering are:

• It is the attitude of being entirely disposed to critically assess problematic situations and similar scenarios that may arise within one's experiences, employing a strategy of logical inquiry and reasoning, according to [16] as a classic contribution.

• Sound and conscientious reasoning focusing on determining what to accept or do [17].

• Intentional thinking, in which individuals systematically and habitually impose intellectual criteria and standards on their thought processes [18].

• CT is proactive, reasoned, and goal-directed, linking to problem-solving processes by attempting to determine the possibility of an event's occurrence using cognitive skills and strategies [19].

• Explicitly directed thinking toward well-structured reasoning, evaluating it based on appropriate norms to discover its true utility [20].

3.2. Attitudes That Engineering Students Should Possess as Critical Thinkers

If a positive attitude toward CT can be awakened in students, it ensures that they are capable of analyzing respective situations, questioning different viewpoints and diverse opinions, and making well-informed decisions [21].

It has been demonstrated that when mathematics teachers succeed in imparting a solid CT education that supports students' critical knowledge, abilities, and dispositions, their academic performance improves significantly, as highlighted by [10].

CT-oriented mathematics is a continuous process that begins with the appropriate attitude of being willing to gather, analyze, interpret, evaluate, question, and openly synthesize information, arguments, reasons, ideas, solutions, or beliefs. It involves an eagerness to obtain reliable information and enthusiastic dedication to knowledge, using a suitable set of cognitive skills, leading to reflective evaluation and resulting in applicable actions in areas of interest [22].

When students engage in research with a critical attitude and a statistical perspective, they should ideally be capable of acknowledging the role of randomness, evaluating the methodological quality of arguments, understanding the differences between correlation and causality, recognizing the complex and multicausal nature of events, and grasping the importance of falsification, as discussed by [23].

For engineering students to be critical thinkers, they must possess a critical spirit or attitude, which includes dispositions, habits, and character traits [24]. A student with such a critical spirit tends to seek reasons and evidence, opposes bias and injustice, and aligns themselves with making objective assessments that leave no room for doubt. A possessor of a critical spirit is inclined to seek reasons and evidence [24]. It is essential to remember that dispositions, attitudes, and habits constitute the intellectual character of students, as highlighted by [25]. The following are actions that involve a scientific spirit with a focus on mathematics teaching:

3.2.1. Dispositions

Through dispositions, students seek reasons and experiences in making judgments, evaluating those reasons carefully in line with notable elements of their evaluation [26].

CT in engineering students is seen as an important interdisciplinary ability that could affect or influence creativity. Thus, the job market requires engineering problem solvers with a high level of technical and technological knowledge, who can improve the social, economic, and physical environment through their skills. These skills can be acquired through a series of attitudes promoted by science educators, and it is here that the disposition allows for the transfer of knowledge between other study disciplines [27].

Students with a high level of problem-solving attitude will become successful because they will not be affected by their problems but will immediately solve them using their creativity and CT. The attitude toward R of P is viewed as a skill in students where they do not easily give up but, by thinking critically, find good solutions, act calmly, confidently, and clearly, avoiding feelings of frustration, stress, and depression when faced with problems [28, 29].

Dispositions are seen as the various manifestations and internal motivations that engineering students face in R of P [14, 30-32]:

• *Curiosity:* The desire to explore other trends that are not necessarily immediately useful and applicable. Curiosity stimulates the ability to question provided information (data), problem-solving procedures, and the results obtained. It also offers the opportunity to understand different mathematical structures in context, leading to admiration and wonder about their development.

• *Open-mindedness:* The student recognizes and values, as appropriate, assumptions (frequent in mathematics), implications, and practical consequences, accepting alternative viewpoints with tolerance, based on sufficient evidence and proof. This occurs when the student accepts, in the case of problem-solving through logical reasoning, a different path from the one they already know and master. Ultimately, this allows them to expand their conceptual framework and, if necessary, reconsider their initial approach to solving the problem at hand.

• *Systematicity:* The student is expected to be orderly, organized, focused, and diligent in solving specific problem situations. They should ensure that the information received (data, parameters, and unknowns) and provided (results and alternative solutions) and the tools used (mathematical models, data tables, graphical analysis) are organized in the best way for better understanding and analysis.

• *Analytical capacity:* Future engineers need to act reasonably with commitment, considering the effects, evidence, and potential consequences of the problem, phenomenon, or process under study. They establish and maintain the direction in conclusions or questions. This requires considering the overall situation and asking classic questions, as [33] did: What is being asked in the problem? Is the problem well formulated? What needs to be solved? What needs to be known? What information is provided, etc.? Mathematics contributes to the decision criteria after considering any constraints.

• *Path to finding the truth:* This disposition allows for finding truth by questioning, being fair, sincere, and intellectually honest with the acquired solutions, despite adversities that may arise. It enables distinguishing between half-truths, lies, deviations, and deceits. The exactness provided by mathematics supports each position, criterion, and judgment made. It is crucial to emphasize that when science seeks the truth, it allows the discovery of some general principles that engineers can use to solve certain problems, as happens with mathematics, an instrument to seek such solutions.

• *Self-confidence:* The desire is for future engineers to confidently rely on their knowledge and not on others for decision-making. They should trust their own experiences, abilities, skills, beliefs, and concepts to make judgments, conclusions, and express their opinions.

3.2.2. Intellectual Traits or Dispositions

Future engineers must cultivate personal and intellectual values and virtues to think with perspicacity and integrity, as recommended by [15] and [34]. It is argued that such traits protect against the development of sophisticated or self-deceptive thinking. To prepare themselves as impartial and intellectually responsible individuals, engineering students must strive to develop intellectual virtues or dispositions and foster the development of conceptual characteristics such as:

• *Intellectual humility:* This involves acknowledging ignorance and being truly sensitive to what one knows and does not know, recognizing that new information could be discovered and admitting one's mistakes. This occurs when facing a completely unknown mathematical algorithm (subject to review under a law or theory) with a logical foundation leading to the same answer. The student must have the ability to assess the problem at hand without allowing attitudes, experiences, or prior knowledge to bias judgment or conclusion regarding the problem.

• *Intellectual autonomy:* This is the ability to self-reason while adhering to the standards of logical thinking, which is essential to avoid accepting other viewpoints without questioning. It involves stating one's thoughts without coercion or conflicts of interest, using one's procedures based on well-founded and supported arguments. Here, the student should be able to compare and differentiate between the technical features already known to him or her, accept the conclusions or judgments of others, and engage in critical rational and irrational reasoning and deliberations.

• *Intellectual integrity:* This means not having double standards and adhering to high intellectual standards expected by others. All information is presented with correct attribution to sources and fair representation of others' work, so it can be subjected to analysis using the same intellectual criteria applied to other analyses (no distinct criteria). In this trait, the student should strive to recognize and exclude self-deception or any personal interest when reasoning or passing judgments on engineering processes.

• *Intellectual courage:* This is the ability of students to question their own beliefs strongly. It includes questioning cultural beliefs and having a disposition to express one's own opinions, even if they are not well-known. The student must have the courage to accept the moment when those beliefs may be refuted and similarly be radical with their beliefs when circumstances warrant it (even if they are ridiculed).

• *Intellectual perseverance:* It is the ability to overcome obstacles in complex tasks and problem-solving without faltering, using special techniques and strategies (including patience), taking into account important and relevant details. In this scenario, one should always aspire to overcome all types of obstacles, considering them as true knowledge in other domains or contexts, following [35]. Thus, the student acknowledges that some mathematical tasks and problems are complicated and not easy to solve at first glance.

• *Confidence in reason:* It is a mix of being open to the positions of others, encouraging more interlocutors to have their own approaches, and abilities not to distort opinions to support one's own position and change viewpoints when other experiences different from the student's lead to more reasonable views. For this, essential guidelines will be used to allow conceiving whether to admit or deny a belief or perspective.

• *Intellectual empathy:* It is important to help engineers grow and mature accurately as they assume different viewpoints and understand those of others, even if they disagree, using assumptions and hypotheses that are not their own with recognition and appreciation. Frequently, reflection is made on the basis of ideas different from their own.

• *Impartiality (justice/neutrality):* Admitted as the disposition to treat all perspectives without prejudice, thereby enabling the issuance of reasonable reasoning when giving judgment and evaluating a particular argument. To achieve this, strong and weak approaches should be balanced to reason accordingly.

3.2.3. Other Traits and Dispositions

Some authors [36] have reviewed the literature on critical thinking disposition and identified seven clearly distinguishable traits:

• The disposition to be broad and adventurous, especially in mathematics, as one must always have the capacity to face problem-solving in engineering, no matter how complicated it may seem.

• The disposition to wander, identify problems, and inquire; in other words, to always have the willingness to seek diverse solutions through conjectures, tests, or reflections.

• The ability to create illustrations and understand them through conceptual frameworks, synoptic charts, and/or flow diagrams that aid in a better understanding of the problem at hand and, therefore, its solution.

• The disposition to use methods and be strategic, all through a plan, supported by logical and structured thinking.

The instructor must stimulate critical thinking through specialized courses and strategies that align with creativity, especially in engineering problem-solving. This can instill attitudes that lead to a critical spirit. If not possible through an initial career course, it should be an integral part of a pedagogical model immersed in an Educational Institutional Project (EIP), as a guideline in engineering programs, involving a series of conferences, group discussions, and analyses of open engineering problems in context, so that future professionals can think with perspicacity and integrity from the beginning, all under faculty support [37].

4. Discussion

Critical thinking in engineering students should be strong enough in any context to be immune to changes in orientation or trends that may affect a concept. By teaching situations from everyday life that future engineers may face, they are given the opportunity to put their own positions into practice, thereby guaranteeing their skills in critical thinking, leading to strengthened and improved abilities to argue, interpret, and make judgments autonomously.

Critical thinking can be strengthened through strategies proposed by instructors, increasing the capacity for amazement, the desire to learn, the thirst for questioning and knowing everything and promoting and arousing curiosity among students through contexts where mathematics can be formally applied in engineering, leading to questions such as: "where does this apply?" or "what is this useful for?" This can be achieved through instruments such as reading, accompanying research or classroom projects, and problem-solving. It is worth mentioning the first rule proposed by [38], which states that nothing should be accepted as true until there is evidence and certainty that it is true, manifesting a constant eagerness to question everything related to the theme or problem at hand.

5. Conclusions

To enhance students' knowledge, skills, dispositions, habits, and traits related to critical thinking, educators can create pedagogy with productive learning activities that foster these critical thinking skills.

• It is important to create a classroom environment that promotes collaboration, open dialog, and acceptance of diverse values, beliefs, and perspectives.

• Students should be encouraged to openly express their concepts without fear of judgment, censorship, or reproach, while their teachers can stimulate optimal critical thinking behaviors and attitudes through effective modeling of these behaviors.

• When teachers succeed in awakening, instilling, and stimulating attitudes (habits, dispositions, and intellectual traits) toward critical thinking in engineering students, it enables them to develop cognitive skills that facilitate understanding of mathematics learning phases, contributing to problem-solving, decision-making, evaluation of reasoning, and effective communication in engineering.

• Methods to cultivate critical thinking should be implemented in engineering education. These methods should highlight the advantages of knowing and implementing critical thinking in professional development from university classrooms through open-ended problems. They should be designed to continuously develop critical thinking as students progress through the undergraduate curriculum.

• An attitude toward critical thinking, starting from mathematics, allows students to understand and reflect on the role of mathematics in engineering to promote justice, ethics, and their participation in society, as mathematical procedures can solve complex problems and lead to impartial, objective, and logical results.

6. Recommendations

• To incorporate an understanding of critical thinking in other engineering courses, it is important to review the curricula of basic engineering areas, professional components, and humanities to include content related to critical theory, reflective judgment, and research on science and technology. Critical thinking in engineering encourages students to question the course content, learning processes, and engineering in society. For this, at least one course should focus on the development of critical analysis skills, which should be integrated with other subjects.

• Students should be encouraged and nurtured with a set of mental attitudes through dispositions, habits, and intellectual traits that will likely enhance their ability and inclination to think critically.

• Promoting critical thinking allows students to examine, evaluate, explain, and reconstruct their thinking, reducing the risk of assuming, acting, or thinking with false beliefs.

• It is crucial to provide students with critical readings on a specific topic (even if mathematics is considered more of an exact science than a humanistic one, it can still be articulated), where they are given tools and sufficient time to stimulate reflective analysis. In the end, open-ended questions should be posed, allowing students to substantiate their answers and be capable of defending their proposals or accepting others' when necessary, while also differentiating relevant information from irrelevant ones. In addition to expected responses, students should be encouraged to ask questions without fear in an atmosphere of free expression and debate.

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