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Characterizing STEM Education in Latin America: A Literature Review on Active Learning and Competencies

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Abstract

STEM (Science, Technology, Engineering, and Mathematics) is an interdisciplinary educational approach developed by the U.S. National Science Foundation to foster research, innovation, and learning. By integrating these fields, STEM education aims to develop theoretical understanding and practical application in real-world contexts. Despite its widespread adoption in developed countries, some initiatives lack a true STEM focus. In Latin America, STEM adoption is increasing, but challenges persist, including confusion between technology and computer science and limited engineering content in curricula. A specific concern is the declining interest in engineering disciplines, particularly in Colombia. This research examines STEM experiences in educational institutions through a literature review of 31 publications from 2018, focusing on Colombian and Latin American engineering institutions. Of these, five are based on practical educational experiences, while 26 are research-based studies. The types of studies reviewed include interventions, diagnoses, and social studies related to STEM education. The analysis shows a notable increase in STEM-related publications, especially during and after the COVID-19 pandemic, with most studies focusing on secondary and primary education. These findings reflect the growing momentum of STEM in educational settings across Latin America. The research categorizes the key findings from the reviewed publications into five primary dimensions: active learning methodology, competence development, individual conditions, context, and the teacher's role. Active learning methodologies such as inquiry-based learning, problem-based learning, and robotics are prominent in STEM education, promoting skills like critical thinking, creativity, and problem-solving. The research also highlights how contextual factors, such as the student's social and cultural environment, play a significant role in shaping STEM experiences. Gender gaps and motivational factors further influence student participation in STEM activities, emphasizing the need to address these issues early on to foster a more inclusive STEM culture. Moreover, the study underscores the importance of the teacher's role in the successful implementation of STEM education. Teachers are required to facilitate active learning, guide students through real-world problem-solving tasks, and continuously develop professionally to stay updated on new methodologies. Proper teacher training is critical for ensuring that STEM approaches are applied effectively in classrooms and that they are adapted to meet the specific needs of the local context. In conclusion, this research characterizes STEM education through five essential aspects: the use of active learning strategies, the influence of contextual factors, the development of student competencies, the impact of individual conditions such as gender and motivation, and the critical role of teachers in guiding and shaping STEM experiences. These findings highlight the shift from traditional educational models to more dynamic, problem-solving-based approaches, which foster meaningful learning and engagement in STEM fields. The study calls for early exposure to STEM for all students, with an emphasis on addressing gender disparities and ensuring proper teacher training to support the growing STEM initiatives in Latin America.

Keywords: STEM education, Active Learning, Competence Development, Gender Disparities, teacher training.

Introduction

STEM is the acronym for Science, Technology, Engineering, and Mathematics (STEM). It is an integration of four sciences that was developed by the U.S. National Science Foundation (NSF) [1]. The NSF seeks the advancement of science and mathematics, research in science and engineering, and scientific innovation.

According to Hasanah, the "S" (science) refers to thinking, answering questions, hypothesizing, and conducting research using the practices of science. The letter "T" (technology) is understood as a way to find answers to human needs by making use of existing resources. The "E" (engineering) is the profession where knowledge, mathematics, and nature are used to build and find the way to generate that benefit for humanity. Finally, the letter "M" (Mathematics) is defined as the science that allows the exact relationship between language, technology, science, and engineering [1].

The application of this integration of disciplines in the teaching-learning processes is understood as a method of integration and development of skills in science, technology, engineering, and mathematics that allows the fostering of interdisciplinary work of the same disciplines and their actors to respond to the needs of a globalized world [2].

According to Botero [3] the STEM approach is based on the following main concepts: (a) the interdisciplinary approach to learning, understood as a deep integration that allows connecting the theoretical foundations of each discipline; (b) the elimination of the barriers of the four disciplines, i.e. transforming the traditional vision of learning from isolated concepts disconnected from reality to a new form of the systemic interrelation of knowledge; (c) integration to reality, which means the conceptual connection of the four disciplines with real-life experiences; and (d) rigorous and relevant experiences for students, which implies engaging the student with the challenge of applying the holistic of the four disciplines to their daily problems [4].

However, Bybee indicates that not all educational initiatives in the global north have a STEM focus, although they call themselves STEM. It has been a permanent trend in developed countries only to present a promise of value that includes a STEM curriculum design and STEM educational resources, which are not necessarily STEM because they do not meet the definition of STEM education [5].

Now, Botero [3] describes that STEM in Latin America is not a trend, so it is not common to find primary, secondary, and middle school institutions with the four disciplines separated or integrated, but it is common to see institutions with a focus on separate learning experiences in science or mathematics. Likewise, technology is often confused with computer science or robotics, while engineering is not even part of elementary, secondary, and middle school curricula, as it is conceived as a discipline exclusive to higher education [4].

Ramos-Lizcano et al. mention that the STEM approach has spread internationally, especially in the United States, and that there is currently a boom in Latin America. These advances in Latin America have occurred thanks to the implementation of education policies that involve the development of programs or projects such as the Latin American STEM Network, the declaration of STEM territories in the cities of Medellin and Bogota, the State of Mexico in Mexico, Valparaiso in Chile, Vicente Lopez in Buenos Aires, Argentina, among others [6].

On the other hand, Rojas Mesa et al. refer to the need to have more engineers in all countries, a situation that seems difficult to achieve given that there is less and less interest in these careers among the new generations. In Colombia, there is marked desertion in engineering programs, an example of this is mentioned by Rojas Mesa et al., when they presented the results of a study conducted at the National University of Colombia, based in Bogota, and noted that 72.35% of the students of the engineering faculty withdrew between the first and fourth semester of their career [7].

Methodology

To identify which characteristics of STEM experiences are developed in educational institutions, a critical literature review [7] of experiences or research in the STEM area was conducted. For this purpose, this review unified the search based on three major criteria for our search algorithm: (a) using keywords in English and Spanish such as STEM, education, and schools; (b) ranging the search period within the last seven years, i.e. publications from 2018; range established giving the momentum, development and wide use of technologies in education during the pandemic period and after it; (c) considering two types of publications: the first for the application of experiences and the second based on research; and (d) through three search sources: publications by the Colombian Association of Engineering Schools (ACOFI), the Latin American, and the Caribbean Consortium of Engineering Institutions (LACCEI).

A total of 31 documents were identified, five of which are experiences applied in education, and the remaining 26 are educational research. Table 1 shows the organization of these documents by type of publication and subtypes.

Table 1. Publications by type and subtype of publication

Type	Subtype	N
Educational experiences	Educational interventions	2
	Collectives initiatives	2
	Retention/desertion	1
Educational research	Literature review	8
	Educational interventions	10
	Educational Diagnosis	6
	Social studies	2

Table 1 shows that in the educational experiences row, two of the references present educational interventions and two more collective initiatives, and the last one is an exercise that addresses student retention. Of the 26 research studies reviewed, 10 are educational interventions, eight are literature reviews, six are educational diagnoses, and the remaining two are social studies.

Concerning the years of publication, Table 2 shows that in recent years, the development of the STEM approach has presented a greater boom, given that 14 publications were found in 2023, 11 publications were found between 2021 and 2022, and 6 publications were found between 2018 and 2020.

Table 2. Publications by year.

Year	Total
2018	1
2019	1
2020	4
2021	6
2022	5
2023	14
Total	**31**

On the other hand, Table 3 shows that, of the 31 publications, five deal with higher education (university) and secondary education, eight with secondary education, eight with primary education, two deal with both primary and secondary education, five deal with the STEM approach in education from a general perspective without addressing any specific population, and the remaining three deal with early childhood education, informal education, and teacher education.

Table 3. Publications on the level of studies addressed-

Level of studies	Total
Higher education	5
Secondary education	8
Primary education	8
Primary and secondary education	2
General	5
Children's education	1
Non-formal education	1
Co-teaching	1
Total	**31**

Results

Fig. 1 is a word cloud representing the keywords of the 31 publications.

Figure 1. Cloud of keywords.

The cloud above shows the most common keywords in publications, such as STEM, education, keywords from our algorithm; but we can also begin to identify less used keywords that allow us to identify characteristics of STEM used, for example, robotics, problem-solving, creativity, computational, problems, active, projects, scientists, contest, design, among others.

A content analysis matrix was used, where general information was provided for all publications, and some aspects were specified for the two types of publications, experiences, and research.

For all publications, the following were identified: year; author; title; DOI (unique and permanent identifier for electronic publications); URL (uniform resource locator); abstract; conclusions; number of pages; ISSUE (volume number, initial page-final page); editor; key words; country; level of studies of participants; type; subtype; main ideas.

In the case of application experiences, the following questions were answered: At what conference was the experience presented; what was the purpose of the experience; what was the target population to whom the experience was directed; what are the results obtained with the experience; and what are the contributions and/or impacts achieved with the experience?

In the case of research, the following questions were answered: What is the research question or objective, what is the sample/participants, what is the method and/or methodological design, what are the theoretical and/or conceptual references, what are the research results that respond to the questions or objectives formulated?

When analyzing and interpreting the above information and the results of the matrix, the following categories of information can be proposed to respond to the objective of this research.

The categories found were reviewed and grouped according to the nature of each one of them as follows:

A. Active learning methodology: Active learning refers to teaching methodologies that generate greater learning, where students are involved and learn through activities such as problem-solving or projects, group discussions, reflective activities, or activities that promote critical thinking [8]. The STEM approach uses active learning strategies such as inquiry-based learning, reflective teaching, problem-based learning, project-based learning, and game-based learning, among others [6].

B. Competence: Competence refers to the capacity of a person demonstrated through his knowledge, skills, abilities, skills, and attitudes that make possible the performance in different contexts and that contribute to obtaining good results in professional activity.

C. Individual condition: The conditions of individuality refer to the differences between individuals that make them unique. Among them, we can identify biological factors such as gender, age, race, etc., or psychological factors such as motivation, emotions, personality, and cognitive styles, among others [9].

D. Context: The context refers to the circumstances surrounding specific situations; in this case, they are the circumstances of the environment where STEM experiences occur. one can speak of the social environment, culture, geographic location, poverty level, etc.

E. Teaching role: The teaching role refers to the role that the teacher assumes in a teaching process promoting educational innovations as new or change interventions [10], when we talk about active methodologies, we talk about the teacher becoming the guide or moderator who offers his students experiences both inside and outside the classroom that allow them to achieve meaningful learning in their lives [6].

These categories identify the impact of the results of the research and experiences analyzed. Table 4 shows the categories of analysis evidenced in each of the 31 articles.

Table 4. Analysis of categories found in the articles.

Paper	Active Learning Methodology	Competences	Individual condition	Context	Teacher role
1			X	X	
2	X		X		
3	X	X			X
4	X				
5	X	X	X		
6		X	X	X	
7	X	X			
8	X	X			
9		X	X		
10	X	X	X		X
11		X	X		
12	X		X		
13	X				
14	X	X			
15		X			
16	X	X	X		
17		X		X	
18	X	X	X	X	
19		X		X	
20	X			X	
21	X	X	X		
22	X		X		
23	X	X	X	X	X
24	X	X			X
25	X	X		X	X
26	X	X	X	X	
27	X		X	X	
28	X	X	X	X	
29	X	X		X	
30	X				X
31			X	X	

The following is a description of the most relevant findings found in the articles reviewed for this research; these results are presented according to the five categories evidenced.

Active Learning Methodology

As observed in the state of the art, the STEAM (i.e., science, technology, engineering, art, and mathematics) approach uses active learning strategies [6]. The didactic models of traditional science teaching should be incorporated into the teaching processes as an element that allows the transfer of knowledge and ensures meaningful learning in the student [11]; the active learning of the STEM approach allows students to develop learning and intellectual enjoyment [12]. Likewise, previous literature refers to the fact that these student-centered active strategies should allow addressing contextualized problems, that is, promoting differentiated strategies according to the needs of each learning community where the experience is taking place [7], [13], [14].

When addressing real-life situations and seeking solutions to them from the STEM approach, it is essential to integrate concepts from STEM areas [15], [16]. This is because STEM helps integrate areas globally by creating links between them [17]. For instance, in primary education mathematics, STEM contributes to the acquisition of skills associated with the use of numbers and calculation, which, in turn, contributes to the use of graphic and statistical languages, associated with the use of technological tools; for their part, natural sciences develop content through the processing of information in different code formats or languages, essential elements of mathematics [18].

Previous work by the academic community has also indicated that STEM methodologies promote autonomous work, allowing students to learn from practice in a given context, considering their circumstances, and leading them to adopt a critical attitude, which leads them to solve situations innovatively, integrating STEM fields [7].

Likewise, previous findings suggest that the STEM approach allows this integration of contents, thanks to the use of different methods in the classroom such as inquiry-based learning, problem-based learning, cooperative learning, and design-based learning [13]. The results of these methods are presented below.

Concerning inquiry-based learning, previous literature shows that education with a STEM approach has scientific literacy as a pillar, which leads to the appropriation of knowledge and concepts to subsequently develop skills, qualities, and perspectives in a culture of inquiry [6]. Moyano et al. confirm the suitability of using a dynamic and flexible methodology such as a scientific inquiry for children to actively learn scientific concepts or phenomena through observation, manipulation, analysis, and dialogue [18]. Arabit and Prendes refer to the importance of the use of active methodologies with practical and experimental activities to work the contents in the classroom from primary school using simple exercises or experiments according to age [17].

Some authors make evident the benefits that scientific inquiry activities have for students, Ferrada et al mentioning that this type of activity awakens the curiosity of students [19]. For Karamustafaoglu and Pektas, these will contribute to the development of creative and problem-solving skills in these situations [20]. For Trujillo et al, the activities developed under the research-based learning method generate interest in inquiry in scientific education, especially when didactic materials, virtual resources, or computer simulators are used since they introduce the student to engineering design [21].

Regarding Problem-Based Learning (PBL), when activities are used under this model, greater practicality is observed, achieving greater interest, concern, and understanding of the contents, science, and technology [22]. Some authors highlight the importance of teaching physics with PBL strategies with methodological guides that structure the knowledge since they allow the student to understand and solve complex problems in an oriented way that allows self-learning [16], [23].

Ramirez, Jurado, and Avila present how the STEM approach in Colombia has brought experiences to rural and urban contexts to address environmental care through the challenge-based learning methodology, with activities that allow diagnosis, design, innovation, implementation, and participation from action research [24]. Under this methodology, González uses robotics as a mediating element for the achievement of learning with practical and real solutions to the challenges posed [25].

Uzun and Sen demonstrate the efficiency of the STEM approach when elementary school students manage to understand and interpret scientific concepts and design products thanks to the activities developed from learning methodology based on engineering design [15]. Rojas et al mention that it is necessary to strengthen engineering activities in education, both in theory and practice, emphasizing computer science and programming with an integrative vision of the disciplines [6]. Ramos-Lizcano et al highlight the importance of integrating learning environments enriched with Information and Communication Technologies (ICT) into teaching practices [5], which will allow, according to Arabit and Prendes, the development of educational engineering with new didactic approaches using technological components [17]. Aneas et al highlight different activities to apply engineering design in the classroom, such as robotics, extended reality, electronic agendas, and gamification [16].

Ferrada et al identify that engineering from robotics contributes to the acquisition of knowledge in scientific areas and helps the development of computational and logical thinking [19]; the activities of manipulation and assembly of the robot facilitate the understanding of abstract concepts of computational thinking; the world of programming puts concepts into practice and promotes thinking, creative processing, and understanding of abstract concepts. For Arabit & Prendes, robotics allows the development of skills through games and playing, enabling students' capacities for exploration and manipulation and the construction of meanings from their own experience [17]. It is not just a matter of incorporating ICT in the classroom but of integrating it with pedagogical intentionality through a planned instructional action. For Hurtado and Soto, activities involving robotics from an early age allow children to appropriate the knowledge of these areas and, in the future, facilitate their performance in them [26].

Sáiz et al work on active learning with virtual learning environments through Serious Games or video games designed with a formative purpose, and demonstrate that these activities facilitate self-regulation and the development of computer and programming skills. The authors suggest the importance of working with simulation methodologies where students use avatar figures [27]. For Aneas et. al, playing is an important part of learning for young children in areas such as mathematics, science, and technology [16].

For its part, Arabit, Prendes, and Serrano refer to the importance of the use of teaching methods with digital technologies of the open resource type since they allow any child to access the STEM approach regardless of the context in which they find themself [13]. Ortiz-Revilla et. al point out the importance of working with an inverted classroom methodology where students assume an active role and teachers are a guide in their process [28].

Competence

The STEM approach has been shown to allow students to acquire different capacities or skills, both cognitive and emotional [14]. The competencies most highlighted by this literature review are presented below.

One of the most highlighted competencies is problem-solving, understood as the ability to use different optics or visions that allow the establishment of reasoned conclusions. Another competency that has been worked on by the authors is critical thinking, which goes hand in hand with problem-solving competency and is understood as the ability to use different optics or visions that allow establishing reasoned conclusions for decision-making.

Likewise, [14], [15], [29] mention that STEM experiences enhance the development of research competencies, understood as the ability to understand scientific concepts, manage information, propose solutions to problems, and communicate these processes. STEM experiences also enhance the development of creative thinking, understood as the ability to invent or create something new. The approach develops students' competencies for collaborative work/teamwork, and with teamwork, they also acquire competencies for the leadership of these teams.

Other cognitive competencies observed by the authors that are developed through experiences with a STEM approach are the capacity for synthesis and analysis [30]; communication [29] digital competencies [17]; student autonomy [14]; and 21st Century Competencies [5].

Individual condition

In the analysis of the 31 articles in this literature review, factors that mark individual conditions for the performance or vocational choice of the STEM area were identified, including biological factors such as gender, age, race, etc; and psychological factors such as motivation, emotions, personality, and cognitive styles, among others [8].

For Ortiz and Solorzano, gender stereotypes do not help to close gaps, they generate little visibility of the results of women in STEM areas [30], in this regard, Tamargo-Pedregal et. al mention that, in general, men select STEM areas than women and that women go more for disciplines of health sciences, arts, and social sciences [31]. For Moyano et. al a change in the paradigm is required where equal opportunities are offered to women and men in the STEM field, thus reducing the gender gap in science and technology[18]. For their part, Ramirez, Herrera, and Meléndez understand that the concept of equity does not mean favoring or prioritizing one gender over the other but rather achieving a balance of opportunities that allows both genders to stand out and be recognized equally [32].

Valero-Matas and Coca suggest that this situation requires a change in the thinking of boys and girls, but from an early age, if girls can be motivated by school, a commitment to learning will be generated, achieving better results, and enhancing their abstraction and team participation skills [22]. Aneas et al, on the other hand, highlight the importance of the STEM approach being used from prekindergarten entry, that is, from the age of three; however, there is no evidence of results when working with one- or two-year-old children [16].

For Ramos-Lizcano et. al, although one of the most important challenges of the STEM approach is the reduction of the gender gap, some barriers also affect African and Black American populations [5]. This gender gap should be closed [33] to promote STEM vocations for the fourth industrial revolution [34], which requires different scouting initiatives such as immersion days in STEM colleges and universities [35].

Different authors have reported that psychological factors such as interests, emotions, motivation, and factors that affect learning intervene in the development of an education with a STEM approach. For instance, Uzun and Sen state that the affective domain is important in science education because factors such as motivation and attitude correlate with students' scientific performance [15]. Likewise, their work indicates that motivation can affect the formative process among others by factors such as learning environments, curricula, teaching methods, and interactions with teachers and peers.

Context

In this analysis, it became clear that a factor recurrently mentioned is the context, i.e., the circumstances surrounding the development of STEM experiences, such as the family, social, or cultural environment (i.e., situational factors).

According to Marín-Rios et. al, STEM education seeks an interdisciplinary approach to contextual or real situations, problems, or needs relevant to students [14]. Likewise, Chavarría and Guede-Cid mention that education with a STEM approach allows students to face future challenges and respond to the problems that arise in their context [36].

On the other hand, Ramos-Lizcano et. al indicate that there are social and contextual factors that intervene in the performance of students in educational experiences with a STEM approach [5]. Among them, the student's family and social network are indicated. For Sáiz et. al, some of the intervening factors in STEM-focused experiences are the student's history, the family's style, and the associated roles in the family versus the gender of the son or daughter [27]. For Tamargo-Pedregal et. al, the influence of agents such as family, friends, and the context surrounding the students is relevant [31]. According to [13]Educational institutions should seek close collaboration with the family to promote access to appropriate resources for boys and girls.

Teacher's role

Londoño et. al mention that the teacher should be a person of dialogue, a researcher who guides the development of activities and who motivates discussion, curiosity, and interest in understanding the world [11]. Gutiérrez and Guativa mention that traditionally, the transmission of contents in the classroom has been privileged, but at this moment, efficient, innovative, didactic proposals that motivate students are required [10].

According to Montoya, to address active learning methodologies, it is important to train teachers in these approaches and develop emotional and social skills to enhance the capabilities of their students [37]. The teacher has the challenge of motivating their students to the STEM approach.

For Arabit and Prendes teacher training is a key element in the implementation of active methodologies and should be aimed at knowing the approach in the development of practical and experimental activities to work content in classrooms, as well as competencies in the design and use of digital resources for the classroom [17]. Marín-Ríos et. al mention that continuous teacher training is required to enable the appropriation of the approach and to allow the solution of problems as soon as possible [14].

Rojas et. al mention that it is essential to train teachers and active methodologies and pedagogies around integrated work and the relationship with the external sector [6]. It is necessary to modify and renew teachers' ideas about teaching-learning, didactics, and interdisciplinarity in STEM areas. Teacher training should have a DEI (Diversity, Equity, and Inclusion) approach to promote faculty development [38].

Conclusions

According to the results of this research, experiences with a STEM approach are characterized: by the type of active methodology used and the activities developed in them; by the conditions of the context where the experience is developed; by the competencies developed in the students; by the intervening factors of the students or individual conditions; and by the competencies of the teachers in the development of experiences with a STEM approach.

The active learning methodology confirms the need to move from traditional training models oriented to the teaching process to processes that guarantee meaningful learning for students. To this end, these methodologies support the STEM approach, allowing the student to approach real, contextualized situations that require an integrative view from the STEM disciplines.

An inquiry-based learning methodology can be used if it is desired to develop scientific, investigative skills that allow the student to experiment, manipulate, and test hypotheses. If you want to develop practical skills or abilities to develop and address actual and contextualized problems, think of using problem-based learning. When the student is required to acquire skills to diagnose a situation, design the solution, innovate, and implement a solution through collaborative work from action research, we can think of challenge-based learning. But if the core of the strategy is the design of a product, with which the student can understand and interpret scientific concepts and create and evaluate a final solution, the method to be applied is learning in engineering design, which could be enriched with the integration of technological components that generate greater interest and dynamism in the activities, such as robotics, extended reality, electronic agendas, gamification, among others.

On the other hand, it must be understood that these experiences with a STEM approach must be developed with situations, problems, or needs specific to the student's context. Developing these experiences requires the student's experience in the problem, situation, challenge, process, or phenomenon to understand, deepen, and provide accurate and appropriate solutions with active participation. To this end, it is also suggested that the experiences involve the student's networks, such as family, friends, and social environment.

As a fourth point that allows characterizing STEM experiences, we have the individual conditions where it is evident that factors such as social stereotypes can affect the performance and taste for STEM disciplines; culturally, individuals have appropriated the STEM approach, contrary to women, whose role has been played more in areas such as the arts or human and social sciences. However, the reviewed research does not provide evidence of real biological differences that generate this gap. Educational institutions are invited to develop experiences with a STEM approach from an early age, where girls and boys without distinction participate in these experiences and thus generate in early stages emotions, interests, motivations, and attitudes that favor performance in this approach and end those gender or race stereotypes.

Finally, to adequately develop experiences with a STEM approach, it is necessary to have a person who guides, has the knowledge, manages the methodologies and activities of this approach; guides the dialogue, motivates curiosity, interest, discussion, and participation, and favors the meaningful learning of students.

For this, the teacher must be qualified, educated, and trained in these types of methodologies. The teacher must know how to design activities where the learning results show the development of competencies of the STEM approach, orient these experiences to meet the needs or situations of the student's immediate context, and motivate children from an early age to get into the STEM approach.

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