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Building computational thinking through the incorporation of STEM education into the secondary curriculum in the Quindío department (Colombia)

Construcción del pensamiento computacional mediante la incorporación de la educación STEM en el currículo de secundaria del departamento del Quindío (Colombia)

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ABSTRACT
There is a need to create theoretical-practical models that, based on existing conceptual contributions, facilitate the informational and technological literacy of new generations. Incorporating STEM Education (science, technology, engineering, and mathematics) into the curriculum has proven helpful for secondary school students. The study aimed to generate the first approach to a model for understanding computational thinking (CT) from a STEM approach. This article displays the results of a conceptual review of topics related to the object of study in the last five years and the critical analysis of the found research. The main results highlight the importance of balancing technical, educational, and pedagogical aspects. Furthermore, critical components for model design are proposed. It is concluded that while achieving a conceptual scheme to guide STEM education is vital, it must be updated and reviewed frequently so that emerging disciplines and processes can be incorporated.

Keywords: documentary analysis, technology diffusion, search strategy, science and society, educational technology.

JEL classification: I23; O32

RESUMEN
En la actualidad, se hace necesario la creación de modelos teórico-prácticos que, a partir de los aportes conceptuales existentes, faciliten la literacidad informacional y tecnológica de las nuevas generaciones. En el caso de los estudiantes de secundaria, la incorporación de la Educación STEM (ciencia, tecnología, ingeniería y matemáticas) en el currículo ha probado ser de ayuda en tal propósito. El estudio realizado estuvo dirigido a la generación de una primera aproximación a un modelo para la comprensión del pensamiento computacional (CT) desde el enfoque STEM. Este artículo muestra el resultado de una revisión conceptual de los temas relacionados con el objeto de estudio en los últimos cinco años y el análisis crítico de las investigaciones halladas. Los principales resultados encontrados apuntan a la importancia de lograr el balance entre los aspectos técnicos, educativos y pedagógicos. Además, se proponen componentes claves para el diseño del modelo. Se concluye que, aunque es vital el logro de un esquema conceptual que guíe la educación STEM con carácter conceptual, este debe ser actualizado y revisado con frecuencia, de manera que se puedan incorporar disciplinas y procesos emergentes.

Palabras clave: análisis documental, difusión de tecnologías, estrategia de búsqueda, ciencia y sociedad, tecnología educacional

Clasificación JEL: I23; O32

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INTRODUCTION

The education of future members of society has been and continues to be a sensitive point in political, educational, and international agendas. Issues related to education content, its organization, and unavoidable aspects such as values, access, and sustainability are inseparable from the discourse (Ramírez-Montoya et al., 2023). Providing quality education that is easy to access is a requirement in preparing new generations to promote the development of countries (Ho et al., 2020). One of the alternatives that has gained relevance has been STEM education, which can also appear as STEAM by incorporating an "a" to signal that the arts have been included, the results of which have been significant at different educational levels and geographical areas (Bui et al., 2023; Mutambara & Bayaga, 2021; Yalçın & Erden, 2021).

The STEM approach is an education designed for curriculum to offer content or subjects organized in science, technology, engineering, and mathematics. However, multiple researchers point out that this position goes beyond adding four disciplines in isolation but should be seen in their common relationships and reference to future disciplines to be incorporated (Yalçın & Erden, 2021).

Another area for improvement associated with the STEM approach is its various academic, political, and cultural resistances (Alonso et al., 2019). Due to its origin as a particular way of counteracting Soviet technological progress and its possible supremacy, the STEM approach arose due to the Cold War and is associated with neoliberal currents. Other limitations associated with the resistances above are the intergenerational transmission and parent-child relationship in STEM education (Gutfleisch & Kogan, 2022), the gender gap in technological use and literacy (Delaney & Devereux, 2019; Sevilla et al., 2023; Siddiq & Scherer, 2019), local development and availability of material resources in rural contexts or developing areas (Ho et al., 2020; Mutambara & Bayaga, 2021).

Although it is vital to recognize these limitations and shortcomings attributed to or existing in the STEM approach, it must highlight that it has also contributed to channel issues of capital importance in the present and future education scenarios for individual and social development. Among other contributions, the use of advanced designs for sustainable development and the responsible use of technology from the STEM approach was identified in the literature (Jeong Y González-Gómez, 2020; Zizka et al., 2021); attention to entrepreneurship as a vocation and its support through the incorporation of entrepreneurial practices (Eltanahy & Forawi, 2020); personalized education in the framework of collaborative learning environments and its contribution to the achievement of interdisciplinary design (Zheng et al., 2020); attention to creativity (van Broekhoven et al., 2020; Thuneberg et al., 2018).

In a historical context with a greater tendency towards interconnection and the construction of digital scenarios for social life and education (Gonzales et al., 2023), the development of computational thinking is a requirement for future education (Kafai & Proctor, 2022). This statement, although seemingly obvious, due to the relevance of computer science in a current and prospectively future society, has been evaluated under the lens of the scant importance that some international curricula attribute to it (Kafai & Proctor, 2022). Several problems have been associated with these difficulties. One of the most striking and pressing was the so-called "unplugged pedagogy," referring to the tendency to teach computer science as traditional content, i.e., without computers (Huang & Looi, 2021).

This problem points to an urgent need, given the separation between the pedagogical and educational aspects involving computational thinking development and the associated skill set. Therefore, it is essential to understand that to meet this need, the concept of computational thinking should not be limited to coding but should be extended to the informational and technological literacy process. These ideas, supported by different studies, imply assuming that computational thinking must be contextually conditioned. Therefore, its development is pedagogically designed by essential aspects such as identity development, participation and activism, and vocational development (Huang & Looi, 2021; Kafai & Proctor, 2022). Thus, the code-centric nature of computational thinking and the pedagogical fracture that tendentiously guides its teaching could be gradually reversed (Kite et al., 2021).

This article is part of a doctoral research project, the genesis of which is found in the reflections on the boom of STEM education worldwide, in Latin America, Colombia, and the Eje Cafetero. From the literature review, it was possible to identify that in computational thinking, the restriction to practical experiences has reduced the importance of the theoretical aspects that epistemically, ontologically, and methodologically support the incorporation of STEM education in the curriculum. Furthermore, it is appreciated that a fundamental achievement must involve the human, ethical, and historical dimensions of the incursion of information and communication technologies in the school in order for STEM education to be sustainable (Campbell & Speldewinde, 2022; Ma, 2021). The curriculum must act as the articulating axis of the theory underpinning the STEM approach and computational thinking to regulate the essential aspects of its education.

Finally, it is concluded that the educational process can be taken beyond the economic, technical, or business aspects through STEM education and promote coexistence and the strengthening of the public and democracy. Thus, not only is the technical aspect considered, but STEM education allows a broader educational vision and gives rise to collaborative work and the construction of materials (Acosta, 2020).

Considering the above, it is pertinent to raise a question that guides the research process and whose answer will facilitate fulfilling the proposed objectives. This question is: How do we identify practical experiences in computational thinking in such a way that they allow the epistemic, ontological, and methodological foundation for incorporating STEM education into the curriculum?

METHODS

Problem statement

This section describes the starting point, the context that guided the development of the proposal, as well as the research question. The questions that functioned as the driving or guiding axis of the research and the arguments that support the need to address the incorporation of STEM education in the high school curriculum to develop computational thinking in students were established.

In this sense, the study focused on the conceptual contributions in curriculum, STEM education, and computational thinking from their origins. In this way, we sought to demonstrate the articulation between theory and practice based on the construction of scientific knowledge. To find this articulation, it was necessary to identify not only from the historical point of view but also the policies that governments have implemented and the importance they have given to this object of study in society.

Research questions

Considering the above, it is pertinent to raise some questions to guide this research process whose answers will facilitate fulfilling the proposed objectives. These questions are: How do we identify practical experiences in computational thinking in such a way that they allow the epistemic, ontological, and methodological foundation for incorporating STEM education into the curriculum? How can STEM education be incorporated into the secondary school curriculum to enhance the construction of computational thinking? What is the relationship between STEM education and the development of problem-solving skills in the cross-cutting areas of knowledge? How to design an educational model that allows the incorporation of STEM education in such a way that it favors the generation of computational thinking?

General Objective

To build a theoretical-practical model based on existing conceptual contributions that allow the generation of computational thinking in high school students through the incorporation of STEM Education in the curriculum.

Specific Objectives

- Develop a conceptual analysis of literature related to STEM education, curriculum and the generation of computational thinking.
- Design an educational model that allows the incorporation of STEM education in such a way that it favors the generation of computational thinking.

Sample selection

Therefore, the design of ways to incorporate STEM education in the secondary school curriculum in the department of Quindío (Colombia) was sought to understand computational thinking. The starting point was to consider how STEM education has been incorporated into the curriculum worldwide, considering research between 2018 and 2023.

By assuming one's own contextual and historical logic, the decision was made to explore the literature in developing countries or studies in scenarios similar to that of the study, which led to the initial identification of two groups:

Group 1: Arlinwibowo et al., (2021) (Indonesia); Nugroho et al., (2021) (Indonesia); Burbaite et al., (2018) (Lithuania); with Dilekci and Karatay (2023) (Turkey); Ma, Y. (2021) (China); Vargas and Garcia (2021) (Colombia); Velazquez and Martin (2021) (Spain).

Group 2: Costin and Pontual (2020) (Brazil), Tovar (2019) (Mexico); Roncoroni and Bailón (2020) (Peru); Chaves (2020) (Costa Rica); Santillán et al., (2019) (Ecuador); Perales and Aguilera (2020) (Spain); Celis and González (2021) (Colombia).

RESULTS

Two fundamental categories emerged from the analysis, which allowed a better understanding of the data obtained. These categories were STEM education and curriculum design (1) and STEM education in non-conventional contexts (2). Based on both, the most relevant results are presented.

STEM education and curriculum design

In Ecuador, we found the documentary work by Santillán et al. (2019), whose main objective was to develop a theoretical basis for STEM education. A literature review of four doctoral theses developed between 2016 and 2017 was conducted with such a task. The results showed that the STEM methodology allows a broader educational vision and gives rise to collaborative work and the construction of materials. Finally, the authors concluded that students have a central role in constructing their knowledge in a transversal and contextualized manner. This work contributes to the research because it broadens the theoretical panorama and points out aspects of the impact of this methodology on the curriculum.

In Costa Rica, Chaves (2020) approached the STEM methodology as a possibility for solving complex problems and stimulating creativity in technological environments. The author states that the Universidad Fidélitas has assumed it to construct a curriculum that responds to current needs. This work was oriented to unveil the relationships produced by STEM methodology, mainly the basis offered by sciences and mathematical operations to research, design, and innovation. As in other studies, this author emphasized the creative character of the methodology in that it favors the emergence of actual technological and social products as part of the process of solving problems present in reality. However, the main contribution of this work is the approach where knowledge and practice are integrated ethically.

In his doctoral thesis, Acosta (2020) proposes several methodologies based on collaborative learning and ICT aimed at both students and secondary school teachers in educational institutions in the Dominican Republic. The methodology was mixed, with a quasi-experimental design that took as a sample 542 teachers to whom a survey was applied for the subsequent pilot test implementation. The results showed significant improvements in pedagogical and motivational aspects, leading to increased learning. In conclusion, it is stated that after the COVID-19 pandemic, ICT management changed. However, due to its abrupt and mandatory nature, some modifications were improvised for various reasons, such as connectivity and lack of training and resources.

In this scenario, the author highlights a crucial aspect shared in the study presented, referring to the need to strengthen technical and pedagogical aspects. This research differs from the study presented by showing a limited representation of technology. However, it contributes to the updating of the subject. It offers a conception of ICTs closely linked to the curriculum, a key aspect in technological integration and the development of computational thinking.

At the University of Granada, Spain, Perales and Aguilera (2020) have conducted research aimed at exploring the interrelation between STEM (Science-Technology-Engineering-Mathematics) and STS (Science-Technology-Society) methodologies. As a result, they explain that the STEM methodology cannot be assumed superficially, i.e., it is not only about the use or introduction of artifacts to make them profitable but about deep transformations in the curriculum. As for their results, the authors assume a critical approach in analyzing the STEM movement and point out the differences in the origin of both approaches.

While the STS movement emerged to qualify the curriculum, i.e., for educational purposes the STEM approach for political purposes (Perales & Aguilera, 2020), results that are shared by other scholars on the subject and that highlight the importance of not decontextualizing STEM education (Alonso et al., 2019; Takeuchi et al., 2020). This difference sometimes leads to a superficial assumption of STEM. Therefore, the work of Perales and Aguilera (2020) is identified as relevant because it highlights the importance of deepening this topic from the academy to achieve profound changes that contribute to uprooting the teaching of science from archaic pedagogical approaches.

In the content analysis conducted in Indonesia by Nugroho et al. (2021), STEM is highlighted as a possibility to enhance integrative practices at the primary and secondary levels. The authors state that its development has been more accessible at the primary level. Its implementation in the curriculum has made it possible to propose solutions to real and significant problems for the educational community and foster critical thinking. Another aspect highlighted by these authors is the affective aspect, which is developed through teamwork, collaborative learning, and discipline (Nugroho et al., 2021). This research is essential for this study because it emphasizes the training of teachers and the community in general so that preparation and training should not occur exclusively in the theoretical field or dimension; it is relevant to include professional praxis in learning. In addition, technical aspects should be incorporated and taught by experts.

In Colombia, professors Celis and González (2021) reviewed the literature on the impact of the STEM education curriculum with a sample of fifty articles. When analyzing the papers, it was obtained that according to the number that have been published, it is a topic that is still current and is characterized by its "flexibility, interdisciplinarity and integrality" (Celis and González, 2021, p. 285). These three characteristics were taken into account when establishing the categories of this research; this work provides a thorough bibliographical analysis that is useful for constructing the background and the theoretical framework for future approaches to the subject. Finally, it is concluded that the STEM methodology can be approached from cooperative learning, project-based, problem-based, and ethnomathematics, which establishes diverse approaches and application frameworks.

Continuing with the contributions from Colombia, Vargas and García (2021) conducted a bibliometric analysis on STEM education and natural sciences based on papers published in the decade between 2010 and 2020, in which they established a common thread that refers to the lines of research. Within the most outstanding results, they obtained data showing that STEM education has acquired prominence in the educational field.

The geographical analysis showed in the distribution that the countries that have published the most on the subject are the United States, Spain, and Indonesia. At the same time, it is a process that is just beginning in Latin America. The most prominent lines of research are: "STEM and technological and computer tools; design of STEM activities in the science classroom, STEM and minorities; STEM and curriculum design" (Vargas & García, 2021, p. 217). From the above, it was deduced that more exploration in this line referred to curricular development, specifically computational thinking.

In Spain, an article was identified due to the research by Velázquez and Martín (2021), who developed a content analysis on computational thinking and its influence on education. Among the findings, reference is made to a mental activity that includes programming, but the authors state that reference should be made to educational constructs. In conclusion, the latest advances in didactics and computer science should be included in this debate, and the terms used should be more precise.

In Mexico, Tovar (2019) developed research on STEM education in Latin America; for this purpose, he approached different experiences in Argentina, Chile, Uruguay, Paraguay, Peru, Bolivia, Ecuador, and Colombia. In the results, the author expresses that, in this context, although there are referents in North America, Korea, and Europe; there needs to be more development because no consensus has been made to standardize the way to assume STEM education (Tovar, 2019). In addition, it was evaluated that the projects have been applied in tiny populations and concluded that there are various proposals from the educational field and the private sector, including commercial purposes, but that can be taken advantage of. This work contributes to providing a panoramic view of Latin America. It makes it clear that in STEM education, it is essential to maintain sight of the approach from which the integration of the different disciplines is assumed.

Finally, Ma (2021) invites a reconceptualization of the curriculum from praxis, adding the A (arts) and forming the new STEAM concept. Therefore, STEM education must be approached from an ethical and value-forming vision in the social context that is promoted so that students develop critical thinking oriented to social development. As a result of these analyses, the authors of this study affirm that history should also be used since it provides a sense of identity and invites us to recreate the past in the present to understand the meaning of technology. This is how STEM education navigates between theory and practice for its sustainability.

STEM education in non-conventional contexts

In his doctoral thesis, González (2020) presents a methodology that interrelates robotics and computational thinking in the context of children's education. The work is divided into three phases: In the first phase, the state of the art is diagnosed, emphasizing tasks related to code design, the activity of programming, and its impact on the development of computational thinking. In the second phase, technologies and strategies are analyzed. In contrast, in the third phase, an inclusive proposal is carried out with a population of 172 students (3 to 5 years old) with Down syndrome and hospitalized.

The study is based "on the maker movement, the Positive Technological Development (PTD) framework, inclusive education and learning through play, using a tangible robot (KIBO)" (González, 2020, p. 122). The results show that, through this strategy, academic and emotional achievements are obtained. Finally, it is concluded that it is necessary to initiate computational thinking from the first years of life, and it should be integrated into the curriculum. This work represents a theoretical, conceptual, and practical contribution, in addition to demonstrating that it is possible to work on these topics in non-conventional environments and without the use of technological devices, which is very appropriate for the Latin American context, especially in areas with accessibility problems or in vulnerable situations.

At the University of Lima, Roncoroni and Bailón (2020) researched to broaden the concept of computational thinking, that is, to link it with the human sciences and art. They first made a conceptualization where neopositivism and technocentrism are criticized, and then the influences of both trends in the educational field are contextualized. The authors conclude that from computational thinking, it is possible to foster creativity without dispensing with analogical elements (Roncoroni & Bailón, 2020). A fundamental contribution of this study is that it points out the possibility of dispensing with technological devices and building computational thinking. The authors define it as a proposal based on building a digital and virtual culture without being directly limited by the computer.

As elucidated in the introduction, this statement points to the risks of an unplugged pedagogy or an uncritical digitalization if the design needs to be done consciously and intentionally. Therefore, teachers should be trained to explore and build critical devices that guide students in achieving the expected performances in these contexts but decentralizing the technological devices without promoting their dependence. In education, according to recent studies, the concept of Computer Science is linked to computational thinking and problem-solving, where the use of new tools, methods, activities, and educational resources that are incorporated into the STEM paradigm is promoted (Li et al., 2020; Lyon & Magana, 2020; Sen et al., 2021; Wang et al., 2022).

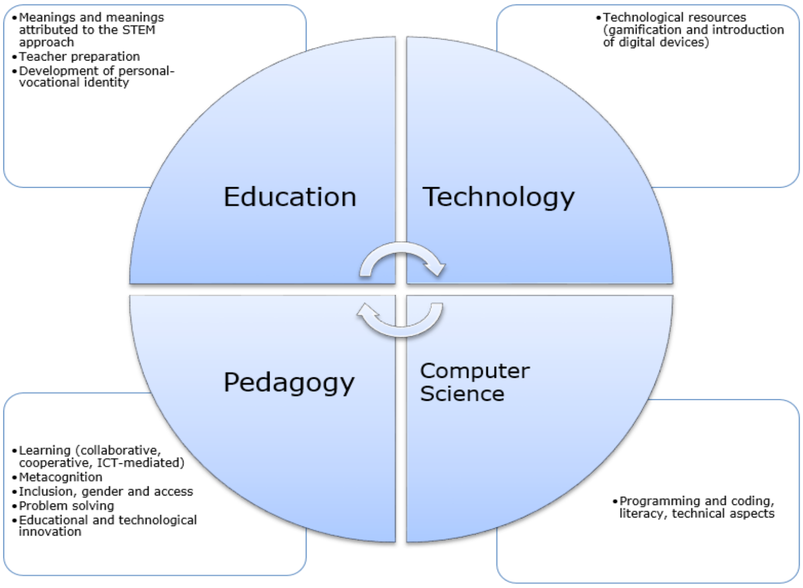
A prominent example identified was the implementation of practical guides in a high school curriculum (Burbaitė et al., 2018). In this research, the authors propose implementing curricular transformation by introducing technologies. To fulfill their purpose, they ground the concepts of educational informatics and propose that developing computational thinking requires tools such as robotics and impact STEM education through programming; they also suggest using technological toys, added to some pedagogical activities driven by technology and programming (Burbaitė et al., 2018).

Based on the results achieved and the synthesis of these results, an initial outline of the essential components and aspects to be considered in developing an educational model that allows the incorporation of STEM education to favor the generation of computational thinking was achieved. Although this sketch is far from being the final outline of the model, it helps to discern the essential elements of the model and the future contributions to be considered (see Figure 1).

Final assessment of results

Although the meticulous analysis of the selected literature made it possible to elucidate the fundamental aspects and the main limitations to be addressed in the context of the proposed model, it is imperative to recognize that its full and effective development requires the incorporation of various additional methodologies that provide robust and multidimensional support for its design and practical application. In this regard, it is vital to ensure that both the conceptual outline presented in this document and future iterations of the model allow for a sufficiently broad and flexible margin for periodic review and the integration of significant advances in critical dimensions of the model. This approach will not only allow the model to adapt to changes and evolutions in the educational and technological context but also ensure that the model's strategies and components remain aligned with the latest trends and best practices in the field, thus contributing to its long-term relevance and applicability in the evolving educational and technological environment.

Figure 1.
Basic outline of the educational model



Source: Own elaboration

This is due not only to the emergence in the literature of new approaches or positions but also to the recent trend that STEM education has experienced concerning the integration of disciplines, processes, and concerns, which, although many are not new, condition how it is produced. Aspects such as educational leadership and its link to the STEM approach (Hatisaru et al., 2023), the link between educational levels and the implications of early selection of STEM programs (Dixon et al., 2020), gamification and the innovative use of electronic devices (Chu et al., 2021; Hu et al., 2023), motivation for learning and achievement of educational goals (Arievitch, 2020; Markandan et al., 2022), as well as teacher preparation and their commitment to improving STEM education (Çiftçi & Topçu, 2022; Yang et al., 2021).

CONCLUSIONS

In today's intricate landscape and projecting into future societal development, STEM education emerges as an approach of undoubted value. This is not only because of its orientation towards technological aspects but also because it stands as an essential tool and model for achieving critical goals in educational agendas, such as improving accessibility, promoting inclusion, reducing the gender gap, and stimulating creative thinking.

The research is appreciated as valuable, supporting crucial aspects of building computational thinking through STEM education. Furthermore, the results underline the imperative need to strengthen the fundamentals of the educational sciences, especially in their integration into the secondary school curriculum, which makes clear the need to develop an integrative model.

Therefore, it is concluded that the STEM approach must be designed intentionally, focusing meticulous attention on the technological, educational, and pedagogical aspects that underpin the curricular transformation. This intentionality must be mediated and adapted to the historical and sociocultural context in which it is intended to be implemented and precisely aligned with the pre-established goals.

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