EUROPEAN JOURNAL OF STEM EDUCATION

European Journal of STEM Education,
2025, 10(1), 13
ISSN: 2468-4368

lectito

# STEM Conceptions and Competencies: Diagnostic Analysis of In-service Teachers in Intermediate Urban Settings

Carlos Mauricio Agudelo-Rodriguez [1]*, Ronald Andres Gonzalez-Reyes [1]

[1] *Antonio Nariño University*, COLOMBIA

***Corresponding Author:** cagudelo27@uan.edu.co

**Citation:** Agudelo-Rodriguez, C. M. and Gonzalez-Reyes, R. A. (2025). STEM Conceptions and Competencies: Diagnostic Analysis of In-service Teachers in Intermediate Urban Settings. *European Journal of STEM Education*, 10(1), 13. https://doi.org/10.20897/ejsteme/17166

**Published:** September 29, 2025

## ABSTRACT

The increasing focus on STEM education has prompted the introduction of teacher training programs at the state level. However, such programs tend to be poorly adapted to specific contexts. Therefore, conducting diagnostic assessments for ascertain the existing conceptions and competencies of in-service teachers to facilitate the implementation of more pertinent teacher training programs is essential. The study's objective was to examine these conceptions and competencies among a group of intermediate urban context (Caquetá, Colombia) working in technology, science and mathematics areas. A sequential mixed-methods combined qualitative and quantitative analysis through an elicitation protocol, focus groups, and test-type diagnostic tests. The data were analysed qualitatively with Atlas.ti and quantitatively using nonparametric analysis in Jamovi. The results indicate that most teachers espouse a conceptual model of "integrated disciplines" for STEM teaching, which aligns with real-world context problem-solving. Regarding competencies, notable variability was evident, with mathematics teachers demonstrating proficiency in the cognitive domain and technology teachers exhibiting expertise in the instructional and affective domains. Nevertheless, some teachers demonstrated a lack of comprehension regarding the interdisciplinary approach. Thus, STEM teacher training programs should be contextualized and focused on strengthening interdisciplinary, technological, and affective competencies to ensure more effective implementation in accordance with local contexts.

**Keywords:** STEM conceptions, STEM competencies, in-service teachers

## INTRODUCTION

In recent years, education with a STEM approach has emerged as a prominent topic in the education field, garnering attention from both political and pedagogical perspectives (Domènech, 2019). Such a role is associated with the necessity for different states to promote scientific and technological competencies and 21st-century skills in their citizens (Castro Inostroza et al., 2020; Mahecha et al., 2021). Nevertheless, several theoretical aspects of STEM education remain a matter of debate, which can sometimes impede its implementation in the classroom (Toma and Retana, 2021).

In the Colombian context, the Ministry of National Education has developed training strategies for teacher communities as a crucial link for achieving the state's objectives (MEN, 2022). However, in order to implement effective training programs, it is essential to conduct comprehensive assessments that enable the identification of knowledge, pedagogical practices, and teachers' attitudes toward STEM education. This information is crucial for the design of appropriate training strategies that align with the identified needs (Domènech-Casal et al., 2019).

From an epistemological standpoint, STEM is regarded as a multidisciplinary pedagogical approach that strives to foster a unified literacy in diverse STEM disciplines while simultaneously reinforcing each of them through an integrated approach (Martín-Páez et al., 2019; Ritz and Fan, 2015; Schulz and Pinkwart, 2015). Although the literature often refers broadly to STEM as an integrated or interdisciplinary approach, it is important to distinguish among the terms "multidisciplinary," "interdisciplinary," and "transdisciplinary," which are frequently conflated (NASEM, 2014; Vasquez et al., 2013). A multidisciplinary approach involves addressing a topic from multiple disciplinary perspectives in parallel, without necessarily integrating them (Beane, 1997). In contrast, an interdisciplinary approach implies a deeper synthesis of methods and concepts from different disciplines to create a more unified understanding (Boix Mansilla, 2005; NASEM, 2014). Finally, transdisciplinary education transcends traditional disciplinary boundaries by engaging with real-world problems through collaboration among disciplines and stakeholders beyond academia (OECD, 2019a; Repko and Szostak, 2020). Clarifying these distinctions is essential to contextualize the pedagogical approaches under discussion and to understand the level of integration required in STEM teaching practices.

However, the concept of STEM education differs across countries. Some proponents argue for a more rigorous and specialized teaching of distinct STEM disciplines, whereas others advocate for an integrative approach that combines subjects (Ritz and Fan, 2015). The continued existence of this diversity of conceptions has led to the term STEM being considered polysemous (Domènech, 2019). Nevertheless, authors such as Ring et al. (2017) and Dare et al. (2019) have made a significant contribution to the identification and categorization of these conceptions. In this regard, eight mental or conceptual models have been described from an educational perspective for the term STEM (García-Yeguas et al., 2023).

Additionally, to align this study with international discourse on STEM education, it is essential to consider globally recognized frameworks. The Next Generation Science Standards (NGSS) from the United States provide a structured vision for integrating scientific practices, crosscutting concepts, and core disciplinary ideas, offering a reference for curriculum design and competency development in science education. Similarly, the Organization for Economic Co-operation and Development (OECD) has proposed a comprehensive framework on STEM competencies, emphasizing cognitive, technical, and socio-emotional skills required in 21st-century learning environments. These frameworks inform the competencies expected of STEM educators as well as provide benchmarks that enhance comparability and contextual relevance of local findings within broader global standards (NGSS Lead States, 2013; OECD, 2019b). These models are developed as acronyms, separate disciplines, integrated disciplines, contexts, real problem solving, science, the engineering design process, the science and engineering design process, and finally, engineering (Ring et al., 2017).

Concerning the competencies of teachers in STEM education, Song (2020) notes that there has been a paucity of research conducted on the subject. Nevertheless, essential competencies and skills have been delineated, that educators engaged in STEM education should possess, encompassing a synthesis of domain-specific knowledge, pedagogical expertise, and interdisciplinary capabilities. Regarding domain-specific knowledge, educators must possess a comprehensive understanding of science, technology, engineering, and mathematics to effectively instruct integrated STEM subjects (Nam and Bui, 2023; Song, 2020; Yang and Ball, 2022). Similarly, pedagogical skills, including instructional design, assessment, and classroom management, are essential for effective STEM teaching (Du et al., 2019; Song, 2020; Wright and Waxman, 2022). In conclusion all the interdisciplinary competencies are important and must be emphasized. Teachers should be able to combine several disciplines, work together on a subject and create interdisciplinary STEM projects (Smith et al., 2022; Wang et al., 2020; Yilmaz, 2022).

Considering the findings of this study, and building on the work of Song (2020), a set of fundamental competencies and pedagogical principles for effective STEM teaching has been identified. These competencies, as perceived and practiced by in-service teachers, are typically grouped into three main domains: cognitive characteristics, practical (or instructional) skills, and affective characteristics. Based on this structure, it is possible to determine the initial level of composite teaching competencies and the conditions under which they emerge.

As to the implementation of STEM education, it implies the engagement of genuine problem posing via effective application of knowledge and skills from an individual's discipline within the context of disciplines (Dan and Gary, 2018). Besides, it requires that educators are willing to accept STEM education and incorporate it into their teaching. Therefore, it calls for other factors such as the setting up of an environment conducive for teaching STEM and the development of a framework for the professional development of integrated STEM (Almarashdi et al., 2022; Osadchyi et al., 2019) among power these factors. These transformations have been influenced by the geographic, social and economic developing contexts.

As indicated by Domènech-Casal et al. (2019), to generate superior levels of appropriation in the training processes developed, it is essential to identify the geographical, social, and economic contexts of the various regions. Reig Martínez et al. (2016) posit that such contexts can be typified at the local level based on demographic characteristics or human intervention on the territory. In the initial classification, urban regions are distinguished as metropolises, which are characterized by high population density, intermediate cities, and small urban areas with populations between 10,000 and 100,000 inhabitants. As indicated by Sánchez and Araque (2023), this typology applies to the land occupation models observed in Colombian cities.

In light of the preceding discussions, it is considered appropriate for teacher training programs to be carried out differentially in the territories, taking into account, at least, aspects linked to demographics, with specific diagnoses on teacher communities, and developing training programs that respond to the needs of the regions. This research seeks to contribute to this premise, identifying, by way of diagnosis, the training needs about the conceptions and competencies of a group of in-service teachers in an intermediate urban environment concerning the STEM educational approach to lay the foundations for the structuring of a pertinent teacher training program with a high degree of appropriation.

## METHODOLOGY

### Study Design and Participants

An exploratory sequential mixed methods approach was employed to identify the conceptions and competencies of practicing teachers regarding STEM education,

The participants were 15 teachers from various urban educational institutions in Florencia (Caquetá, Colombia), with an estimated population of 180,000 inhabitants, who are responsible for teaching technology, mathematics, and natural sciences at the middle school level. The educators were invited to participate in a training program designed to enhance their pedagogical skills with an emphasis on STEM education. Their participation was voluntary.

### Procedure and Data Analysis

To identify the conceptual models of STEM education held by in-service teachers, the protocol proposed by Ring et al. (2017) was employed. This entailed requesting that they create a drawing that, in their estimation, represented the STEM approach. In addition, they were requested to provide an account of the experience that had motivated the creation of their representation. The conceptual models were subjected to qualitative analysis following the eight categories established by Ring et al. (2017). Furthermore, the absolute and relative frequencies of the various conceptual identified models were calculated.

Two data collection techniques were employed to diagnose teaching competencies. The data collection techniques implemented were a focus group and an entry test. In both instances, a document comprising guiding questions was prepared based on the competency dimensions proposed by Song (2020). The contents of the focus groups were recorded with the consent of the participants. To conduct a comprehensive analysis of the focus group, we began by transcribing the audio recordings and establishing categories of analysis. These categories are defined as concepts derived from the data that represent phenomena (Strauss and Corbin, 2002), with a particular focus on the study's objective. The Atlas.ti software was employed to facilitate the categorization and grouping of the data, with consideration given to both the common and divergent elements present in the descriptions.

The diagnostic test was developed as an 18-item questionnaire, which was then subjected to expert evaluation. A panel of nine experts was assembled as a source of information, selected based on their doctoral training, experience in STEM disciplines, and scientific research expertise. For the evaluation, a single modality was selected, whereby each judge completed a written questionnaire independently, without contact between them. The survey was then refined based on the individual observations, and a final version was prepared. Afterwards, it was distributed to four in-service teachers on a personal basis, simulating the conditions of the official population. The teachers in question were two science teachers, one technology teacher, and one mathematics teacher. Then, an interview was conducted to ascertain the perceptions of the test. The responses from this cohort of teachers enabled the final adjustments to be made and the data to be organized in a manner conducive to the pertinent statistical analysis. The instrument was administered to the participants via Google Forms. In addition to the expert review and pilot testing, the diagnostic instrument's internal consistency was assessed using Cronbach's alpha, evaluating the coherence of the items measuring teachers' conceptions and competencies in STEM education.

The competency domains established by Song (2020) and the performance areas of in-service teachers were taken as variables and subjected to quantitative analysis with Jamovi software (Version 2.3). Descriptive analyses were conducted, including the calculation of the mean, median, standard deviation, minimum, and maximum values, as well as the generation of histogram plots with density.

A Student's t-test was conducted to ascertain the validity of the normality assumption (Shapiro-Wilk). It was determined that the data did not satisfy the assumptions of normality, and thus, they were transformed. Three types of transformations were applied to each of the selected variables: the logarithmic transformation (Log), in which the natural logarithm was applied to each value; the square root transformation (Sqrt), in which the square root was applied to the values; and the Box-Cox transformation, which optimizes the data to approximate a normal distribution, automatically adjusting a lambda parameter (λ).

Subsequently, nonparametric tests were employed. In this instance, a one-factor ANOVA (Kruskal-Wallis) was employed, wherein the grouping variables were the disciplines, and the dependent variables were the categories or domains previously described. Additionally, two-by-two Dwass-Steel-Critchlow-Fligner comparisons were conducted. The analysis of the test was completed with the presentation of a correlation matrix, which identified the Pearson correlation coefficient.

This study was approved by the ethics committee of Antonio Nariño University, in accordance with national regulations and international ethical standards for research involving human participants. All participants were informed of the purpose of the study and voluntarily signed an informed consent form prior to their involvement.

## RESULTS

### Conceptual Models of In-service Teachers

Seven in-service teachers who participated in the research presented a conceptual model of integrated disciplines (**Table 1**), in which they constructed schemes representing a confluence among the STEM disciplines (**Figure 1**). In some instances, the conceptual model developed by the participants tended to a particular discipline, particularly technology (**Figure 2**).

**Table 1.** STEM models frequency *(n=15)*

| Model | Scheme | | Explanation | |
|---|---|---|---|---|
| | F | % | F | % |
| STEM as an acronym | 1 | 7% | 0 | 0% |
| Real-life problem solving as a context | 1 | 7% | 1 | 7% |
| Science as a context | 1 | 7% | 1 | 7% |
| STEM as separate disciplines | 1 | 7% | 0 | 0% |
| Integrated disciplines | 7 | 47% | 8 | 53% |
| Engineering as a context | 0 | 0% | 1 | 7% |
| Science and engineering as a context | 2 | 13% | 1 | 7% |
| Not assignable | 2 | 13% | 3 | 20% |

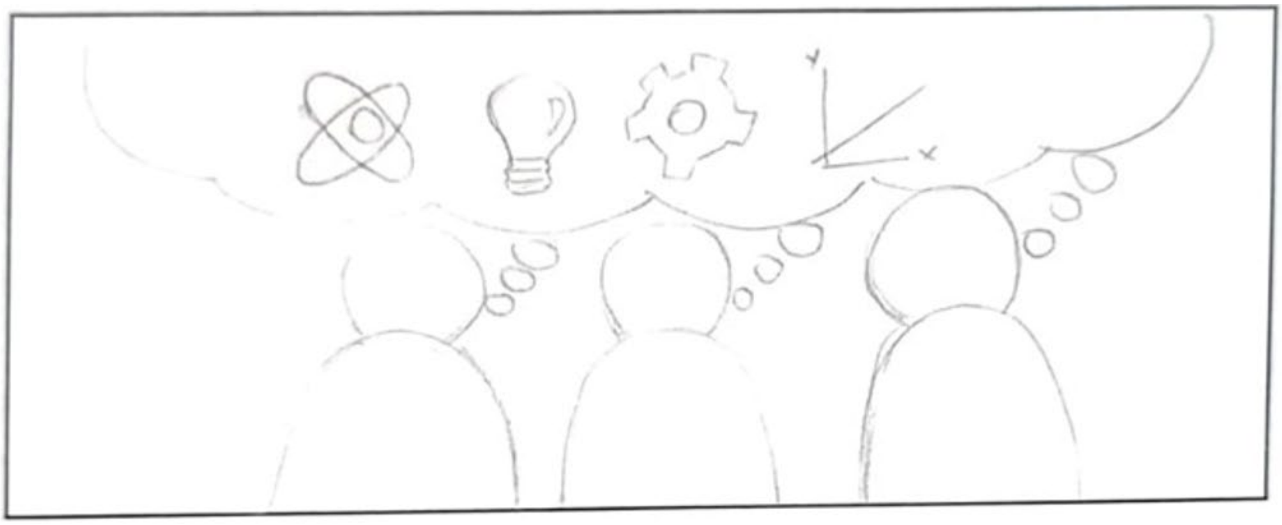

**Figure 1.** Example of a scheme identified as "integrated disciplines"

There are some discrepancies between what is illustrated and what is described. However, the tendency of the group of pre-service teachers is towards a STEM model of integration of disciplines, with a focus on solving problems of context. These findings are consistent with the proposals of Dare et al. (2019) and Ring et al. (2017). These proposals suggest that the models of integration of disciplines and real-life problem solving as context reflect a more appropriate perception of STEM education.

On the other hand, two participants' schemas do not show a defined mental model about STEM education, therefore it is not possible to assign them to the schemas established by Ring et al. (2017). These cases were classified into the category of "not assignable" (**Figure 2**).

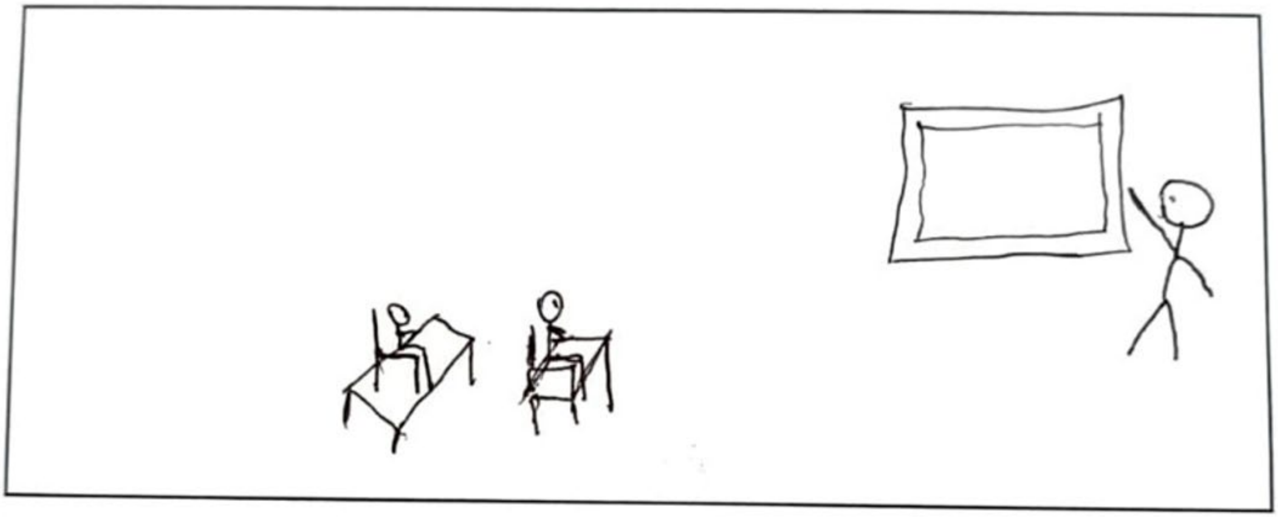

**Figure 2.** Example of a schematic identified as "not assignable"

Regarding their previous experiences, the participants expressed that they were acquired through institutional and personal exercises and interests, such as reading articles, teaching experiences, and project work.

It is interesting to find few works with diagnostic tests on STEM education in practicing teachers, especially in this protocol, although it is common to find them in pre-service teachers, such as the one conducted by Toma and Retana-Alvarado (2021). They revealed very simple and poorly developed conceptualizations before the start of a training program, citing as the main reason for this finding the lack of consensus in the literature on what STEM is.

However, García-Yeguas et al. (2023), in a study also with pre-service teachers, obtained results similar to those of this research. Therefore, it is necessary to consider that in-service and pre-service teachers with some previous experience, as is the case of the population studied, have a more contemporary and consensual conception of inclusiveness, as proposed by Dare et al. (2019) and Ring et al. (2017), indicating that previous experience, as well as training programs, has a positive effect on conceptualization.

## Diagnosis of Teaching Competencies

### *Focus group*

Focus group data were collected and systematically organized according to the three domains of competencies proposed by Song (2020). As shown in **Figure 3**, each domain corresponds to an analysis category. The subcategories identified for each domain are derived from these categories.

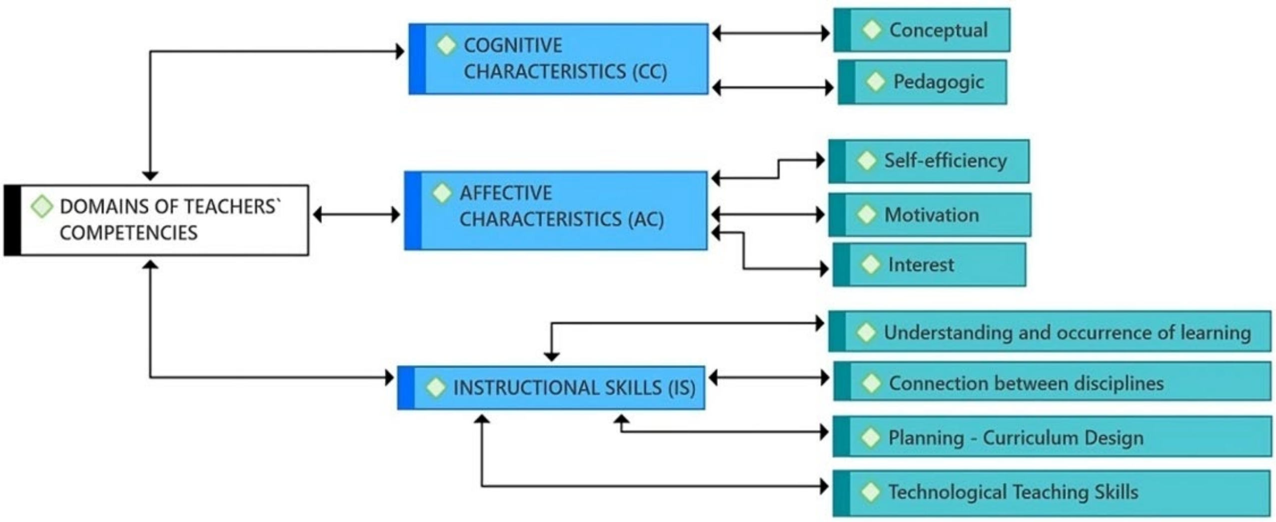


**Figure 3.** ATLAS.ti software network plot. Categories and subcategories detected in the focus group analysis

These categories are not entirely consistent with those identified by Song (2020) (**Table 2**). Once the categories were identified, five out of the fifteen participants were interviewed.

**Table 2.** Song domains and competencies (2020)

| Cognitive characteristics (CC) | Instructional skills (IS) | Affective characteristics (AC) |
|---|---|---|
| Knowledge of the subject | Student-directed learning | Communication |
| Pedagogical knowledge | Problem solving related to authentic local and global issues and everyday life | Enthusiasm |
| Curriculum knowledge | Instructional strategies | Passion |
| Ability to plan lessons and adjust course components | Evaluation | Empathy |
| Learner understanding and learning occurrence | Collaboration | Professionalism |
| Making connections between disciplines | Technological skills/ ICT and multimedia skills | Self-efficacy |
| Transversal skills | | Belief that all children can learn |
| Flexibility: creativity, innovation | | |

It was found that "instructional skills" does not cover the full range of teaching practices. Therefore, it is considered that the domain should be called "practical skills". Likewise, these skills should be identified as general and specific. In this sense, it is considered that teachers should have at least three types of general practical skills: planning, pedagogical practice, and evaluation. An example of this can be seen in competencies such as "ability to plan lessons and adapt course components" and "making connections between disciplines", which are specific competencies to curriculum design and should therefore be included in the general planning skills, which, although they require a cognitive assumption, are developed by teachers through their curriculum design practice. Similarly, the competencies "student understanding and learning" and "evaluation" should be included in the general competence of evaluation.

The position identified in the group of teachers is in line with Copriady (2014) and Lestari et al. (2018) who, about planning, express that teachers should be experts in designing, planning, and implementing lessons that meet diverse learning needs. Similarly, concerning pedagogical practice, teachers need strategies, practices, and practical rules that guide them to improve instruction and student performance, and with this, effective management of classroom dynamics to create a conducive learning environment (Hamdan et al., 2010; Welsh and Schaffer, 2017; Zhou et al., 2023). In terms of assessment, the teachers' position is consistent with that of Selvi (2010), who suggests that to assess students appropriately, teachers must have a set of specific competencies that ensure fair and effective assessment. The competencies that teachers must possess to effectively assess students include the ability to develop authentic assessments, engage students in the assessment process, and critically evaluate the quality of assessments (Gulikers et al., 2008; McMillan, 2016; Schons et al., 2024).

In this sense, the general domains of teaching competencies in STEM education are proposed as cognitive characteristics, practical skills, and affective characteristics. Likewise, within the domain of practical skills, the subdomains of planning, pedagogical practices, and evaluation should be consolidated, as shown in **Figure 4**.

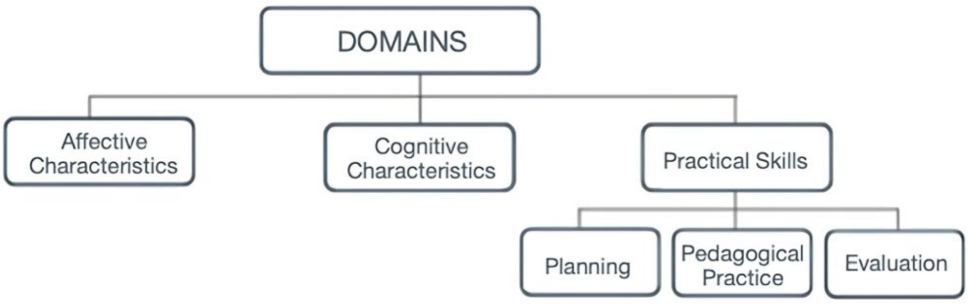


**Figure 4.** Proposed adjustment to the domains of teaching competencies in STEM education

Conversely, three Sankey diagrams related to the disparate domains of teaching competencies were constructed to ascertain the distribution and interconnections between the categories and subcategories. Concerning cognitive competencies, it is evident that pedagogical characteristics are predominantly linked to practical approaches, including "project-based learning" and "teamwork," as well as to didactic methods. This illustrates the significance of employing active and collaborative pedagogical strategies in the teaching process (**Figure 5**). Moreover, it enables educators to facilitate active learning. As Felder et al. (2009) have demonstrated, active learning, which entails students' direct involvement in the learning process, is an effective tool for enhancing comprehension of complex concepts and fostering critical thinking. Regarding collaborative strategies, Bielaczyc and Collins (1999) propose the formation of learning communities within the classroom setting, wherein students engage in collective knowledge construction. This approach enhances academic performance and fosters the development of social competencies through the promotion of interaction and active participation.

 

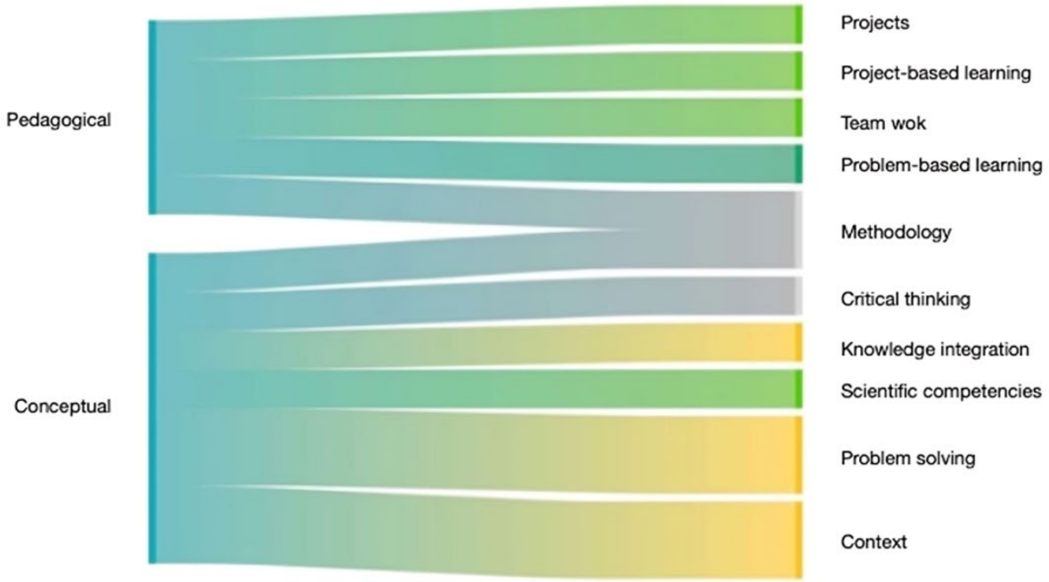


**Figure 5.** Sankey Co-occurrence Plot – ATLAS.ti Software. Subcategories and components of the conceptual category

In the subcategory of conceptual components, critical thinking elements such as "knowledge integration" and "scientific competencies" are related, indicating a strong linkage with analytical skills, problem-solving, and contextualization of knowledge. This network of relationships demonstrates the interdependence between pedagogical and conceptual dimensions developing teaching competencies, emphasizing the necessity for an integrative approach that encompasses both practical application and critical thinking in teacher education. Similarly, it is proposed that effective teaching requires the articulation of a range of competencies, whereby the implementation of active methodologies and the promotion of critical thinking are mutually reinforcing. As indicated by Felder et al. (2009), these methodologies contribute to the development of a more holistic and contextualized educational practice.

The Sankey diagram of practical skills provides a visual representation of the interconnections between distinct teaching competencies and associated pedagogical practices (**Figure 6**). It is evident that the "curriculum planning and design" component is closely associated with key elements such as "context," "problem-solving," and "brainstorming". This reasoning agrees with the views expressed by Hammerness et al. (2005) and Moore (2012), who argue that while curriculum effectiveness is appreciated in most cases, there is a need to provide for the learning situation and use of the different approaches to addressing the situation.

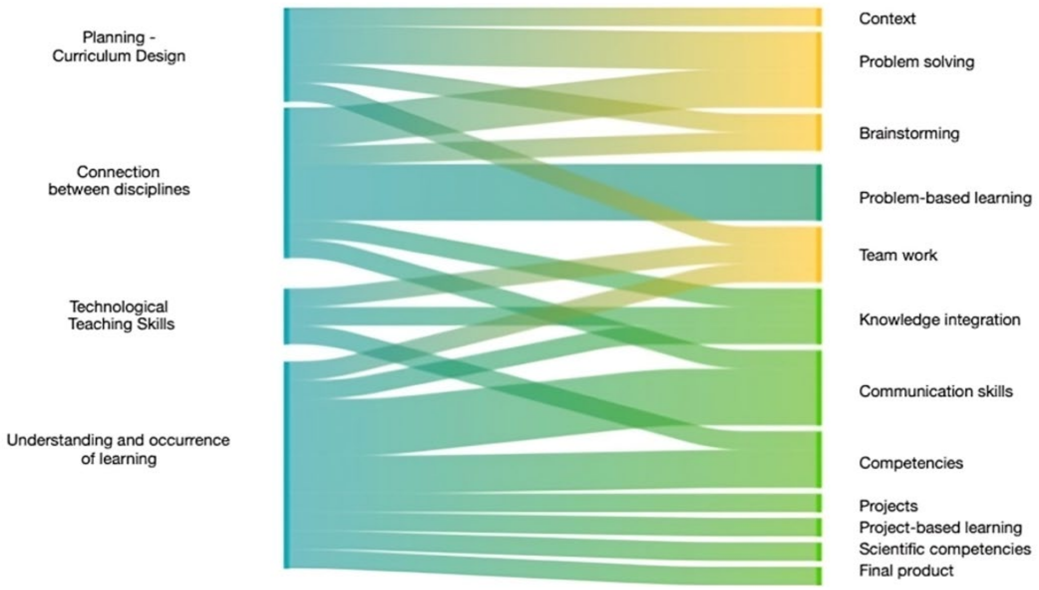


**Figure 6.** Sankey Co-occurrence Plot – ATLAS.ti Software. Subcategories and components of the practical skills category

The component of strong influence as a form of knowledge transfer can show connections with certain concepts such as "problem-based learning" and "knowledge integration": atypical classroom practice is perceived, whose purpose is to facilitate better practical understanding of concepts by ways of teaching that are more comprehensive. As Capraro and Jones (2013) have pointed out, cross disciplinary approach to teaching, especially in STEM education, enhances understanding of content by linking content from various areas of study. In this way learners get to practice what they have only learnt in theory and through different forms of assessment in real and authentic situations. It encourages a more natural approach to learning and seeks to combine skills and knowledge that may otherwise be separable into different subjects. Also, Kelley and Knowles (2016) sustained this idea showing that there is such a thing as static cognition and presenting explicit interdisciplinary bridges helps to develop problem-solving as well as analytical thinking.

By and large, the sub-component "technological skills in teaching" reveals a high level of possibility for transfer to other practices including "teamwork", "competencies", "communication skills", and "project-based learning." The above arguments clearly support the notion that technology promotes collaboration and mastering of important skills among the learners. As Magen-Nagar and Shonfeld (2018) have noted, the introduction of technology into cooperative learning processes tends to create a positive change in students' perception of the hardware and encourages them to perform better. Technological interaction in these types of environments enhances collaboration among students and their successful attainment of competencies and skills which are essential for 21st-century citizens.

The aspect "concept and process of learning process" brings according to the finding to an understanding at least some concepts such as 'projects', 'project being based learning', 'science competencies' and 'endpoint'. The above includes the promotion of an emerging understanding of learning and a structure of organization of activities and instructional and curricular processes that can best promote learning outcomes.

This analysis of teacher's practical skills proves the understanding of the need for a rounded and holistic teaching model focusing on orchestration that brings in curriculum design, disciplinary learning practices which learners have to suspend their other teacher roles. The diagram illustrates the interconnection between pedagogical practices and teaching competencies, which collectively shape a dynamic educational environment. Strategic planning and the implementation of active methodologies assume particular significance in this context, as they facilitate the comprehensive formation of the student.

As illustrated in the Sankey diagram of the affective competencies dimension, there is a notable correlation between the construct of interest and the implementation of active teaching methods, such as project-based and problem-based learning. Additionally, there is a significant association between interest and collaborative elements, including teamwork and contextual factors (**Figure 7**). This illustrates that the teacher's interest is of critical importance regarding the implementation of teaching strategies that promote active participation and collaborative work. Indeed, scholars such as Magen-Nagar and Shonfeld (2018) and Timperley et al. (2014) assert that a teacher's interest in enhancing their professional practice through collaboration directly influences the quality of instruction and the development of essential competencies in students.

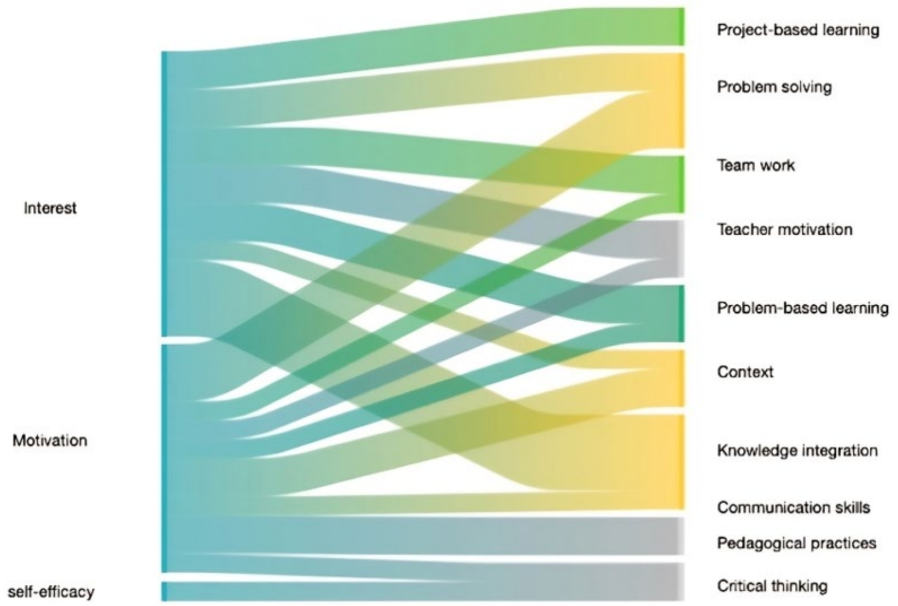


**Figure 7.** Sankey Co-occurrence Plot – ATLAS.ti Software. Subcategories and components of the affective competencies category

 

Conversely, motivation is associated with a range of practices, including knowledge integration and critical thinking, which suggests that teacher motivation is linked to implementing pedagogical approaches that facilitate a more profound and essential understanding of content. This assertion aligns with the findings of Magen-Nagar and Shonfeld (2018), who posit that when educators are motivated and perceive an intrinsic connection with active pedagogical approaches, such as online collaborative learning, it creates a more conducive learning environment and enhances student engagement, and, in turn, promotes deeper and more effective learning. In turn, Timperley et al. (2014) emphasize that the active participation of teachers in collaborative inquiry cycles fosters a more dynamic learning environment in which teamwork and constant reflection allow for the adaptation of pedagogical strategies to better respond to the needs of students.

"Self-efficacy" demonstrates a direct correlation with both "pedagogical practices" and "critical thinking", although exhibiting less diverse interconnections. This illustrates the significance of teacher self-confidence in the development and execution of efficacious educational strategies. Indeed, Gardner et al. (2019) posit that teacher self-efficacy directly influences teachers' capacity to teach STEM content and to integrate innovative pedagogical approaches in the classroom. The implementation of interdisciplinary STEM lessons has been observed to improve due to professional development programs designed to increase self-efficacy, which aligns with the findings of Gardner et al. (2019). This, in turn, has been shown to positively impact students' academic performance and engagement in cognitively challenging activities.

In conclusion, the evidence presented thus far supports the assertion that affective characteristics are relevant in teaching practice. It can be stated with confidence that interest, motivation, and self-efficacy influence the selection and implementation of methodologies that promote active and critical learning.

### *Competency test*

As part of the data analysis process, the internal consistency of the diagnostic instrument was examined using Cronbach's alpha. The coefficient obtained was $\alpha = 0.84$, which indicates good internal consistency across the items and confirms that the instrument reliably measures the targeted constructs.

The descriptive analyses presented in **Table 3** and the histograms with density demonstrate superior performance in the domain of cognitive characteristics among mathematics teachers (**Figure 8a**), indicating that mathematics teachers perceive greater competency in this area. This may be related to the intrinsic nature of mathematics teaching, which necessitates advanced levels of logical and abstract reasoning, competencies that are pivotal to STEM thinking (Tricot and Sweller, 2014). Conversely, the mean score for science teachers is the lowest (3.60), although it is not significantly different from that of technology teachers (3.83). This may be attributed to the perception that science entails greater uncertainty or dependence on practical contexts, which may lead teachers to perceive their cognitive abilities as less robust compared to mathematics, where concepts are more systematic and defined (Deboer, 2000). Similarly, the test of technology teachers revealed superior performance in the domains of instructional skills and affective characteristics (**Figure 8b** and **Figure 8c**).

**Table 3.** Statistics descriptive test of STEM competencies

| | Discipline | N | Lost | Media | Median | DE | Minimal | Maximum |
|---|---|---|---|---|---|---|---|---|
| Cognitive | Mathematics | 4 | 0 | 4.50 | 4.50 | 0.577 | 4 | 5 |
| | Technology | 6 | 0 | 3.83 | 4.00 | 0.753 | 3 | 5 |
| | Sciences | 5 | 0 | 3.60 | 3 | 0.894 | 3 | 5 |
| Instruction | Mathematics | 4 | 0 | 3.25 | 3.00 | 0.500 | 3 | 4 |
| | Technology | 6 | 0 | 3.67 | 4.00 | 0.516 | 3 | 4 |
| | Sciences | 5 | 0 | 2.80 | 3 | 0.837 | 2 | 4 |
| Affective | Mathematics | 4 | 0 | 3.00 | 3.00 | 0.816 | 2 | 4 |
| | Technology | 6 | 0 | 3.33 | 3.50 | 1.366 | 1 | 5 |
| | Sciences | 5 | 0 | 1.80 | 1 | 1.095 | 1 | 3 |

In the domain of instructional skills, the mean score for technology teachers is the highest (3.67), exceeding both mathematics (3.25) and science (2.80). This result may be attributed to the perception that technology teaching is more closely aligned with practical, everyday applications, where educators may possess greater confidence in their capacity to facilitate applied learning environments (Sanders, 2009). In contrast, science instruction may be perceived as more complex or challenging, which is reflected in a lower mean. The discrepancy in instructional approaches between science and other disciplines may be attributed to the perception that science teaching necessitates a greater reliance on experimentation and the management of uncertainty, which may contribute to a sense of diminished competence among teachers in this domain (Bybee, 2013).

 

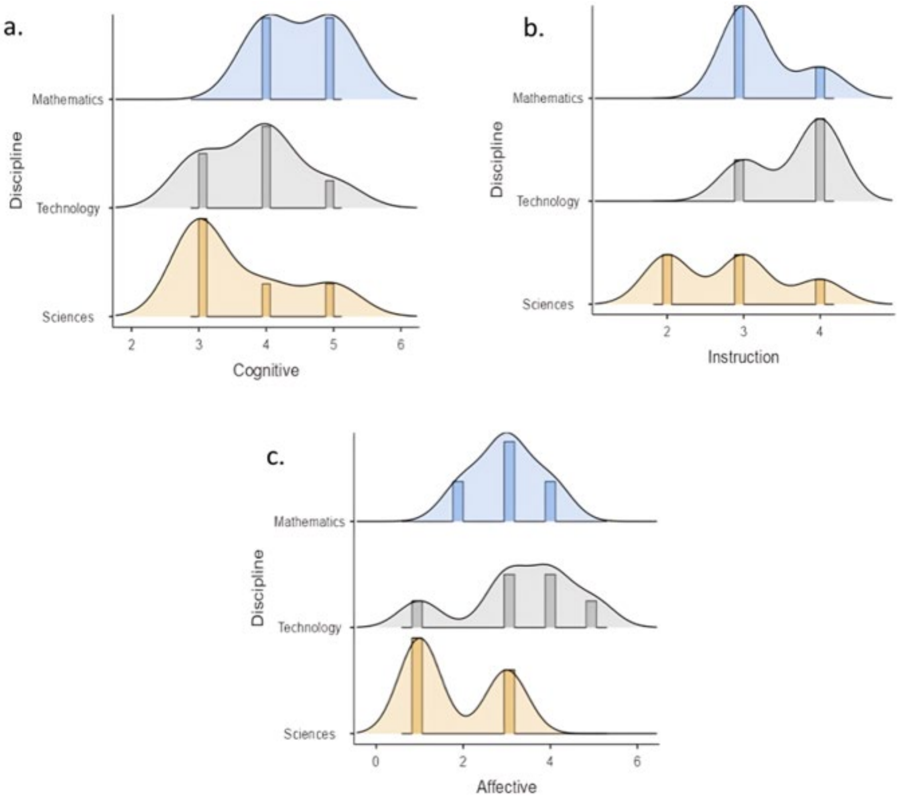


**Figure 8.** Histograms with density, proficiency domains versus STEM disciplines. a) Cognitive, b) Instructional and c) Affective

The affective component indicates that the results for technology teachers also have the highest mean (3.33), while those for science teachers have the lowest (1.80). This indicates that technology teachers exhibit greater emotional comfort and connection to their discipline compared to science teachers, who appear to experience heightened emotional challenges when teaching. The lower affectivity scores observed among science teachers may be associated with diminished perceived self-efficacy in teaching this discipline, as evidenced by prior studies on science teaching (Guskey, 1988).

It is noteworthy that the standard deviation (SD) is relatively high in certain categories, including "affective" in "technology" (SD = 1.366) and "affective" in "science" (SD = 1.095). These figures indicate greater variability in teachers' affective perceptions. In technology, this dispersion may be attributed to individual differences in how teachers cope with the emotional challenges of teaching a rapidly evolving discipline that may have varying levels of acceptance or interest among teachers (Lemke, 2001). In science, the high deviation may reflect the uncertainty and emotional challenges that many teachers face in dealing with topics that require experimentation and scientific reasoning, which generates a greater diversity of emotional responses.

Conversely, the outcomes of the Kruskal-Wallis test (**Table 4**) and paired comparisons indicate no statistically significant differences in the cognitive domain between mathematics, technology, and science (**Table 5**). The effect size is moderate, indicating that the findings have some practical relevance. The absence of statistical significance indicates that these discrepancies are insufficient to be regarded as statistically meaningful.

**Table 4.** Kruskal-Wallis

| | $\chi^2$ | df | p | $\varepsilon^2$ |
|---|---|---|---|---|
| Cognitive | 3.04 | 2 | 0.219 | 0.217 |
| Instruction | 3.86 | 2 | 0.145 | 0.276 |
| Affective | 4.18 | 2 | 0.123 | 0.299 |

**Table 5.** Two-to-two comparisons Dwass-Steel-Critchlow-Fligner couple comparisons - cognitive

| | | w | p |
|---|---|---|---|
| Mathematics | Technology | -1.964 | 0.347 |
| Mathematics | Sciences | -2.191 | 0.268 |
| Technology | Sciences | -0.836 | 0.825 |

The Kruskal-Wallis test and the paired comparisons in the instructional domain indicate no statistically significant differences between mathematics, technology, and science (**Table 6**). The moderate effect size indicates that, although not statistically significant, there may be noteworthy variations in specific contexts, but not to a degree that can be discerned in this analysis.

**Table 6.** Two-to-two comparisons Dwass-Steel-Critchlow-Fligner couple comparisons - instruction

| | | w | p |
|---|---|---|---|
| Mathematics | Technology | 1.73 | 0.439 |
| Mathematics | Sciences | -1.34 | 0.609 |
| Technology | Sciences | -2.51 | 0.179 |

In the affective domain, no statistically significant differences were observed. However, this finding demonstrates the largest effect size and the greatest variability between groups (**Table 7**). This could suggest that the emotional or affective impact of these approaches differs to a greater extent, suggesting that this is an area that requires further investigation with larger samples or in different contexts.

**Table 7.** Two-to-two comparisons Dwass-Steel-Critchlow-Fligner couple comparisons - affective

| | w | p |
|---|---|---|
| Technology | 0.946 | 0.782 |
| Sciences | -2.211 | 0.262 |
| Sciences | -2.579 | 0.162 |

The Kruskal-Wallis test and paired comparisons in the cognitive, instructional, and affective domains revealed no statistically significant differences between mathematics, technology, and science. Nevertheless, moderate effect sizes, particularly in the affective domain, suggest the possibility of practical differences that may not be fully captured by the current sample size.

The observed correlations of the test results indicate a positive and considerable magnitude correlation between the instructional and affective domains, suggesting a direct and moderately strong relationship between the two domains. This result indicates a significant relationship between instructional perceptions or methods and affective responses (**Table 8**). Similarly, the p-value is statistically significant ($p < 0.05$), indicating that the relationship between the instructional and affective domains is not only apparent but also statistically significant. This finding demonstrates that how instruction is conducted has a notable impact on affective responses among individuals, a phenomenon that is particularly relevant in the context of education, given the pivotal role that emotions play in the learning process.

**Table 8.** Differences between current and previous studies

| | | **Cognitive** | **Instruction** | **Affective** |
|---|---|---|---|---|
| Cognitive | Pearson correlation coefficient | - | | |
| | df | - | | |
| | p-value | - | | |
| Instruction | Pearson correlation coefficient | 0.288 | - | |
| | df | 13 | - | |
| | p-value | 0.298 | - | |
| Affective | Pearson correlation coefficient | 0.051 | 0.640* | - |
| | df | 13 | 13 | - |
| | p-value | 0.856 | 0.010 | - |

*p < .05; **p < .01; ***p < .001

## DISSCUSSION

The present research is based on the STEM conceptions and competencies of in-service teachers working in an intermediate urban context and has revealed an interesting fact as well: the use of the model of disciplinary integration is more dominant among many participants. This trend supports the suggestions made by some authors: Dare et al. (2019), Ring et al. (2017) who are stressing the importance of the cross-discipline integration by applying problem-centred education while training experts in STEM subjects. Even so, the discrepancies in conceptions which have been noted, for instance, several teachers refusing to make a simple model explaining their concepts. Such observation suggests that more levels of understanding of the interdisciplinary amount are left. Such statements strengthen the need for more specific teacher education programs to be developed such that all teachers will have the same understanding of the STEM approach and especially how it can be employed in given situations.

 

In this vein, the works of Huang et al. (2022) or Domènech-Casal et al. (2019) state that the lack of such contextualized training forms a major barrier to the successful use of integrated models, especially in STEM. This also came to the fore as teachers' conceptions appear to indicate that there are missing tools required to efficiently combine the disciplines. This means that training programs should not be limited to the theoretical teaching of the concepts but rather focus on the practice where the teachers will be able to use the STEM approach systematically into the background of their education.

Another important aspect identified within the framework of this study is the way how teaching competences may be distributed, in particular the teachers' survey data obtained from the focus group supports this enhancement. It was found that the term "instructional skills" which was elaborated upon at the beginning is too narrow in scope vigorously addressing only a few activities within teaching. To put it simply these are both course and skill oriented hence referred to as practical skills marking a step forward in understanding the skills constitutional for effective STEM teaching practice. The issues presented in this proposal tentatively accept that general planning skills such as planning, and curriculum design are correctly categorized into planning skills while evaluation and understanding of learning skills belong to the understanding skills zone as these skills are mostly learned on the job.

Such an adjustment of core competencies is in consonance with the argument advocated by Copriady (2014) where he contends that teachers need to be able to design, plan as well as deliver lessons that address the different learning requirements of the learners. And furthermore, Hamdan et al. (2010) and Welsh and Schaffer (2017) similarly advocate the need for clear pedagogical strategies that help teachers improve the quality of instruction and skill fully deal with classroom activities. This new redistribution of competencies also concedes with the theory of Selvi (2010) who argues that, for any assessment to be effectively performed, teachers have to have a specialized set of core competencies which guarantee that the assessment will be not only equitable, and successfully conducted, but also contain vital information on the assessed outcomes.

Further, the investigation of cognitive, instructional and affective competencies indicates that there is disparity among teachers in the distribution of the three competencies, which concurs with previous studies conducted by Song (2020) and Zhou et al. (2023). The findings of this research inform the fact that in mathematical disciplinary content and applications or practices, mathematics teachers were more competent, whereas technology teachers had better performance in instructional and affective competencies. Consequently, this reinforces the idea that because it is more practical and related to use, teachers of subject technology are more self-assured and thus improve their self and change motivation as Gardner et al. (2019) has noted. Furthermore, those findings are also in agreement with those of Yıldırım et al. (2022), who note the importance of developing affective and cognitive self-regulation such as self-efficacy because it is essential for the success of new teaching strategies that involve the use of technology.

On the other hand, the observed patterns of differences among disciplines in the affective and instructional domains demonstrated that most of science educators presented low efficacy perceptions and high levels of uncertainty compared to mathematics and technology education teachers. This may be because it is believed that science teaching is accompanied by more difficult and more hands-on activities, which therefore creates problems within emotions and trust. Teacher efficacy is the degree of belief a teacher has towards their capacity to successfully guide students towards instructional objectives. Guskey (1988) advances those self-efficacious teachers always face low difficulties in the execution of measures relevant to their self-efficacy and student achievement.

Although there were no outstanding statistically significant inconsistencies found in the cognitive and the instructional parts of the analysis however, the analysis of the moderate effect sizes suggests that these differences may be consequential under different circumstances. This makes it imperative to enhance the training programs in accordance with the specific features of the particular discipline as these disciplines are suggested by Wright and Waxman (2022). They argue that optimal effectiveness of teaching should be pursued through the use of specific approaches to imparting instruction as dictated by the by the characteristics inherent in each bit of that body of knowledge.

Such features of the study aid the understanding of in-service teachers' conceptions of and STEM competencies and highlight the need for more contextual and educator-centred focused training. This reorganization of teaching competencies proposes that for effective STEM teaching, it is not sufficient to look at only the cognitive domain of the teacher, but also the hands-on and the emotional domains of the teacher enabling teachers to fully embrace the incorporation of this transdisciplinary approach. Furthermore, these findings support the justification of the need to further explore the variations between disciplines and the revision of training approaches to facilitate the constant employment of STEM strategies in the classroom.

These pedagogical implications must be interpreted in light of the study's methodological boundaries. While the study provides relevant insights into in-service teachers' conceptions and competencies regarding STEM education, its findings are based on a relatively small sample of fifteen participants from a single intermediate urban setting. This limitation restricts the generalizability of the results to broader populations. Moreover, there is a possibility of selection bias, as participants may have been more inclined or motivated toward STEM initiatives, which could influence both the self-reported data and their engagement with the training process. Acknowledging these constraints is essential for interpreting the findings with caution and highlights the need for further research involving more diverse and larger samples across different urban and regional contexts.

## CONCLUSIONS

The approach in question is predominantly that of integrated disciplines. The observed trend towards a conceptual model of integrated disciplines within the STEM framework reflects teachers' capacity to relate disparate areas of knowledge to solve real-world problems. However, the discrepancy in conceptualizations and the presence of unassignable schemas underscore the necessity to reinforce the comprehension of interdisciplinary principles in teacher training programs, particularly in those aiming for effective STEM implementation.

A significant outcome of the study is the recommendation to redefine the domain of "instructional skills" as "practical skills," delineating between general and specific skills. This proposal allows for a more precise categorization of teaching competencies, emphasizing the importance of curriculum planning and evaluation as fundamental pillars of STEM teaching performance. This new structure permits a more suitable methodology for the design of training programs, with the alignment of cognitive, practical, and affective competencies by the requirements of the contemporary educational context.

The discrepancies observed between cognitive, instructional, and affective competencies, particularly among the disciplines of mathematics, science, and technology, emphasize the necessity for personalized teacher training programs. While mathematics teachers exhibited superior competence in the cognitive domain, technology teachers demonstrated proficiency in both the instructional and affective domains. Conversely, science teachers encountered challenges related to self-efficacy and confidence in their pedagogical practice, underscoring the importance of a more balanced approach to competency development.

The research outlines the importance of such associated capabilities as motivation and self-efficacy which are necessary for applying new teaching methods in STEM. It has been found that teachers with a high level of self-efficacy and motivation can use more active methods of pedagogy, including project-based learning and teamwork, which enhance the efficiency of interdisciplinary teaching.

The results suggest that the teachers' STEM education should be designed and developed in accordance with the real needs of the teachers, given the local economic, and geographic and disciplinary contexts. The introduction of differentiated teacher training depending on the specifics of the environment would enhance the appropriateness of ownership regarding the implementation of the STEM approach, which is critical in addressing the issues raised in this study.

After all, this study provides relevant knowledge that can be useful in reforming how STEM teachers are trained. It emphasizes the importance of relevant expansion of approaches towards more practical understanding as well as contextualized understanding shifting teacher's cognitive competencies only to practical and emotional competencies of teachers.

Finally, it is important to mention that this research offer insights into the conceptions and competences of in-service teachers within the STEM frame for intermediate urban cities. Particularly, the study was centred in a regional context, which, might imply that the conclusions may not be representative for a broader diversity of realities. However, these findings allow for both discussion and the opening of new research processes in different geographical contexts. By expanding the participants, a more robust and generalizable conclusions might be achieved, aspect that is essential for fostering STEM education.

**Author contributions: CMAR:** methodology, conceptualization, formal analysis, writing – original draft, writing – review & editing; **RAG-R:** methodology, conceptualization, formal analysis, writing – original draft, writing – review & editing. Both authors have agreed with the results and conclusions.

**Declaration of interest:** No conflict of interest is declared by authors.

**Data sharing statement:** Data supporting the findings and conclusions are available upon request from the corresponding author.

## REFERENCES

Almarashdi, H. S., Abulibdeh, E. S., Zaitoun, E., Taha, S. and Libdeh, A. A. (2022). Pre-service mathematics teachers' perspectives on STEM education, in *Proceedings of the 2022 23rd International Arab Conference on Information Technology (ACIT 2022)*, November. https://doi.org/10.1109/ACIT57182.2022.9994120

Beane, J. A. (1997). *Curriculum Integration: Designing the core of democratic education*. Teachers College Press.

 

Bielaczyc, K. and Collins, A. (1999). Learning communities in classrooms: A reconceptualization of educational practice, in C. M. Reigeluth (ed), *Instructional Theories and Models: A new paradigm of instructional theory* (Vol. II, pp. 269–292).

Boix Mansilla, V. (2005). Assessing student work at disciplinary crossroads. *Change: The Magazine of Higher Learning*, 37(1), 14–21. https://doi.org/10.3200/CHNG.37.1.14-21

Bybee, R. W. (2013). *The Case for STEM Education: Challenges and opportunities*. NSTA Press.

Capraro, M. M. and Jones, M. K. (2013). *Interdisciplinary STEM Project-Based Learning*. Springer. Available at: https://api.semanticscholar.org/CorpusID:151016714

Castro Inostroza, Á., Iturbe Sarunic, C., Jiménez Villarroel, R. and Silva Hormázabal, M. (2020). ¿Educación STEM o en humanidades? Una reflexión en torno a la formación integral del ciudadano del siglo XXI [STEM or humanities education? A reflection on the comprehensive development of 21st-century citizens]. *Utopía y Praxis Latinoamericana*, 25(9), 197–208.

Copriady, J. (2014). Teachers' competency in the teaching and learning of chemistry practical. *Mediterranean Journal of Social Sciences*, 5(8), 312–318. https://doi.org/10.5901/mjss.2014.v5n8p312

Dan, Z. and Gary, W. (2018). Teachers' perceptions of professional development in integrated STEM education in primary schools, in *Proceedings of the 2018 IEEE Global Engineering Education Conference (EDUCON)* (pp. 472–477). IEEE. https://doi.org/10.1109/EDUCON.2018.8363268

Dare, E. A., Ring-Whalen, E. A. and Roehrig, G. H. (2019). Creating a continuum of STEM models: Exploring how K–12 science teachers conceptualize *STEM education. International Journal of Science Education*, 41(12), 1701–1720. https://doi.org/10.1080/09500693.2019.1638531

DeBoer, G. E. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching*, 37, 582–601. https://doi.org/10.1002/1098-2736(200008)37:6<582::AID-TEA5>3.0.CO;2-L

Domènech, J. (2019). Tema d'anàlisi: STEM: Oportunidades y retos desde la enseñanza de las ciencias [Subject of analysis: STEM: Opportunities and challenges from science teaching]. *UTE. Revista de Ciències de l'Educació Monogràfic*, 155–168. https://doi.org/10.17345/ute.2019.2

Domènech-Casal, J., Lope, S. and Mora, L. (2019). Qué proyectos STEM diseña y qué dificultades expresa el profesorado de secundaria sobre aprendizaje basado en proyectos [What STEM projects do secondary school teachers design and what difficulties do they express regarding project-based learning?]. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias*, 16(2). https://doi.org/10.25267/rev_eureka_ensen_divulg_cienc.2019.v16.i2.2203

Du, W., Liu, D., Johnson, C., Sondergeld, T., Bolshakova, V. and Moore, T. (2019). The impact of integrated STEM professional development on teacher quality. *School Science and Mathematics*, 119, e0001. https://doi.org/10.1111/ssm.12318

Felder, R. M., Celanese, H. and Brent, R. (2009). Active learning: An introduction. *ASQ Higher Education Brief*, 2(4), 1–5.

García-Yeguas, A., Arias, M. D., González-García, F. and Aguilera Morales, D. (2023). Análisis del impacto de un programa formativo STEM en los modelos mentales y la actitud de docentes en formación [Analysis of the impact of a STEM training program on the mental models and attitudes of teachers in training]. *Espiral. Cuadernos del Profesorado*, 16(32), 39–50. https://doi.org/10.25115/ecp.v16i32.8748

Gardner, K., Glassmeyer, D. and Worthy, R. (2019). Impacts of STEM professional development on teachers' knowledge, self-efficacy, and practice. *Frontiers in Education*, 4, 1–10. https://doi.org/10.3389/feduc.2019.00026

Gulikers, J., Sluijsmans, D., Baartman, L. K. J. and Bartolo, P. (2008). The power of assessment in teacher education, in In R. K. Murray (ed), *Becoming A Teacher Educator: Theory and practice for teacher educators* (pp. 173–188). Springer. https://doi.org/10.1007/978-1-4020-8874-2_13

Guskey, T. (1988). Teacher efficacy, self-concept, and attitudes toward the implementation of instructional innovation. *Teaching and Teacher Education*, 4, 63–69. https://doi.org/10.1016/0742-051X(88)90025-X

Hamdan, A. R., Abdul Ghafar, M. N. and Li, L. T. H. (2010). Teaching competency testing among Malaysian school teachers. *European Journal of Social Sciences*, 12, 610–617.

Hammerness, K., Darling-Hammond, L., Bransford, J., Berliner, D., Cochran-Smith, M., McDonald, M. and Zeichner, K. (2005). How teachers learn and develop, in L. Darling-Hammond and J. Bransford (eds), *Preparing Teachers for A Changing World: What teachers should learn and be able to do* (pp. 358–389). Jossey-Bass.

Huang, X., Erduran, S., Zhang, P., Luo, K. and Li, C. (2022). Enhancing teachers' STEM understanding through observation, discussion and reflection. *Journal of Education for Teaching*, 48(5), 576–591. https://doi.org/10.1080/02607476.2021.2006571

Kelley, T. R. and Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, 3(1). https://doi.org/10.1186/s40594-016-0046-z


 

Lemke, J. (2001). Articulating communities: Sociocultural perspectives on science education. *Journal of Research in Science Teaching*, 38, 296–316. https://doi.org/10.1002/1098-2736(200103)38:3<296::AID-TEA1007>3.0.CO;2-R

Lestari, N. A., Suprapto, N., Deta, U. A. and Yantidewi, M. (2018). Implementation of multimodel active learning to improve basic teaching skills of pre-service physics teachers. *Journal of Physics: Conference Series*, 1108(1), 0–5. https://doi.org/10.1088/1742-6596/1108/1/012119

Magen-Nagar, N. and Shonfeld, M. (2018). The impact of an online collaborative learning program on students' attitude towards technology. *Interactive Learning Environments*, 26(5), 621–637. https://doi.org/10.1080/10494820.2017.1376336

Mahecha, Á. (2021). *La educación STEM en la práctica docente: Una propuesta pedagógica para fortalecer las 4 C's del siglo XXI en los estudiantes de grado 9° del Colegio Champagnat de Bogotá* [STEM education in teaching practice: A pedagogical proposal to strengthen the 4 C's of the 21st century in 9th grade students at Champagnat School in Bogotá.] [Master's thesis, Universidad La Gran Colombia]. https://repository.ugc.edu.co/bitstream/handle/11396/6992/Alvaro_Mahecha_2021.pdf?sequence=1

Martín-Páez, T., Aguilera, D., Perales-Palacios, F. J. and Vílchez-González, J. M. (2019). What are we talking about when we talk about STEM education? A review of literature. *Science Education*, 103(4), 799–822. https://doi.org/10.1002/sce.21522

McMillan, J. (2016). National board-certified teachers' perspectives on using measures of student learning for teacher evaluation. *The Educational Forum*, 80, 48–60. https://doi.org/10.1080/00131725.2015.1102366

Ministerio de Educación Nacional (MEN). (2022). *La formación docente en Colombia (Coalición)* [Teacher training in Colombia (Coalition)]. https://www.mineducacion.gov.co/1780/articles-363488_recurso_18.pdf

Moore, A. (2012). *Teaching and Learning: Pedagogy, curriculum and culture* (2nd ed.). Routledge. https://doi.org/10.4324/9780203134061

Nam, N. and Bui, L. (2023). Enhancing STEM teaching competency for mathematics teachers in Vietnam. *AIP Conference Proceedings*, 2685, 50007. https://doi.org/10.1063/5.0111691

National Academies of Sciences, Engineering, and Medicine (NASEM). (2014). *STEM Integration in K–12 Education: Status, prospects, and an agenda for research*. National Academies Press. https://doi.org/10.17226/18612

NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states*. The National Academies Press. https://doi.org/10.17226/18290

OECD. (2019a). *Future of Education and Skills 2030: OECD learning compass 2030 – A series of concept notes*. OECD Publishing. https://www.oecd.org/education/2030-project/

OECD. (2019b). *OECD Learning Compass 2030: A series of concept notes*. OECD Publishing. https://www.oecd.org/education/2030-project/

Osadchyi, V., Valko, N. and Kushnir, N. (2019). Determining the level of readiness of teachers to implementation of STEM education in Ukraine. *CEUR Workshop Proceedings*, 2393, 144–155.

Reig Martínez, E., Goerlich Gisbert, F. J. and Cantarino Martí, I. (2016). Delimitación de áreas rurales y urbanas a nivel local, *Fundación BBVA*. http://www.fbbva.es/TLFU/tlfu/esp/publicaciones/informes/fichainforme/index.jsp?codigo=818

Repko, A. F. and Szostak, R. (2020). *Interdisciplinary Research: Process and theory* (3rd ed). SAGE Publications.

Ring, E. A., Dare, E. A., Crotty, E. A. and Roehrig, G. H. (2017). The evolution of teacher conceptions of STEM education throughout an intensive professional development experience. *Journal of Science Teacher Education*, 28(5), 444–467. https://doi.org/10.1080/1046560X.2017.1356671

Ritz, J. and Fan, S.-C. (2015). STEM and technology education: International state-of-the-art. *International Journal of Technology and Design Education*, 25, 1–15. https://doi.org/10.1007/s10798-014-9290-z

Sánchez Torres, Z. X. and Araque Solano, A. S. (2023). Elementos para definir un modelo de ocupación del territorio en las ciudades colombianas [Elements to define a model of territorial occupation in Colombian cities]. *Revista Ciudades, Estados y Política*, 10(2), 51–70. https://doi.org/10.15446/rcep.v10n2.103950

Sanders, M. (2009). STEM, STEM education, STEMmania. *The Technology Teacher*, 68, 20–26. https://vtechworks.lib.vt.edu/bitstream/handle/10919/51616/STEMmania.pdf?sequence=1&isAllowed=y

Schons, C., Obersteiner, A., Fischer, F. and Reiss, K. (2024). Toward adaptive support of pre-service teachers' assessment competencies: Log data in a digital simulation reveal engagement modes. *Learning and Instruction*, 94, Article 101979. https://doi.org/10.1016/j.learninstruc.2024.101979

Schulz, S. and Pinkwart, N. (2015). Physical computing in STEM education, in *Proceedings of the Workshop in Primary and Secondary Computing Education* (pp. 134–135). ACM. https://doi.org/10.1145/2818314.2818327

Selvi, K. (2010). Teachers' competencies. *Cultura. International Journal of Philosophy of Culture and Axiology*, 7(1), 167–175. https://doi.org/10.5840/cultura20107133

 

Smith, K., Maynard, N., Berry, A., Stephenson, T., Spiteri, T., Corrigan, D., Mansfield, J., Ellerton, P. and Smith, T. (2022). Principles of problem-based learning (PBL) in STEM education: Using expert wisdom and research to frame educational practice. *Education Sciences*, 12(10), Article 728. https://doi.org/10.3390/educsci12100728

Song, M. (2020). Integrated STEM teaching competencies and performances as perceived by secondary teachers in South Korea. *International Journal of Comparative Education and Development*, 22(2), 131–146. https://doi.org/10.1108/IJCED-02-2019-0016

Strauss, A. and Corbin, J. (2002). *Bases de la Investigación Cualitativa: Técnicas y procedimientos para desarrollar la teoría fundamentada* [Foundations of Qualitative Research: Techniques and procedures for developing grounded theory]. Universidad de Antioquia. https://books.google.com.co/books?id=TmgvTb4tiR8C

Timperley, H., Kaser, L. and Halbert, J. (2014). *A framework for transforming learning in schools: Innovation and the spiral of inquiry* [Seminar Series No. 234]. Centre for Strategic Education.

Toma, B. and Retana, A. (2021). Improving pre-service teachers' conceptions of STEM education. *Revista Iberoamericana de Educación*, 87(1), 15–33. https://doi.org/10.35362/rie8714538

Tricot, A. and Sweller, J. (2014). Domain-specific knowledge and why teaching generic skills does not work. *Educational Psychology Review*, 26(2), 265–283. https://doi.org/10.1007/s10648-013-9243-1

Vasquez, J. A., Sneider, C. and Comer, M. (2013). *STEM Lesson Essentials: Integrating science, technology, engineering, and mathematics*. Heinemann.

Wang, H. H., Charoenmuang, M., Knobloch, N. A. and Tormoehlen, R. L. (2020). Defining interdisciplinary collaboration based on high school teachers' beliefs and practices of STEM integration using a complex designed system. *International Journal of STEM Education*, 7(1). https://doi.org/10.1186/s40594-019-0201-4

Welsh, K. and Schaffer, C. (2017). Developing the effective teaching skills of teacher candidates during early field experiences. *The Educational Forum*, 81, 301–321. https://doi.org/10.1080/00131725.2017.1314574

Wright, K. and Waxman, H. (2022). A multilevel analysis of malleable school and teacher factors contributing to middle grades' teachers use of effective STEM practices. *Educational Studies*, 50, 1–21. https://doi.org/10.1080/03055698.2021.2023474

Yang, K.-L. and Ball, L. (2022). STEM teacher education programs for preservice and in-service secondary mathematics teachers: A review study. *Journal of Mathematics Teacher Education*, 27, 1–23. https://doi.org/10.1007/s10857-022-09557-0

Yıldırım, B., Akcan, A. T. and Öcal, E. (2022). Teachers' perceptions and STEM teaching activities: Online teacher professional development and employment. *Journal of Baltic Science Education*, 21(1), 84–107. https://doi.org/10.33225/jbse/22.21.84

Yilmaz, H. S. (2022). A study of determination of benchmarks during the new formation of integrated STEM leader preparation program. *European Journal of STEM Education*, 7(1), 10. https://doi.org/10.20897/ejsteme/12634

Zhou, Q., Li, M., Yan, Y., Chen, M., Wang, J., Yi, K., Han, X., Wang, S. and Wang, S. (2023). Teaching competency development, in *Handbook of teaching competency development in higher education* (pp. 63–125). Springer. https://doi.org/10.1007/978-981-99-6273-0_4