Original Research

SAGE Open
January-March 2026: 1–21
© The Author(s) 2026
DOI: 10.1177/21582440261417701
journals.sagepub.com/home/sgo
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Misconceptions of Mathematics Teacher Candidates on STEM: What Lies Under the Cognitive Structure

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Abstract

This study aims to deeply analyze the cognitive structures of mathematics teacher candidates regarding STEM and to identify their underlying misconceptions about this educational approach. The participants of the study, which adopted the case study design, consisted of 182 mathematics teacher candidates. Research data were collected using metaphor technique, independent word association test, and writing-drawing technique together. The data were analyzed using content analysis. The results of the study show that mathematics teacher candidates perceive STEM in a narrow framework through specific components, rather than as a holistic educational approach. Participants perceive STEM content as technology and experiment-oriented, and see it as an applicable approach only in science and mathematics courses. In the cognitive structures of teacher candidates, STEM is mostly identified with doing experiments, a subject in mathematics course, and technologically equipped classrooms. In addition, from a pedagogical point of view, the results show that they identify STEM with traditional approaches and do not fully grasp its student-centered and interactive structure.

Plain Language Summary

What Do Future Math Teachers Really Think About STEM? This Study Uncovers Common Misunderstandings, Finding That Many Student Teachers See STEM Not as a Connected, Hands-On Educational Approach, but as Something Limited to Technology, Science Experiments, or Traditional Math and Science Classes.

Education that connects Science, Technology, Engineering, and Mathematics (STEM) is seen as vital for equipping students with skills like problem-solving and critical thinking. However, for STEM to be taught effectively, it's crucial that teachers understand it correctly. This study explored what future mathematics teachers truly think about STEM and aimed to identify any common misunderstandings they might have. We conducted our research with 182 university students training to become math teachers. To understand their perspectives, we used three creative methods: asking them to create metaphors for STEM (e.g., "STEM is like a…"), to list words they associate with STEM, and to draw a picture of what STEM means to them. Our findings reveal that while these future teachers associate STEM with its core subjects, they have a narrow view of it. Many believe STEM is just about using technology, conducting experiments, or is only relevant for science and math lessons. Their drawings often showed traditional classrooms where the teacher lectures from the front, rather than the interactive, student-centered learning environment that is central to the STEM approach. Through the metaphors alone, we identified 55 distinct misconceptions about STEM. These results show that

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Data Availability Statement included at the end of the article

many future teachers have not grasped the holistic nature of STEM, which integrates subjects to solve real-world problems. They often mistake it for a traditional lesson enhanced with technology. This highlights a critical need for university teacher-training programs to provide more comprehensive and hands-on education about the STEM philosophy, ensuring future educators are fully prepared to bring this innovative approach into their classrooms.

Keywords
STEM, Mathematics, teacher candidate, misconceptions, cognitive structure

Introduction

In the 21st century, the necessity of acquiring skills such as problem-solving, critical thinking, and collaboration has led researchers to explore alternative educational approaches. In this context, STEM (Science, Technology, Engineering, Mathematics) stands out as one of the most effective educational approaches today (Goodwin & Hein, 2014; Myers & Berkowicz, 2015). STEM, which first entered the literature in the early 2000s by the National Science Foundation (NSF), enables students to make sense of the integrated world we live in by making learning connected and relevant instead of learning and applying pieces of information (Dugger, 2010; Stohlmann et al., 2012). STEM, which has become the focus of interest for many researchers from different disciplines in the last 25 years, contributes to making students better problem solvers, innovators, inventors, self-confident, logical thinkers, and technology literate (Morrison, 2006).

Mathematics is an integral part of STEM. It provides a precise language for technology, science, and engineering. Mathematics can help by simulating how a proposed technological design will work (Dugger, 2010). In STEM classes, individuals' mathematics achievement increases (Bicer et al., 2014, 2015; Gündüz & Dokumacı Sütçü, 2025; Han et al., 2016; Hansen & Gonzalez, 2014; Ing, 2014; Tashtoush et al., 2024), problem-solving (Bybee, 2010; Capraro et al., 2013; Erol et al., 2023; Margot & Kettler, 2019; Moore et al., 2014; Stone-MacDonald et al., 2015; Wendell & Rogers, 2013), mathematical thinking (Miller, 2019; Singh et al., 2018; Tashtoush et al., 2024), mathematical creative thinking (Suherman et al., 2021), quantitative reasoning (Elrod & Park, 2020; Hasanah, 2020; Jensen et al., 2017) skills are developed. STEM education improves students' numerical literacy skills by increasing their capacity to read, interpret and analyze mathematical data (Bybee, 2010). It is seen in the literature that STEM supports spatial thinking (Stohlmann et al., 2012) and algebraic thinking (Becker & Park, 2011) skills. In addition, STEM contributes to individuals' developing positive attitudes by increasing their self-confidence in mathematics (Honey et al., 2014; Margot & Kettler, 2019). In this context, beyond being an indispensable discipline for STEM, it is also an approach that should be taken into account in terms of mathematics education in terms of acquiring mathematical skills.

Although countries are making efforts to improve STEM education in the face of the increasing demand for STEM skills to cope with economic challenges; there are still many uncertainties about how STEM education will be implemented (Breiner et al., 2012; Kelley & Knowles, 2016). In order for STEM education to be implemented successfully in classrooms, practitioners need STEM pedagogy knowledge as well as subject area knowledge (Honey et al., 2014; Su Ling et al., 2020). STEM pedagogy contributes to teachers ensuring that the subject is learned meaningfully, as well as shaping students' attitudes and self-efficacy perceptions toward learning (Margot & Kettler, 2019). Another factor that has a critical role in the successful implementation of STEM is understanding the essence of STEM for practitioners (Bybee, 2013). STEM is not just about transferring the knowledge of the STEM fields that make it up; in order to provide students with meaningful experiences, it plays an important role for practitioners to develop an interdisciplinary understanding (Kennedy & Odell, 2014; Moore et al., 2014; Shernoff et al., 2017). Practitioners with a positive view of STEM are more willing to organize projects and activities in the classroom that increase students' interest and curiosity (Margot & Kettler, 2019). However, various myths and misconceptions, which will be discussed in more detail in the conceptual framework of the current study, also draw attention (Ansberry & Morgan, 2019; Morrison, 2006). Such misconceptions make it difficult to reveal the true potential of STEM and can create various obstacles in the implementation process. Considering that mathematics is another discipline at the center of STEM, examining the misconceptions developed by mathematics teacher candidates regarding this concept constitutes an important dimension in the implementation of STEM in classrooms. This examination will contribute to the field in terms of planning the trainings to be carried out in the teacher training process and increasing its effectiveness.

Current Study

The aim of this study is to deeply analyze the cognitive structures of mathematics teacher candidates about STEM and to determine the misconceptions in this field. The study aims to contribute to increasing the effectiveness of teaching processes by revealing the conceptual deficiencies and misconceptions of teacher candidates in the context of STEM.

The research questions of the study were structured as follows:

R1: What are the cognitive structures of mathematics teacher candidates toward STEM?

R2: What are the misconceptions of mathematics teacher candidates about STEM?

Conceptual Framework

Cognitive Structures Regarding STEM

Cognitive structure is a concept that defines how an individual organizes, relates, and positions information (Finkelstein et al., 2009). It exhibits the mutual associations of the concepts recorded in long-term memory (Shavelson, 1974). Cognitive structures are the sum of isolated pieces of information in the mind. While weak structures are formed by inefficient acquisition of new information, they also affect the person's academic success and ability to apply knowledge (Tsai & Huang, 2002). Cognitive structure is the representation in our minds of our knowledge and behaviors. From this point of view, all the expressions of the schemas in our minds about a subject are included in cognitive structures. For example, if we take the concept of parabola; the definition of the concept, its algebraic representation, its analytical expression, its drawing in the coordinate system, concept images, misconceptions, what it is useful for in daily life, are all stored in cognitive structures. Similarly, educators' knowledge of an approach, method, and technique is hidden in their cognitive structures. Cognitive structures contain a lot of information such as general information about the approach that educators will adopt, application examples, what the classroom environment will be like, and the role of the teacher and student at this stage. Considering that the knowledge and application skills of the practitioners in that subject have a critical role in the success of an approach (Darling-Hammond, 2000; Guskey, 2002), it is noteworthy that it is important to reveal their cognitive structures.

In the literature, studies on cognitive structures related to STEM are mostly conducted with teacher candidates. Contrary to the experimental study in which Altunışık and Ekici (2022) concluded that problem-based STEM education developed the cognitive structures of science teacher candidates toward the STEM concept, other studies are aimed at determining the cognitive structures existing in individuals' minds. Hacıoğlu et al. (2016), in their study with science teacher candidates by referencing the four disciplines that constitute STEM, concluded that the STEM disciplines and the cognitive structures related to science education are independent of each other; they did not associate technology, engineering, and mathematics with the concepts of science and science education. Çetin (2020) determined in his study that classroom teacher candidates frequently included the basic components that constitute STEM, such as science, mathematics, engineering, and technology, in their concept networks and the statements they established; they shaped their cognitive structures around these concepts by enriching the definition of STEM with elements such as creativity, collaboration, and problem-solving. A study by Çetin (2020) with teacher candidates studying in different undergraduate programs (e.g., Computer Education and Instructional Technology-Science-Mathematics), it shows that teacher candidates associate the concept of STEM more with robotics, coding, and Arduino, and perceive science and mathematics especially as courses and course subjects. Distinct from other studies, Koerfer et al. (2025) demonstrate that STEM university teachers possess a range of conceptions regarding the role of mathematics within their own disciplines, spanning from a computational tool to a philosophical foundation. While students generally perceive mathematics as a computational tool, these varied conceptions among teachers directly influence their instructional styles. Recent studies examining the perceptions of in-service mathematics teachers show a generally positive outlook toward STEM integration, though they also highlight significant challenges in practice. For instance, a mixed-methods study by Khalil et al. (2024) found that mathematics teachers held positive perceptions regarding their teaching competence and the suitability of textbook content for a STEM framework. However, the same study revealed a significant gap between this positive perception and practical readiness. According to the qualitative findings, despite their confidence, teachers reported challenges in designing integrated STEM tasks due to a lack of specific training and in-depth STEM knowledge. Furthermore, teachers expressed neutral views regarding student interaction and motivation, linking this to students' limited understanding of STEM and weak foundational math skills.

Myths and Misconceptions About STEM

Misconceptions are misunderstandings or beliefs that differ from expert opinions and are strongly adopted by students, rather than individual meaningless errors

(Hammer, 1996; Haryono et al., 2021; Şen et al., 2019). Misconceptions primarily arise from conceptual misunderstanding, procedural errors, and the systematic repetition of these mistakes by students. (Weliwita et al., 2020). They are directly related to the cognitive structures formed in the minds of students (Exacta et al., 2024) and generally originate from individuals' incomplete or incorrect cognitive structures (Haryono et al., 2021; Şen et al., 2019). The literature examines how misconceptions are formed and sustained through three perspectives: (1) the constructivist approach, which emphasizes active knowledge construction; (2) conceptual change theory, which explains the revision of knowledge; and (3) dual-process models of cognition, which highlight intuitive and analytical thinking (System 1 and System 2).

Constructivism posits that learners actively construct knowledge by interpreting new information through their existing cognitive frameworks (Smith et al., 1994). According to this view, learning is not passive reception but the learner's own meaning-making. In any learning situation, "all learning involves interpretation in light of the learner's existing knowledge." When new concepts are assimilated into a flawed or incomplete schema, misconceptions arise. Students build naive theories from their own experiences, which may be internally coherent but inconsistent with science (de la Hera et al., 2019; Smith et al., 1994). de la Hera et al. (2019) emphasize that from infancy, children form intuitive understandings based on everyday experiences (e.g., "things that move are alive"), which later form coherent mental theories that constrain how new information is interpreted. Thus, a child who consistently observes that heavy objects fall faster than light ones may form an intuitive theory ("heavier = faster") that persists because it seems internally consistent, even when confronted with new examples. From a sociocultural perspective (Vygotsky, 1978), ideas emerge through language and interaction. Vygotsky stressed that children learn through "active participation in a collaborative effort" with teachers and peers, and that language directs thought (Howe, 1993). Thus, students adopt explanations they hear from adults or peers, which can lead to misunderstandings. For instance, everyday language metaphors (e.g., "heavy gas") or analogies ("more is faster") can lead to incorrect beliefs. Furthermore, social negotiation (peer discussion, cultural narratives) can reinforce shared intuitive ideas. In short, constructivism emphasizes that personal experience, language, and social context filter new phenomena, so if the initial mental model is flawed, new information is assimilated incorrectly, forming persistent misconceptions (de la Hera et al., 2019; Smith et al., 1994).

Conceptual Change Theory (Posner et al., 1982) offers a model for how students revise their conceptions. Posner et al. suggest that learning typically involves either assimilation (fitting new data into old schemas) or accommodation (restructuring schemas). When students' prior concepts conflict with scientific evidence, a cognitive conflict should trigger genuine conceptual change. According to Posner et al. (1982), for conceptual change to occur, a student must be dissatisfied with their old concept and find the new concept intelligible, plausible, and fruitful. Özkan and Selçuk (2013) summarize these conditions as follows: A student must realize their existing idea is inadequate (dissatisfaction), understand the new idea (intelligibility), believe it is logical (plausibility), and see that it helps solve problems effectively (fruitfulness). Misconceptions, however, are often highly resistant to change because they meet very few of these conditions. Students are often not dissatisfied with their intuitive beliefs until they encounter striking contradictions. Moreover, intuitive concepts often form coherent, naive theories that have explanatory power and make consistent predictions (Özdemir & Clark, 2007). Özdemir and Clark (2007) state that students possess a small number of experience-based, well-developed, theory-like conceptions that have "explanatory power for making consistent predictions." Such coherent frameworks are deeply entrenched. For instance, Chi (1992) argued that some misconceptions stem from fundamental category mistakes (assigning a concept to the wrong ontological category), making them especially difficult to revise without a major restructuring. Indeed, adopting a new scientific concept often requires reorganizing an entire mental framework, a cognitively demanding task. As sources note, confronting a misconception requires "extra cognitive effort" (Y. Wen et al., 2024). In practice, this means that even when students are taught correct concepts, their initial misconceptions often coexist with the new information. Recent perspectives emphasize that misconceptions are not simply erased by instruction but may persist in parallel with correct ideas (Vosniadou, 2020). This coexistence reinforces why standard instruction (lectures, labs, or texts) often fails to eliminate misconceptions; such strategies do not automatically restructure a learner's deep frameworks (Lucariello & Naff, 2019).

Dual-process theories distinguish between two modes of reasoning: a fast, intuitive system (System 1) and a slow, analytical system (System 2). System 1 thinking is automatic, unconscious, and uses heuristics, whereas System 2 is deliberate, conscious, and logical (Kahneman, 2011; Stanovich & West, 2000). According to this view, many misconceptions arise naturally from System 1 processing. Heuristics lead students to make quick judgments based on surface features (e.g., "more mass means more speed") without analytical checking. These gut judgments often align with common misconceptions. For example, when predicting motion problems, a student's System 1 might intuitively conclude that "higher launch means longer flight," triggering the known range-time misconception in projectile motion (Y. Wen et al., 2024). Cognitively, learning correct concepts often requires building a mental model that competes with System 1 intuition, which demands reflective thought and inhibitory control (Houdé, 2000; Neys, 2006). In sum, dual-process explanations clarify why even basic errors are so persistent: intuitive System 1 responses are fast and automatic, so students often rely on them, and only deliberate System 2 effort can correct these misconceptions. Educationally, this means that instruction must encourage students to slow down, reflect on their intuitive answers, and consciously engage in analytical reasoning (Kahneman, 2011; Stanovich & West, 2000).

These three perspectives—constructivism, conceptual change theory, and dual-process models—offer complementary insights into misconceptions. Constructivism explains how misconceptions arise: students build new ideas by fitting experiences into their existing mental frameworks, often creating internally consistent but incorrect concepts (de la Hera et al., 2019; Smith et al., 1994). Conceptual Change Theory explains why these concepts are so hard to change: entrenched naive theories require meeting four strict conditions (dissatisfaction, intelligibility, plausibility, fruitfulness) before change, making true accommodation a challenging process (Özdemir & Clark, 2007; Özkan & Selçuk, 2013). Dual-process models explain what is happening cognitively: intuitive (System 1) thinking produces the initial misconception, and deliberate (System 2) thinking must be engaged (often through inhibitory control) to override it (Y. Wen et al., 2024).

Individuals tend to develop misunderstandings about a concept when they have a limited understanding of that concept. These misconceptions are not only in the context of school lessons (e.g., science, mathematics, social sciences, etc.). Teachers can also develop misconceptions about teaching approaches, strategies, or techniques in terms of their pedagogical field knowledge. In the literature, there are misconceptions about constructivist approach (Gordon, 2009; Tan & Ng, 2021; M. L. Wen & Tsai, 2003), cooperative learning (Koutselini, 2008), project-based learning (Lev et al., 2020; Wolk, 2022), differentiated instruction (Putra, 2023), and even misconceptions (Keeley, 2012). Misconceptions significantly affect not only individuals' information acquisition processes but also their ability to apply information and their behaviors (Haryono et al., 2021; Schulman & Demantowsky, 2022). Therefore, in order for any approach to be implemented effectively and achieve success, it is of critical importance to determine what it means for the individuals who will implement it and whether there is a misconception about it.

STEM education is an important paradigm that brings together science, technology, engineering, and mathematics with an interdisciplinary approach. However, when the literature on STEM is examined, it is seen that there are various misconceptions that are commonly believed regarding the implementation and understanding of this field:

Misconceptions About the Weights of the Disciplines That Constitute STEM. Ansberry and Morgan (2019) emphasize that there is a common misconception that the disciplines that constitute STEM should be equally weighted. This situation includes misconceptions such as not only that it should be equally weighted but also that it is related to only one discipline (e.g., physics; Yıldırım & Sevi, 2016). According to Mafugu et al. (2024), the primary misconception regarding STEM content is that teachers perceive it not as an integrated framework, but as the superficial addition of technology or engineering elements onto traditional, teacher-centered science instruction. Additionally, Morrison (2006) states that there are misconceptions in STEM that technology and engineering are different from mathematics and science education and will be handled as a separate course. STEM teaches the disciplines of science, technology, engineering, and mathematics in a consistent manner as an integrated single unit (Brown, 2012). Students should make natural connections while conducting research and solving problems in a meaningful context (Ansberry & Morgan, 2019). In this context, neither can disciplines be handled separately, nor is there a requirement for equal weighting. It naturally emerges in the process of solving a real-life problem and requires this interdisciplinary collaboration.

Misconceptions About STEM Career Fields. The increase in the need for STEM professions causes misconceptions that STEM is only career-oriented (Ansberry & Morgan, 2019) and addresses workforce problems (Morrison, 2006). This situation leads individuals to the misconception that all STEM-educated students will be forced to choose technical fields (Morrison, 2006).

Misconceptions About the Learning Levels at Which STEM Will Be Applied. It is a misconception that STEM education should wait until the upper grades of primary school (Ansberry & Morgan, 2019). Thoughts that children's career awareness cannot begin at a young age cause misconceptions about the learning levels at which STEM will be applied. However, since elementary school students' narrow views on careers in science continue in middle school, it is important to provide STEM education at an earlier age (Archer et al., 2012).

Misconceptions About the Emotional Dimension of STEM. There are three different myths on this subject: (1) People working in STEM fields are antisocial, (2) Social stereotypes that STEM fields are only suitable for older, specific types of children and that it is an innate talent, (3) Teachers' anxiety about teaching STEM subjects (Ansberry & Morgan, 2019).

Misconceptions About Gender Stereotypes in STEM. There are stereotypes based on social norms that male students will perform more successfully than female students in STEM fields (Rosenzweig & Wigfield, 2016). The basis of this misconception is the socially constructed perception that male students are better or naturally more talented than girls in science (Archer et al., 2012). Even in the current age, women are not sufficiently represented by women (Ceci et al., 2014). Women cannot achieve sufficient representation not only in science but also in many STEM occupational fields, and as a result, girls are moving away from STEM occupational fields. For this reason, awareness studies of women role models in STEM fields, especially for girls, will help to overcome the obstacles created by social norms.

Misconceptions About the Potential of Individuals to Whom STEM Will Be Applied. Studies show that there are misconceptions that STEM is only suitable for gifted children (Yıldırım & Sevi, 2016). The basis of this perspective is the perception that STEM requires solving complex problems, innovative thinking, and advanced technical skills (Bybee, 2013). Gifted students mostly prefer STEM fields when they enter university (Vu et al., 2019). However, the success of students in STEM fields is not due to the potential high achievements brought by their superior intelligence and talents, but rather the fact that the educational programs/schools (e.g., Talent Search program) applied specifically to these children help to intensify their interest in STEM (Steenbergen-Hu & Olszewski-Kubilius, 2017). In this context, studies aimed at increasing the interest of students with different cognitive development and abilities in STEM fields are likely to help them reveal their potential in these fields and be effective in their choices.

Misconceptions About the Content of STEM Activities. One of the main misconceptions is that it can only be applied in science lessons. Yıldırım and Sevi (2016) study reveals that teacher candidates have misconceptions that STEM can only be applied in physics lessons. STEM is not just a science lesson, and contrary to popular belief, it does not neglect scientific methods and laboratory work (Morrison, 2006). Another misconception is that activities are only given with lego and toys (Yıldırım & Sevi, 2016). This understanding also brings with it misconceptions that STEM education requires expensive and advanced technology materials (Ansberry & Morgan, 2019). This myth about materials causes teachers to have difficulties in finding materials when implementing STEM (Ceylan et al., 2018; Çınar & Terzi, 2021; Eroğlu & Bektaş, 2016; Tosmur-Bayazıt et al., 2018; Ürek & Çoramık, 2023). However, STEM can also be done with economical materials (Stohlmann et al., 2012). Another misconception is that every STEM activity involves engineering challenges based on a standard design process. However, there is no standard approach at this stage. At any step, students can redefine the problem and produce new solutions instead of a non-working idea (Ansberry & Morgan, 2019).

In the context of this study, a participant's view was identified as a "misconception" if it contradicted the holistic, interdisciplinary, and student-centered nature of STEM education as established in the literature. Specifically, views that reduced STEM to a single discipline (e.g., only science), equated it with specific tools (e.g., only technology), or framed it within a traditional, teacher-centered pedagogy were classified as misconceptions.

Methodology

In the study, the case study design, one of the qualitative research methods, was adopted. The case study, which aims to examine a phenomenon, event, process, or social unit in its natural context (Yin, 2018), involves a detailed examination of individuals, groups, or institutions to comprehensively understand a specific situation (Stake, 1995). Since the current study aims to examine the cognitive structures and misconceptions of mathematics teacher candidates about STEM, the case study was effective in adopting the case study due to its context sensitivity and potential to provide in-depth data. In addition, the necessity of developing an understanding of the participants' cognitive structures is one of the reasons for choosing the case study. Qualitative studies play an important role in context and meaning construction (Patton, 2015). Case studies allow for the holistic analysis of the data obtained by the combined use of various data collection tools (Creswell & Poth, 2016).

In the study, in which 182 mathematics teacher candidates studying in the third and fourth grades at a state university in the west of Türkiye participated; data diversification was achieved by using metaphor technique, word association test, and writing-drawing technique together. The participants of the study were determined using the convenience sampling method, which is a non-probability sampling technique. This method was chosen due to the researcher's accessibility to the mathematics teacher candidates at a state university. The inclusion criteria for the study were as follows: participants had to be (1) actively enrolled as mathematics teacher candidates, and (2) in their third or fourth year of study at the faculty of education. Third and fourth-year students were specifically selected because they have completed most of their core content courses and have started their pedagogical training, making them more likely to have formed cognitive structures and potential misconceptions about educational approaches like STEM. Candidates from other departments or in their first or second year of study were excluded from the research. While qualitative studies often use smaller samples, a larger sample size of 182 participants was intentionally chosen for this study. The primary rationale was to capture a broad diversity of perspectives and mental models regarding STEM that might exist within a large cohort of teacher candidates. A larger sample increases the likelihood of identifying a wide spectrum of metaphors, word associations, and drawings, thus providing a richer and more comprehensive understanding of the common cognitive structures and misconceptions present in this population. The goal was not statistical generalization but to ensure the robustness and breadth of the qualitative findings.

Metaphor Technique

The first part of the data collection tool includes the question related to the semi-structured metaphor technique, "*STEM is like… Because*................" The metaphor technique is a powerful qualitative tool used to reveal the underlying cognitive structures and conceptual frameworks individuals hold about a particular phenomenon (Cheng et al., 2024; Conrad & Libarkin, 2022; Ediz & Uzun, 2025; Giuliani, 2023; Gündoğdu & Vural, 2025; Hava et al., 2025; Lim, 2024; Teich et al., 2025; Yariv, 2024; Zambon Ferronato, 2022). In the second context, cognitive structures and underlying misconceptions are tried to be revealed in the reasons/logical justifications they presented with the expression because.

Word Association Test

The second part of the data collection tool consists of the independent word association test. The WAT is a widely recognized method for mapping the cognitive structure and revealing the conceptual connections in an individual's long-term memory regarding a specific stimulus word (Akman & Durgun, 2023; Baris, 2022; Kurt et al., 2013; Meij et al., 2025; Prihatini, 2022; Tóth, 2024). It is particularly useful for identifying the most prominent concepts associated with a key term without direct prompting. In this section, participants were asked to write 10 words that the keyword "STEM" evokes in 30 s. Then, the participants were expected to form sentences with this keyword within 1 min.

Drawing-Writing Technique

In the third step of the data collection process, the drawing-writing technique (Ekici, 2019) was used to visualize the cognitive structures of the participants about the STEM concept. This technique is a frequently used in the literature to access participants' mental models and conceptual understandings that may not be easily expressed through verbal or written language alone (Ediz & Uzun, 2025; Fan et al., 2023; Kiliç, 2018; Kurt et al., 2013; Yue et al., 2024). Participants were asked the question "*Explain what you know about STEM by drawing*."

A qualitative content analysis approach was used to analyze the data collected through the metaphor technique, word association test, and the drawing-writing technique. The analysis was conducted in a systematic, multi-stage process to ensure rigor and objectivity.

1. Preparation and Initial Coding: All participant responses were transcribed and anonymized. Initially, two researchers (the author and an independent expert in qualitative research) independently read approximately 20% of the data to gain a general sense of the content. During this phase, they performed open coding by assigning initial descriptive codes to segments of the data. This process was primarily inductive, meaning the codes emerged directly from the participant responses.
2. Development of the Coding Framework: The two researchers then convened to compare their initial codes, discuss discrepancies, and collaboratively develop a unified coding framework (or codebook). This framework included a list of codes, their definitions, and clear examples to ensure consistent application. For instance, responses identifying STEM with specific tools (e.g., "computer," "smart board") were grouped under the code "Technology" as equipment.
3. Full Data Analysis and Categorization: Using the finalized framework, both researchers independently coded the entire dataset. The organization of the data and the management of the coding process were conducted manually. Coded segments were systematically extracted and grouped into broader, overarching categories (themes). Frequency counts for the most common metaphors and associated words were calculated using Microsoft Excel. The logical justifications given with the expression because in metaphors, and the concepts associated with the keyword in the

word association test were grouped according to their semantic similarities and categories were determined. In the drawing-writing technique, the drawings of the teacher candidates were categorized and the findings obtained from the metaphor and word association test were supported. During the coding process, each response was evaluated against the operational definition of a misconception established for this study. Responses that aligned with the criteria for a misconception, such as portraying STEM in a narrow or pedagogically traditional manner, were systematically coded under the "Misconceptions" category for further analysis.

4. Inter-Rater Reliability: To ensure the reliability of the coding process, an inter-rater reliability analysis was conducted. The level of agreement between the two coders was calculated using the Miles and Huberman (1994) formula. Any disagreements were resolved through discussion until a 100% consensus was reached. The final reliability coefficients were calculated after this consensus process and found to be 0.91 for metaphors, 0.89 for the word association test, and 0.92 for the drawing-writing technique, indicating a high level of consistency. Direct quotations from the sample views of the participants were given by coding as M1.

This study is grounded in an interpretivist research paradigm, which seeks to understand the social world through the subjective experiences and interpretations of individuals (Creswell & Poth, 2016). In line with this, the study adopts a constructivist perspective, positing that teacher candidates actively construct their understanding and mental models of STEM based on their prior knowledge and experiences. Therefore, the goal of this research is not to find a single objective truth, but to explore the variation in these constructed meanings and identify common patterns in their cognitive structures. Within this paradigm, the researcher is not a detached observer but an active instrument in interpreting the data (Creswell & Poth, 2016). Acknowledging this role is crucial for the credibility of the research, and reflexivity was practiced throughout the study to manage potential biases. As a researcher in mathematics education with a professional commitment to a holistic view of STEM, a primary potential bias was the predisposition to interpret participant responses through the lens of established expert definitions. The interpretation of qualitative data, particularly projective techniques like metaphor analysis and drawings, inevitably involves a degree of researcher subjectivity. As Armstrong et al. (2011) argue, the meanings of metaphors are not universal but are situated in specific social and cultural contexts, which can pose a methodological challenge. Furthermore, from a cognitive perspective, metaphor comprehension itself is a complex process requiring the suppression of irrelevant literal meanings, a skill known as interference control, which highlights the potential for varied interpretations. Yoon et al. (2021) demonstrate that metaphor comprehension is a cognitively demanding process that relies on "interference control"—the ability to actively suppress dominant yet irrelevant literal meanings to derive a figurative interpretation. Their findings highlight the inherent subjectivity and potential for bias in metaphor analysis, thereby underscoring the methodological importance of using systematic safeguards, such as triangulation and inter-rater reliability, to enhance the trustworthiness of the researcher's interpretations. To address these challenges and enhance the trustworthiness of the findings, this study implemented Guba and Lincoln's (1982) systematic strategies often used in in qualitative studies to mitigate interpretive bias.

Credibility or the confidence in the truth of the findings, was primarily enhanced through two strategies:

1. *Methodological Triangulation:* By collecting data using three distinct methods (metaphor analysis, word association test, and the draw-and-write technique), the study allowed for the cross-verification of findings. Emerging themes, such as the perception of STEM as "experiment-focused," were consistently identified across all three data sources, strengthening the credibility of the interpretation.
2. *Inter-Rater Coding:* As described in the Data Analysis section, a second independent expert was involved in the coding process. The high level of agreement, calculated using the Miles and Huberman (1994) coefficient, serves as a form of "multiple analyst" approach that reduces the potential for single-researcher bias.

Dependability, which refers to the stability of findings over time, was addressed by creating a clear audit trail. The detailed, step-by-step description of the data collection and analysis procedures in the Methodology section allows other researchers to follow the logic of the study and assess its consistency.

Confirmability, ensuring that findings are shaped by the participants and not researcher bias, was supported through reflexive journaling. Throughout the research process, a journal was kept to document personal assumptions, methodological decisions, and reflections on the analysis. This practice helped to make the researcher's influence on the interpretation transparent and manageable.

Table 1. Teacher Candidates' Metaphors for STEM.

Category	Metaphor
Interdisciplinarity (f = 71)	System (f = 5), puzzle (f = 5), tree (f = 4), Noah's pudding (f = 3), adhesive (f = 2), rainbow (f = 2), voltran (f = 2), life (f = 2), cake (f = 2), the world we live in, flower garden, dancing, mathematical operations, blending of research, salad, multi-purpose program, wallet, mixture, honey bee and hive, clock, concretion, integration, smart phone, map, combination, versatile tool, mixture, artificial intelligence, union set, package, blending, mathematics engineering, house gathered under one roof, orchestra conductor, growing plants, bulk shopping, mixed nuts, gift package, rubik's cube, new generation questions, cooking, the reality of science, engineer, ant, pizza, rice pudding, poem, magnificent rectangle, building, brain blood vessels, our organs, orchestra conductor, an all-inclusive whole
Functionality (f = 27)	Life (f = 2), experiencing real life (f = 2), life itself, food, tree bearing fruit in spring, water, philosophy, technology, bee, discovering electricity, preparation for life, cable, literacy, preparation for the future, living space, tools, electricity, assistant, rules, robot, problem-solving tool in our lives, factory, technical knowledge about the universe, fruit cake, key
Supporting the learning process (f = 25)	Bee (f = 3), art (f = 2), tree bearing fruit in spring (f = 2), thought development program (f = 2), ant, kitchen, preparation for the future, developer machine, winning lottery ticket, colors, hypothesis, combination, rules, problem, sun, a helping hand, activity, dancing, dessert, gathering the fruits of the tree
Innovation (f = 18)	Innovation movement (f = 8), innovation (f = 2), a new sunflower, step, a tool to carry the student to the future, technology, research tool, a long road, time, technology
Inclusivity (f = 8)	A general judgment (f = 2), an all-inclusive whole, combined class, school life, universality, watching 3D cinema
Difficulty and Obstacles (f = 8)	Tree (f = 2), soul (f = 2), imagination, palm oil, life, newly invented machine
Misconceptions (f = 55)	Lesson (f = 6), game (f = 3), workshop (f = 2), doing experiments (f = 2), the heart of mathematics (f = 2), computer (f = 2), technology use (f = 2), robot (f = 2), fractal (f = 2), food, computer program, teaching with technology, technical knowledge about the universe, adding technology to education, effective computer use, calculator, colors, science, coordination of information, spider web, meeting at a common denominator, mind, branches of the tree, interdisciplinary activity, chain, flavored chocolate, rules, laboratory, teaching technique, a helping hand, robotic coding, Technomat, innovation, invention, factory, chain, building block, scale, planning teaching, teaching model, information gathering movement

Transferability, or the extent to which findings can be applied to other contexts, was enhanced by providing a thick description of the research context. Detailed information about the participants (182 third and fourth-year mathematics teacher candidates at a state university), the data collection tools, and the analysis process allows readers to make informed judgments about the applicability of the findings to their own situations.

Results

Findings from Metaphors

As a result of the metaphor analysis, 137 different metaphors were obtained. The most frequently repeated metaphors are innovation movement (f = 8), lesson (f = 6) and tree (f = 6), respectively. The determined metaphors were grouped within the scope of the thoughts attributed to the source of the metaphor in the participants explanations; They were collected under seven categories: interdisciplinarity, functionality, supporting the learning process, innovation, inclusivity, difficulties and obstacles, and misconceptions. Some of the metaphors were evaluated under more than one category in terms of their meaning (Table 1).

Teacher candidates' metaphors for STEM largely focus on the integration of the disciplines that make up STEM (*Interdisciplinarity* f = 71). Emphasizing that STEM integrates different disciplines, M69 expresses STEM with the metaphor of cake, making an analogy that "*just as the chocolate, strawberry, and decorations come together to form a sweet cake, STEM brings science branches together*." Similarly, M168 draws attention to the holistic harmony of the disciplines that constitute STEM with the statement "*STEM is like an orchestra conductor. Because, the real power and efficiency emerges when all the parts come together*." Another semantic category of metaphors for STEM is functionality (f = 27). M95's metaphor "*STEM is like electricity. Because it illuminates us, allows us to see ahead and makes our lives easier*" emphasizes the life-facilitating aspect of STEM. Similarly, M89's metaphor "*STEM is like life itself. Because it offers solutions to life's problems*" points out that STEM offers solutions to daily life problems. When the metaphors of mathematics teacher candidates regarding the concept of STEM are examined, the expressions in the category of supporting the learning process ($f = 25$) present noteworthy findings. For example, M129's kitchen metaphor emphasizes that it encourages interaction with the statement "*In STEM education, students bring together different talents with their communication skills and obtain products*." Similarly, M125's art metaphor points to the cognitive process supporting aspect of STEM with the statement "*Because it allows the student to develop and use critical thinking and creativity*." The other two categories where the participants' metaphors are collected are innovation ($f = 18$) and inclusivity ($f = 8$). M46's innovation movement metaphor emphasizes that STEM has the potential to lead to reforms in education with the statement "*it aims for a radical change*." M71's combined class metaphor draws attention to its inclusive aspect that appeals to different grade levels with the explanation "*a system that includes all class levels. Not for a single level*." In addition to the positive metaphors presented above, negative metaphors about STEM were also identified.

These metaphors are collected under the categories of *difficulty and obstacles* ($f = 8$) and *misconceptions* ($f = 55$). It has been stated that the fact that students, who are one of the important components in the success of STEM education, do not have sufficient knowledge about this education makes it difficult to implement. For example, M107 emphasizes that the interdisciplinary structure of STEM is not sufficiently understood at the student level with the explanation "*STEM is like a newly invented machine. Because I don't think it is used effectively yet. Students do not have enough knowledge in the interdisciplinary approach, they evaluate the fields separately*." Similarly, M12 states that certain conditions must be met in the implementations of STEM, otherwise success cannot be achieved, with the statement "*STEM is like palm oil. Because it is negatively affected if not used under appropriate conditions*."

The findings obtained from the metaphor analysis regarding the question "What are the misconceptions of mathematics teacher candidates about STEM?," which is the second sub-problem of the current study, are remarkable. 55 of the metaphors created by the participants about STEM were found to have misconceptions. The leading misconceptions are the false perceptions about the content of STEM. In the misconceptions about the content, it was determined that the teacher candidates perceived STEM only as the use of technology ($f = 12$), a lesson ($f = 6$), applicable only in science lessons ($f = 5$), applicable only in mathematics lessons ($f = 4$), game ($f = 3$), robot ($f = 3$), technology-supported mathematics teaching ($f = 2$), or technology-supported science teaching ($f = 1$). These findings show that mathematics teacher candidates perceive the STEM concept not as a holistic educational approach, but in a narrow framework through specific components. These misconceptions are revealed in more detail with the metaphor examples presented below:

> STEM is like a computer. Because it contains technical information about understanding and living the universe.M21

> STEM is like lessons. Because the relationship between mathematics lesson and science is established.M173

> STEM is like a laboratory. Because it is used in science class.M20

Another misconception identified from the metaphor analysis is related to the integration of STEM disciplines. In this context, when the meanings underlying the metaphors of the teacher candidates who expressed their opinions are examined, it is seen that they interpreted the integration of the disciplines that constitute STEM only as explaining interdisciplinary relations, as in traditional education ($f = 13$) and considered it in the context of relating it to daily life ($f = 2$). This finding shows that teacher candidates tend to evaluate STEM within the scope of traditional course content, rather than as an interdisciplinary interaction as a holistic learning process. Examples of the participants' metaphors are presented below:

> STEM is like a chain. Because it is transferred to the student by establishing a relationship between mathematics, science, engineering and technology.M155

> STEM is like an invention. Because the subject is explained by relating it to daily life.M113

Apart from those mentioned, another teacher candidate with misconceptions, M147, defined STEM as "a tool that measures students' thinking, feeling, and knowledge levels" using the scale metaphor. Similarly, metaphors that interpreted STEM as planning teaching ($f = 1$), teaching model ($f = 1$) and information acquisition tool ($f = 1$) were also identified. These findings show that some teacher candidates perceive STEM as a component of the measurement and evaluation or teaching process, rather than a teaching approach or an interdisciplinary education model.

Findings from the Word Association Test

As a result of the WAT analysis, a total of 307 different words were derived about STEM. These words were repeated 1,570 times in total. The most frequently used words are mathematics ($f = 152$), technology ($f = 126$), science education ($f = 117$), science ($f = 87$), engineering ($f = 89$). It is seen that the associations of teacher candidates are related to the disciplines that constitute STEM. As a result of clustering the word groups according to their semantic similarities, 22 different categories were obtained (Table 2).

When Table 2 is examined; It is seen that the word association test responses of mathematics teacher candidates for STEM are mostly collected in the mathematics category in terms of similarity ($f = 208$). This situation can be explained by the fact that mathematics is one of the basic disciplines that constitute STEM, as well as being the field in which the participants are studying. The other categories that teacher candidates associate with STEM were determined as technology ($f = 208$) and science education ($f = 182$), respectively. Among these categories, which are directly related to the main disciplines of STEM, it was determined that the concepts in the engineering category were associated less than the others ($f = 106$). Indeed, the fact that the most frequently repeated words, independent of the categories, are mathematics ($f = 152$), technology ($f = 126$), science education ($f = 117$), science ($f = 87$), engineering ($f = 89$); It shows that teacher candidates' cognitive structures regarding STEM are related to the main disciplines that constitute STEM. However, mathematics and technology stand out as the disciplines with the most associations. However, unlike the findings obtained from the metaphor analysis, it was determined that the words included in the interdisciplinarity ($f = 81$) category were associated with STEM to a more limited extent.

The data in the table reveals that education and teaching also have a place in teacher candidates' associations with STEM. Among the words grouped in the education environment ($f = 163$) category, the most frequently associated word is education ($f = 64$), which is one of the basic elements of the learning process, while the concepts of student ($f = 26$), teacher ($f = 16$), and class ($f = 13$) follow this. Similarly, the words teaching ($f = 18$), collaborative work ($f = 10$), approach ($f = 8$), method ($f = 8$), new generation education ($f = 7$) associated in the teaching strategies ($f = 101$) category also point to the importance of teaching strategies, methods and techniques in STEM.

Another point that draws attention among the findings obtained is that teacher candidates address STEM in the context of its main disciplines and education and teaching processes, rather than its benefits. In addition, negative associations ($f = 18$) associated with expressions such as difficulty ($f = 5$), complexity ($f = 2$) were also identified. This situation shows that teacher candidates' cognitive structures regarding STEM are shaped not only by its interdisciplinary structure, but also by the difficulties experienced in its applicability in learning environments.

Findings from Participants' Drawings

The drawings of mathematics teacher candidates regarding the statement "Explain what you know about STEM by drawing;" STEM disciplines, content of STEM activities, classroom layout and teacher-student roles were examined under the categories, and the findings are presented in Table 3:

When Table 3 is examined, it is seen that the science education and mathematics ($f = 18$) relationship is relatively at the forefront in the drawings of teacher candidates about STEM. Although it was determined that mathematics and technology words were more associated with STEM in the word association test findings (Table 2), it was not reflected in the drawings. Although the science education-mathematics relationship, which is one of the basic components of STEM, is evident in the drawings, it has been observed that these associations reflect traditional learning environments. In particular, it has been determined that the science education and mathematics disciplines are presented in a way that is parallel to the traditional teaching approach. As a matter of fact, when the classroom layout category is examined, it is seen that the traditional (row) layout ($f = 53$) is dominant in the participants' drawings. In addition, when evaluated in terms of teacher-student roles, it was determined that the teacher was in the position of information transmitter ($f = 58$) in the vast majority of the drawings. The findings regarding the content of STEM activities reveal that teacher candidates conceptualize STEM as doing experiments ($f = 32$), the lecture of the mathematics lesson ($f = 19$), and technologically equipped classrooms ($f = 19$). These findings point to a situation that is not directly noticeable in the metaphor analysis and word association test results, but becomes evident through the drawings. Teacher candidates position STEM within the traditional teaching approach and may have misconceptions about the content of STEM activities. This situation shows that STEM is not fully internalized by teacher candidates and is perceived as an approach limited to certain activities.

Examples of teacher candidates' drawings about STEM disciplines are presented in Figure 1. The drawing on the left (M67) reflects a traditional classroom setting where the science-mathematics relationship is established through a specific topic, positioning the teacher as the transmitter of information. In contrast, the drawing on the right (M18) presents a more holistic and student-centered learning environment, integrating all four STEM disciplines with a variety of materials and flexible seating arrangements.

When the M67 drawing, which reflects the science education-mathematics relationship, is examined, it is seen that the teacher candidate establishes the science-mathematics relationship through ordering relations and the ordering of blood groups. Although an interdisciplinary relationship is established, it is noteworthy that the traditional row classroom layout is preserved and the

Table 2. Associations with STEM.

Category	Associated concepts
Mathematics (*f* = 208)	Mathematics (*f* = 152), problem (*f* = 11), operation (*f* = 7), numbers (*f* = 7), modeling (*f* = 6), solution (*f* = 4), calculation (*f* = 3), problem solving (*f* = 3), statistics (*f* = 3), numerical (*f* = 3), logic (*f* = 2), ordering, infinity, geometry, integral, coordinate system, correlation, drawing
Technology (*f* = 202)	Technology (*f* = 126), computer (*f* = 20), robot (*f* = 8), internet (*f* = 7), software (*f* = 6), artificial intelligence (*f* = 6), 3D (*f* = 3), digital (*f* = 3), information technology (*f* = 2), coding (*f* = 2), calculator (*f* = 2), screen (*f* = 2), electronic environment, geogebra, barcode, keyboard, projector, smart board, electrical cable, cable, projector, electron, Arduino, augmented reality, hardware, drone, web 2.0
Science Education (*f* = 182)	Science education (*f* = 117), experiment (*f* = 17), physics (*f* = 16), chemistry (*f* = 8), laboratory (*f* = 8), biology (*f* = 7), mixture (*f* = 3), astronomy (*f* = 2), workshop, molecular physics, sound, rain
Science (*f* = 165)	Science (*f* = 87), information (*f* = 19), project (*f* = 16), research (*f* = 16), scientist (*f* = 7), professor (*f* = 3), scientific knowledge (*f* = 2), NASA (*f* = 2), observation (*f* = 2), data (*f* = 2), scientific process, hypothesis, science center, conference, qualified research, popular science journal, positive sciences, theory, TUBITAK
Education Environment (*f* = 163)	Education (*f* = 64), student (*f* = 26), teacher (*f* = 16), class (*f* = 13), constructivism (*f* = 8), activity (*f* = 6), interaction (*f* = 5), material (*f* = 3), instructor (*f* = 2), lesson (*f* = 2), book (*f* = 2), subject (*f* = 2), notebook, pen, academy, tools, education program, technology in education, faculty, secondary school, institution, homework, private school, time saving, university, learning environment
Engineering (*f* = 106)	Engineering (*f* = 89), system (*f* = 11), design (*f* = 3), technique (*f* = 2), construction
Teaching Strategies (*f* = 101)	Teaching (*f* = 18), collaborative work (*f* = 10), approach (*f* = 8), method (*f* = 8), new generation education (*f* = 7), integrated learning (*f* = 7), learning by doing (*f* = 6), contemporary education (*f* = 5), holistic education (*f* = 4), group work (*f* = 4), active learning (*f* = 3), innovative education (*f* = 2), presentation (*f* = 2), narration techniques, information transfer, computer-aided education, invention, trial and error, concept maps, teaching style, teacher guidance, teacher-student interaction, pedagogy knowledge, strategy, full learning, discussion environment, technology integration, technology use, new model, guidance
Interdisciplinarity (*f* = 81)	Interdisciplinary (*f* = 24), association (*f* = 14), integration (*f* = 13), combination (*f* = 7), discipline (*f* = 7), connection (*f* = 4), unity (*f* = 2), harmony (*f* = 2), union, different disciplines, interrelated parts, relating between subjects, coordination, richness, common ground, relating to real life
Cognitive Skills (*f* = 69)	Adaptation (*f* = 9), thinking (*f* = 8), skill (*f* = 7), intelligence (*f* = 6), higher order thinking (*f* = 5), perspective (*f* = 5), 21st century skills (*f* = 3), literacy (*f* = 3), perception capacity (*f* = 3), analysis (*f* = 3), inquiry (*f* = 2), rational (*f* = 2), reasoning (*f* = 2), computational thinking, scientific thinking, critical thinking, different perspective, generalization, imagination, metacognition, mathematical thinking skill, reasoning, synthesis, systematic thinking
Learning Processes (*f* = 51)	Learning (*f* = 8), permanent learning (*f* = 5), active participation (*f* = 4), exploration (*f* = 4), ease (*f* = 4), comprehension (*f* = 3), understanding (*f* = 3), multidimensionality (*f* = 3), efficiency (*f* = 3), working (*f* = 3), benefit (*f* = 2), versatility (*f* = 2), functionality, information acquisition, access to information, individual speed, individuality, rote-free, self-regulation
Daily Life and Society (*f* = 47)	Development (*f* = 12), daily life (*f* = 9), life (*f* = 6), community (*f* = 3), time (*f* = 3), order (*f* = 2), family, democracy, Dr. Doofenshmirtz, Transformers, young, sweet, chocolate, daily life problems, realistic, profession, money, development level of countries
Innovation (*f* = 41)	Innovation (*f* = 18), change (*f* = 6), currency (*f* = 5), progress (*f* = 4), future (*f* = 2), modern (*f* = 2), renewal movement, new age, vision, forward-looking
Environment and Nature (*f* = 32)	Yellow daisy (*f* = 11), space (*f* = 3), tree (*f* = 3), universe (*f* = 2), web (*f* = 2), soil, light, branch, nature, world, planet, sun, root, bird, fruit, leaf
Motivation (*f* = 24)	Fun (*f* = 6), attracting attention (*f* = 5), curiosity (*f* = 4), feeling (*f* = 2), pleasure (*f* = 2), motivation, happiness, self-confidence, attitude, excitement
Transportation and Industry (*f* = 18)	Machine (*f* = 4), vehicle (*f* = 3), car, factory, microwave, radio, clock, industry, telephone, television, transfer, transportation, printer
Art and Esthetics (*f* = 18)	Art (*f* = 7), architecture (*f* = 2), harmony, dance, visual, rhyme, conservatory, fiction, color, poem, green
Creativity and Innovation (*f* = 18)	Creativity (*f* = 10), innovation (*f* = 2), productivity (*f* = 2), product creation (*f* = 2), invention, production
Personal Development (*f* = 8)	Self-sacrifice (*f* = 2), responsibility (*f* = 2), career (*f* = 2), experience, mission
Social Sciences and Culture (*f* = 8)	Civilization (*f* = 2), social sciences (*f* = 2), Finland, history, Turkish, English
Global Perspective (*f* = 6)	International (*f* = 3), universality (*f* = 3)
Social Skills (*f* = 4)	Communication (*f* = 3), entrepreneurship
Negative Associations (*f* = 18)	Difficulty (*f* = 5), complexity (*f* = 2), game (*f* = 2), uncertainty, impossibility, rebellion, crowd, fear, boring, troublesome, intensity, illness

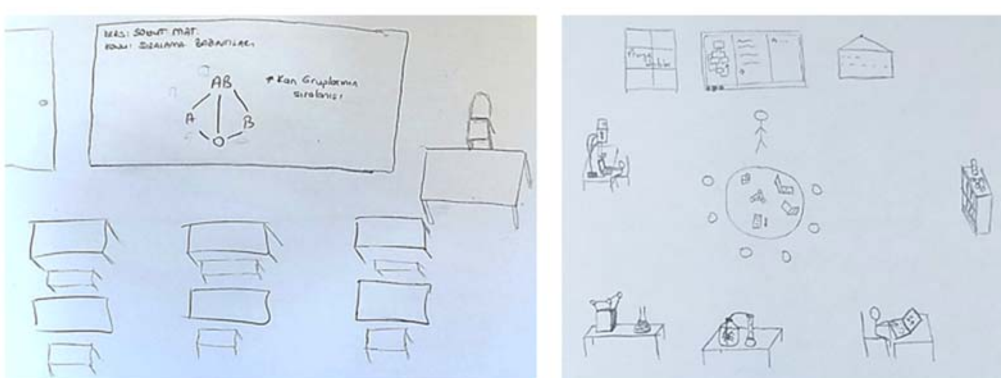
Table 3. Teacher Candidates' Drawings Related to STEM.

Category	Subcategory	*f*
STEM disciplines	Science education-mathematics	18
	Science education-technology-engineering-mathematics	14
	Science education-technology	6
	Science education-mathematics-technology	6
	Science education-mathematics-history	2
	Science education-technology-engineering	1
Content of STEM activities	Doing experiments	32
	A subject in mathematics class	19
	Technologically equipped classrooms	19
	Technology-supported mathematics education	5
	Science education lesson	4
	Game	3
	Robot	3
	Seminar	3
	Drawing pictures	2
	Online education	1
	Project	1
Classroom layout	Traditional (row) layout	53
	Cluster (team) work	38
	U-shape/circle layout	19
	Individualized layout	8
	Stadium layout	1
	Conference layout	1
	Informal learning	1
Teacher-student roles	Teacher as transmitter	58
	Collaboration	33
	Individual study	12

teacher is in the position of information transmitter. Another important element that stands out in the drawing is that the lesson taught has abstract mathematics content and in this context, it reflects a university-level learning environment. The example that deals with the holistic relationship between STEM's science education-technology-engineering-mathematics disciplines more comprehensively is M18′s drawing. In this drawing, it is observed that a wide variety of materials from experimental materials to technological tools are used, a circle layout is preferred in the learning environment, and also desk arrangements that allow students to work individually are included. In this respect, the M18 drawing presents a model more suitable to STEM's interactive and student-centered structure.

Examples of teacher candidates' drawings about the content of STEM activities are presented in Figure 2. These drawings illustrate common misconceptions. M1 depicts STEM as an activity limited to conducting experiments within a science lesson. M110 conceptualizes STEM as a traditional, teacher-led mathematics lecture. M51 identifies STEM with a technologically equipped classroom, focusing on tools rather than pedagogy.

When Figure 2 is examined, it is seen that STEM is conceptualized as conducting experiments in drawing M1. There are experiment materials in the learning environment, and there are science education-related visuals such as DNA and atomic models on the board. Another notable element is that the teacher candidate states that the name of the lesson is science and the topic is STEM education. This indicates that the teacher candidate perceives STEM as a topic covered in science class. As seen



M67 M18

Figure 1. Examples of STEM disciplines category from teacher candidates' drawings.

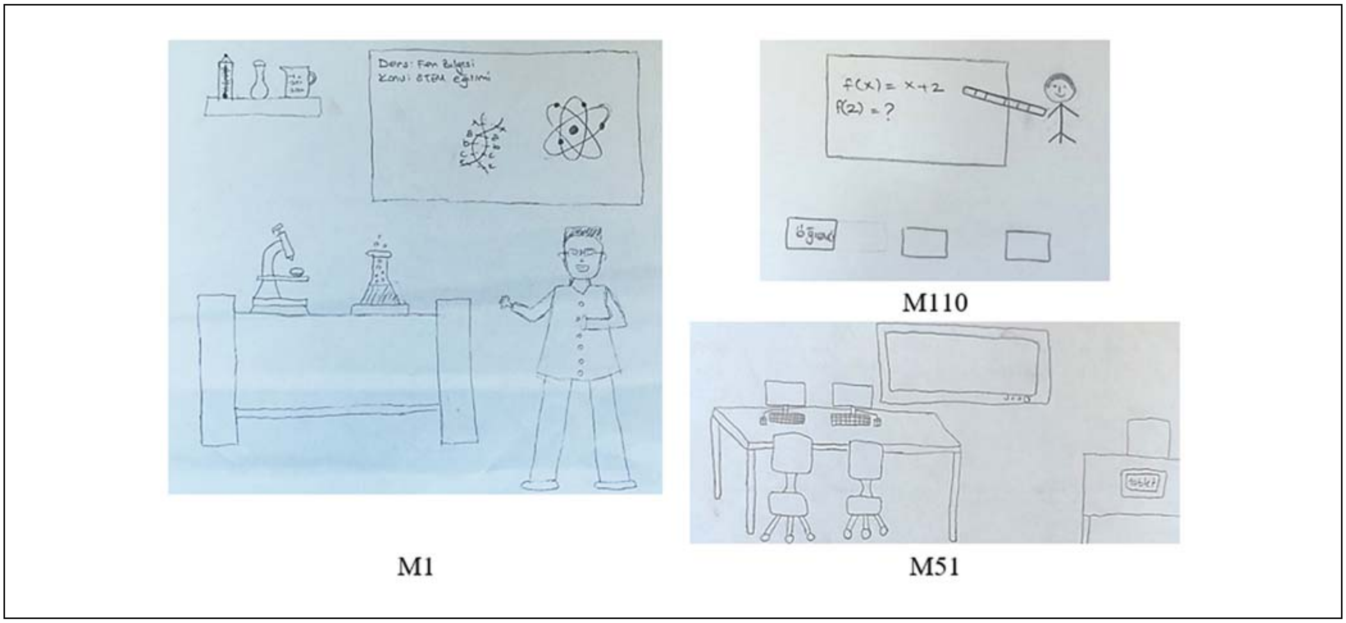


Figure 2. Examples from teacher candidates' drawings in the STEM activities content category.

in Table 3, $f = 32$ indicates that STEM is perceived as conducting experiments in the drawing. The data in Table 3 also supports this finding. Indeed, STEM was determined to be conceptualized as conducting experiments in the $f = 32$ drawing. This suggests a misconception that STEM's interdisciplinary nature is disregarded and limited only to science education. On the other hand, when drawing M110 is examined, it is seen that the teacher is giving a traditional mathematics lesson where they are in the position of transferring information. As stated in Table 3, although the mathematical concepts in the $f = 19$ drawing change, it has been determined that similar drawings reflect the traditional teaching approach. This finding shows that teacher candidates tend to associate STEM with traditional lecturing. Drawing M51 is directly related to the equipment of the classroom environment. Similar findings were encountered in 19 different drawings (Table 3), and it is understood that their perceptions of STEM regarding the learning environment are identified with the use of technology. For example, in drawing M51, technological tools such as the smart board in the classroom, computers on student desks, and the tablet on the teacher's desk are at the forefront. This reveals that some teacher candidates perceive STEM as a technologically equipped learning environment.

On the other hand, it has been determined that mathematics teacher candidates also have misconceptions about STEM activities being; technology-supported mathematics teaching ($f = 5$), games ($f = 3$), robots ($f = 3$), seminars ($f = 3$), drawing ($f = 2$), and online education ($f = 1$).

Conclusion & Discussion

This study aims to determine the misconceptions about STEM by deeply analyzing the cognitive structures of mathematics teacher candidates regarding STEM with a holistic approach (metaphor analysis, word association test, and drawings). The results of the study show that teacher candidates conceptualize STEM in their cognitive structures as a structure that includes basic disciplines and the relationships between them, but there are misconceptions about STEM on a wide scale from its epistemological foundations to its pedagogical foundations.

Teacher candidates mostly perceive STEM as bringing together separate disciplines (mathematics, science, technology, engineering) and do not adequately grasp the integration and holistic approach between these disciplines. In this context, the results of the metaphor analysis show that 55 different misconceptions about STEM have emerged. Participants define STEM only as the use of technology, a teaching method applicable in certain courses, or a structure limited to specific activities such as games and robots. The prominence of experiment materials, technological tools, and the traditional classroom setting in the drawings supports these misconceptions observed in metaphors. In particular, conducting experiments, a topic in mathematics class, and technologically equipped classrooms, which stand out in the drawings, reveal misconceptions about the content of STEM activities. The frequent repetition of discipline names (mathematics, science, technology, engineering) in the word association test and their perception of STEM only as the association of course content indicate that STEM is coded as a structure consisting of separate disciplines in their cognitive structures; however, the dominance of the traditional classroom setting and teacher-centered approach in their drawings shows that they do not have sufficient understanding of how interdisciplinary knowledge will be synthesized and how harmony will be achieved. These dominant traditional approaches in the drawings show that teacher candidates do not fully grasp the student-centered and interactive nature of STEM. In addition, seeing STEM only as a tool for acquiring knowledge, a method of measurement and evaluation, or a system for planning teaching, shows that STEM's pedagogical approach, which focuses on problem-solving, creativity, critical thinking, and innovative production processes, is ignored.

While the primary findings indicate that teacher candidates perceive STEM through a fragmented framework and struggle to grasp its holistic nature, their cognitive structures also contain intuitive seeds of an integrated understanding. This is particularly evident in the metaphors related to "cooking" (e.g., "cake," "Noah's pudding," "salad") and the recurring idea of "bringing together" various elements to create something new. These metaphors suggest that despite their inability to articulate a formal integrated pedagogy, the participants hold a latent concept of STEM as a fusion—a synthesis of different subjects and skills to produce a new whole. This intuitive grasp represents a crucial, albeit underdeveloped, counterpoint to their more explicit misconceptions. This latent understanding of fusion has significant implications for teacher education. Rather than approaching training programs as a process of correcting deficits from scratch, professional development can leverage these existing mental models as a valuable starting point. For instance, instructors can use these very metaphors of "cooking" or "blending" to concretely illustrate how different disciplines (the ingredients) and instructional methods (the recipe) must be fused to address a real-world problem. By building upon this intuitive foundation, it may be possible to help teacher candidates transition their latent understanding into a conscious and applicable pedagogical competence for integrated STEM education.

When compared with the literature, the participants' failure to grasp the holistic approach between STEM disciplines supports the findings that emphasize misconceptions about the weights of the disciplines that make up STEM (Ansberry & Morgan, 2019; Mafugu et al., 2024; Morrison, 2006; Yıldırım & Sevi, 2016). Research has shown that teachers' cognitive models of STEM often lack the necessary interdisciplinary structure for effective implementation. A study of life science teachers by Mafugu et al. (2024) illustrates this gap, finding that their understanding of "integrative STEM" was often constrained to superficial additions of technology or engineering onto a traditional, teacher-centered science curriculum. Their mental models remained fragmented, without the deep integration of mathematics and engineering required for a holistic approach. This suggests that a mere awareness of the STEM acronym does not equate to a functional understanding of its interdisciplinary nature, causing teachers to fall back on familiar, non-integrated teaching practices. The Ansberry and Morgan (2019) study draws attention to the existence of misconceptions about STEM needing to be equally weighted, while Yıldırım and Sevi (2016) shows that science teacher candidates associate it with only one discipline. The participants' definition of STEM only as the use of technology, a teaching method applicable in certain courses, or a structure limited to specific activities such as game robots, coincides with Morrison's (2006) misconceptions about technology and engineering in STEM being treated as separate courses from mathematics and science education. This situation shows that teacher candidates are far from the teaching understanding of STEM, which Brown (2012) stated as an integrated single unit, and conceptualize it as the association of separate disciplines in the traditional approach. Indeed, while a study conducted with science teacher candidates (Yıldırım & Sevi, 2016) found a misconception that STEM can only be applied in physics lessons, the current study reveals that teacher candidates perceive STEM activity content as limited to a specific topic and experimentation in mathematics lessons. One of the most important reasons for this situation is the poor definition of STEM. The STEM abbreviation is labeled as an activity involving the combination of four disciplines, which leads to a lack of clarity and meaning (Bybee, 2013; Vasquez et al., 2013). However Alrwaished (2024) showed that while the planning skills of pre-service math teachers who received special STEM training increased—such as in problem-solving, collaboration, and integration—their continued perception of having "limited interdisciplinary knowledge" indicates that they still perceive STEM as separate disciplines rather than a holistic structure.

The identification of STEM with traditional approaches, which was detected in the cognitive structures of teacher candidates in the drawings, and their limited understanding of how to synthesize and harmonize interdisciplinary knowledge, also reveals the lack of pedagogical content knowledge on this subject. The literature shows that teacher candidates have insufficient content knowledge about STEM (Epstein & Miller, 2011; York, 2018), and this situation is an obstacle to implementing STEM activities (Büber, 2023). Similarly, teachers do not have sufficient knowledge and skills to implement STEM in their classrooms (Custer & Daugherty, 2009; Le et al., 2023; Rockland et al., 2010). According to Le et al. (2023), although it is useful for the literature that different researchers put forward different classifications according to the clarity of the boundaries between subjects, it is difficult for STEM educators to apply this directly in teaching and learning practices. However, for the successful implementation of STEM education in schools, teachers need to be equipped with STEM pedagogical content knowledge (Rahman et al., 2022; Yıldırım & Topalcengiz, 2018).

The results suggest that teacher candidates do not have sufficient experience with STEM education and have not been sufficiently exposed to practices that emphasize its interdisciplinary structure. Their perception of STEM as limited only to science or mathematics lessons, which is consistent with the results in their identification with traditional education, is consistent with the structure in which the relationship between conventional science and mathematics is explained in teaching, and suggests that they do not receive sufficient guidance on how to integrate other STEM disciplines, namely engineering and technology dimensions, into educational processes. In this regard, teacher candidates need to be included in a more comprehensive education on STEM education. Interdisciplinary studies should be supported by hands-on activities aimed at understanding the nature of STEM and the processes of designing, implementing, and evaluating activities. In addition, encouraging teacher candidates' participation in interdisciplinary collaboration and mentoring programs will be an important step in enriching STEM learning experiences and disseminating STEM education; it will contribute to the full use and evaluation of STEM's potential.

A critical shift required in teacher professional development is to reframe mathematics not as an isolated subject, but as the "linchpin" or "glue" that holistically connects the four components of STEM. To overcome the fragmented view identified in this study, practitioners need to see and experience how mathematics provides the foundational language for interdisciplinary problem-solving. This principle can be illustrated through both complex industrial products and tangible classroom projects. A real-world example, such as the creation of a smartphone, serves as a powerful model. In this context, mathematics is integral at every stage: it is connected to Science for material calculations, informs Engineering in component design, and underpins the Technology used to build the device. To bring this holistic perspective into the classroom, professional development should focus on designing integrated, project-based learning (PBL) units. A project requiring students to design a small-scale, cost-effective water filtration system (Ridlo et al., 2020) for a community is a prime example of such a practical application. In this scenario, mathematics again acts as the unifying language to calculate flow rates, analyze data, and optimize the design. These interdisciplinary practices not only foster content knowledge but also cultivate essential 21st-century skills such as teamwork, communication, persistence, and creative problem-solving (Gündüz & Dokumacı Sütçü, 2025).

The results of this study suggest that the misconceptions and lack of a holistic perspective among prospective teachers can be addressed through sustained and practical professional development programs. This is supported by the research of Wilson et al. (2025), which demonstrated that long-term, interdisciplinary professional development programs focused on integrating mathematics and science significantly improve teachers' content knowledge and pedagogical strategies. Furthermore, their study showed that these programs not only enhance teacher competence but also positively impact student engagement and achievement In this context, "Interdisciplinary Project Design Workshops" can be organized to enable mathematics, science, and technology teachers to collaborate on designing similar projects. Additionally, "Industry-School Partnerships" can be encouraged, allowing teachers to observe how engineers or data scientists use mathematics in the real world through short-term workplace visits or collaborative projects. Furthermore, professional development programs should emphasize "Application-Focused Lesson Plan Development" to support teachers in integrating practical STEM applications into their own lesson plans.

Limitations and Further Research

This study was conducted with mathematics teacher candidates. However, a similar study to be conducted with experienced teachers in the field may reveal different findings due to their experience in managing the teaching process and their better understanding of students' learning needs. Such studies can contribute to the current knowledge base on the implementation of STEM education and fill an important gap in the literature. The data collection tools used in the research are metaphor analysis, word association test, and writing-drawing technique. Metaphor analysis and word association tests have provided information about broader associations and analogies by revealing participants' mental representations of STEM and the relationships between these representations. On the other hand, the writing-drawing technique has made it possible to identify teacher candidates' misconceptions more clearly and concretely by visualizing these misunderstandings. Future studies involving in-depth interviews with participants may provide more detailed and explanatory data about the causes of the identified misconceptions. Such data will provide an important perspective in understanding how STEM education is understood and what obstacles there are to its implementation.

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Ethical Considerations

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee The study was approved on October 12th, 2023 by Ethics Committee of Balıkesir University (approval number 2023/6).

Consent to Participate

Prior to data collection, written informed consent was obtained from all participants involved in this study. Date of informed consent received: October 12th, 2023. Participants were provided with a clear and comprehensive overview of the study's objectives, procedures, and their rights as research subjects. They were informed that their participation was entirely voluntary and that they could withdraw from the study at any time without any penalty or negative consequences. Given the nature of the study, which included the use of metaphor analysis, word association tests, and the draw-and-write technique to explore cognitive structures, participants were assured that all data would be treated with strict confidentiality. No personally identifiable information was collected, and all responses were anonymized to protect the privacy of the participants. Participants were also informed that the data collected would be used solely for academic research purposes and that the findings might be published in anonymized form in scientific journals, conference proceedings, or educational reports. By signing the informed consent form, participants confirmed their understanding of these terms and their voluntary agreement to participate in the study.

Author Contributions

The study has a single author.

Funding

The author received no financial support for the research, authorship, and/or publication of this article.

Declaration of Conflicting Interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Data Availability Statement

The datasets generated or analyzed during this study are available from the corresponding author upon reasonable request.

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