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Preservice Teachers' Conceptualization and Understanding of STEM Activities

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Abstract

There are many different views on the conceptualization of STEM, and there is no consensus. The aim of this study is to investigate how pre-service teachers conceptualize STEM. They were also asked to describe the specific characteristics of a STEM activity. The research was designed as phenomenological research design . The study group comprised 37 senior pre-service science teachers, 32 females and five males. An open-ended questionnaire was used as the data collection tool. The data obtained were analyzed by content analysis. According to the findings, a significant part of the study group listed the possibility of problem-solving, being related to daily life, correctly associated with disciplines, and being student-centered when describing specific features of STEM activities. It was revealed that most pre-service teachers had challenges in associating disciplines in STEM integration.

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Introduction

There are many definitions in the literature on integrating STEM and no agreed methodology (Breiner et al., 2012; Martin-Páez et al., 2019; Venville et al., 1998). While there is a convergence of views that at least two disciplines should be present, there are difficulties in determining the nature of STEM integration due to differences in conceptualizing the role of the disciplines (Dare et al., 2021; Moore et al., 2020). A lack of clarity in understanding the nature of STEM integration and its conceptualization can lead to problems in the effectiveness of STEM practices (Dare et al., 2021). Indeed, teachers report that they mostly have not experienced STEM integration during their education process and are not adequately prepared to incorporate it into interdisciplinary learning as required by national standards documents (Brown & Bogiages, 2019).

Dare et al. (2021) emphasize that there is a need for more research investigating how teachers conceptualize STEM components within their teaching. Similarly, preservice teachers also need to have a good knowledge of STEM education to effectively teach STEM in the classroom when they become teachers (Bybee, 2013; Putra et al., 2021). In addition to teachers' uncertainty about how to proceed in their classrooms, preservice teachers also experience confusion about STEM learning (Radloff & Guzey, 2016; Ring et al., 2018).

In studies conducted with teachers on how STEM is conceptualized, it has been determined that teachers in different STEM disciplines have different insights about STEM integration, leading to various classroom practices as technology is seen as the most challenging discipline to integrate (Wang et al., 2011), and also engineering and technology dimensions are less represented in conceptualization in drawings than in science and mathematics (Kloser et al., 2018). Teachers see the science and engineering components as independent of each other and have difficulties striking a balance between teaching science content and ensuring that the engineering design challenge engages students and is something that students can reasonably achieve (Dare et al., 2018).

Pimthong and Williams (2018) revealed that while most of the pre-service teachers understood STEM as the integration of science, technology, engineering, and mathematics, they lacked a deeper understanding of how these disciplines would actually integrate and the nature of STEM itself. Another study by Putra et al (2021) demonstrated that science content knowledge, STEM self-efficacy, and STEM anxiety play important roles in shaping the conceptualization of STEM education. In a STEM workshop organized by Berisha and Vula (2021), collaborative practices were found to impact positively on pre-service teachers' understanding of STEM. However, the researchers also noted that there was a wide spectrum of responses to STEM conceptualization among pre-service teachers, which did not necessarily align with their teaching experiences. Therefore, further research is needed to better understand the conceptualization and instruction of STEM education (Radloff & Guzey, 2016).

Thus, there is a need for research on how pre-service teachers, who are a stakeholder in the process, conceptualize STEM (Bartels et al., 2019). This is because pre-service teachers' understanding of STEM concepts and practices significantly impacts their ability to teach STEM subjects to their students effectively. Although they will play a critical role in developing students' STEM abilities when they become teachers, there are few studies in this field

(Margot & Kettler, 2019). Thus, determining how pre-service teachers conceptualize the STEM process and their ideas about how to conduct STEM integration, revealing the difficulties or deficiencies they experience, will give policymakers, teacher educators, and administrators an argument in terms of achieving success in the implementation of STEM programs and taking the necessary measures. Unlike other studies, this study focused on asking participants to define the specific features of a STEM activity and which disciplines an activity should include.

Additionally, this research contributes by investigating pre-service teachers' operational conceptualizations, focusing specifically on the functional aspects of STEM activities and the practical integration of disciplines. The study questioned whether they could associate any disciplinary approach with these statements. Thus, knowledge about the gaps and deficits in pre-service teachers' conceptualization of STEM can be used to inform the design of teacher education programs for effective teaching of STEM subjects by identifying areas where additional support and professional development may be needed. In this context, answers to the following questions were sought.

1. What are pre-service science teachers' opinions on a STEM activity's distinguishing features and STEM disciplines?
2. How do they relate to the disciplines they mentioned in a STEM activity?

Literature Review

Diverse STEM integration definitions

There are many definitions and different opinions about STEM integration. One of the reasons for this is that there is no globally accepted definition of STEM education, and implementation approaches differ within and across countries (English, 2016). However, one of the most comprehensive classifications of STEM integration is disciplinary, multidisciplinary, interdisciplinary, and transdisciplinary (Vasquez et al., 2013). The disciplinary approach is defined as working in complex phenomena or situations on tasks requiring students to use knowledge and skills learned from separate disciplines (Honey et al., 2014). The multidisciplinary approach refers to the coordination of teaching by teachers of different subjects to emphasize connections across the curriculum. According to this approach, concepts and skills are learned separately in each discipline but within a common theme (Vasquez et al., 2013).

The interdisciplinary approach integrates (parts of) two or more disciplines, focusing on making explicit connections between topics in related fields (Klein, 2004; Gao et al., 2020). The techniques used in the interdisciplinary approach aim to enable students to see different perspectives, work in groups and make the synthesis of disciplines the ultimate goal (Jones, 2010). When the transdisciplinary approach is compared to the interdisciplinary approach, this approach focuses on the problem area or topic at hand without paying much attention to the individual traces of disciplines (Gao et al., 2020; Klein, 2008). It is also stated that STEM education can be addressed with an interdisciplinary approach to STEM education that emphasizes the connections between disciplines and includes the totality of disciplines in STEM dimensions (Gao et al., 2020).

STEM is sometimes considered a pedagogical approach emphasizing inquiry and problem-based learning approaches (Breiner et al., 2012). According to the STEM Task Force Reports (2014), it is noted that the focus should not only be on linking disciplines but also on using appropriate disciplines to enable problem-based learning from real life. Shaughnessy (2013) described STEM education as using proper technology by combining the teamwork and design methodology of engineering to solve problems based on math and science concepts and procedures. However, it is seen that STEM integration is done with different combinations of disciplines, but one assumes a dominant role (Honey et al., 2014; Martin-Páez et al., 2019; National Academy of Sciences, 2014). It is stated that mathematics and engineering dimensions are inadequately served in studies on STEM integration (English, 2016). Kelley & Knowles (2016) pointed out that STEM education focuses on developing science and mathematics as isolated disciplines, and the attention given towards technology or engineering integration was insufficient. This situation is a problem, especially in the measurement and evaluation dimension of interdisciplinary STEM education, due to the traditional discipline-based approach that is existing and customary in the educational system (Gao et al., 2020).

The nature and integration of STEM education is a topic that sparks debates and differing opinions. As there is agreement that STEM involves problem-solving and the utilization of various disciplines, there are differing views on how and to what extent these disciplines should be integrated. Despite the growing emphasis on STEM integration and the increase in research on the subject, there is a lack of studies that provide concrete evidence of the desired learning outcomes in many curricula and policy reports (English, 2016). In this study, using Drake & Burns' (2004) STEM integration approach was used as one of the most comprehensive classifications of STEM as disciplinary, multidisciplinary, interdisciplinary, and transdisciplinary (Vasquez et al., 2013).

Method

Given that the study aims to explore the essence of pre-service teachers' conceptualizations and experiences of STEM, a phenomenological research design was employed, enabling an in-depth understanding of how individuals interpret a specific phenomenon (Creswell & Poth, 2016). Data were collected through an open-ended form to examine their conceptualizations of STEM.

Participants

The study consists of senior students of a science education program at a state university in Turkey. They will work at the middle school level (K4-K8 levels) when they graduate. During the first two years of their undergraduate education, they received intensive content related to the content knowledge of science-oriented courses (biology, chemistry, physics, earth science, mathematics). They performed laboratory experiments related to these courses. Throughout their undergraduate education, students took courses related to scientific research methods, science teaching, learning and teaching approaches, teaching principles and practices, and learning methods, as well as applied courses in teaching professional knowledge, such as computer and technology applications and material development. With the program updates made in Turkey since 2018, STEM applications have been included in science courses. For STEM integration, engineering design and entrepreneurship skills are integrated into existing curricula (MoNE, 2018). Pre-service teachers are expected to gain theoretical and practical competence regarding STEM applications and STEM integration before graduating. These pre-service teachers had previously acquired theoretical knowledge about STEM in various classes. This study was conducted at the end of the semester after the interdisciplinary science teaching course was conducted with those who participated voluntarily in the research. The implementation was performed within a theoretical course that lasted two hours a week and included interdisciplinary science teaching. In this context, in the weeks before the study was implemented, pre-service teachers learned theoretical information about the development and historical foundations of an interdisciplinary approach, Interdisciplinary education and educational policies in the world, Interdisciplinary teaching approach strategies, STEM education, and STEM Integration models. In addition, they examined different STEM integrations and examples of STEM, STEAM, and E-STEM applications. Although the course was compulsory and 43 students were taking the course, the research was conducted a total of 37 volunteered participants, 32 females and five males, who participated in the study. Purposive and criterion sampling were employed in this study (Creswell, 2013). The criteria for inclusion were being a senior pre-service science teacher and enrolling in theoretical courses related to STEM and interdisciplinary teaching. This ensured that participants had the necessary background knowledge to provide informed perspectives on the phenomenon under study. Ethics consent for the study was granted by the University Ethics Committee.

Data Collection Tool

STEM Practices Opinion Form

In order to understand pre-service teachers' conceptualizations of STEM and to obtain their views on the integration of STEM disciplines, a STEM application opinion form was developed. While developing the form, the opinions of two science education experts with Ph.D. degrees in science education and publications on STEM education and a science teacher with seven years of experience were taken to ensure conceptual validity. The expert opinions focused on the form's alignment with the research questions, the clarity of the statements, and their relevance to the study's objectives. Based on this feedback, minor linguistic adjustments were made to ensure the questions were clear to the pre-service teachers and the form was finalized by taking expert opinions. The structure of the form consists of two parts. The first part consisted of demographic characteristics (age, gender, and previous STEM experience), and the second part consisted of three questions focusing on the features of the STEM activity and the role of disciplines in STEM integration. The three questions in the form are as follows:

In the first question, they were asked to describe the features of a STEM activity specifically. In the second question, they were expected to explain how the STEM integration process was carried out. They were asked how the STEM activity starts and ends in this context. In the third question, they were asked their opinions about which disciplines would be used in the STEM activity and how. In this context, it was tried to determine how many disciplines were needed. The participants filled out the form in about 30 minutes.

Data Analysis

The qualitative data obtained from the form were analyzed by content analysis. During the content analysis, open coding was performed, and themes were created. Data were coded with open coding (Strauss & Corbin, 1990), and then a common code category (themes) was determined for codes related to the same title or topic. While coding, the specific characteristics of the STEM activity, the STEM implementation process, the use of disciplines in STEM integration, the role of each STEM discipline in STEM education, and how to integrate STEM were focused on. The codes were finalized, and the codes were combined and presented under themes. The reliability of the data was tried to be ensured by the triangulation method (Merriam & Tisdell, 2015). Coder reliability was confirmed by coding the data separately by a researcher who is an expert in science education (Patton, 2014). The coders met to discuss their comments, codes, and coding inconsistencies. It was decided that new codes should be added, and the sample data should be recoded. It was seen that there was 86% consistency between the coders (Miles & Huberman, 1994). Besides, to address validity insurance, after data collection, participants were asked to check whether the answers were understood correctly. The data were then transferred and analyzed using NVivo 12 program, which facilitated the creation of a systematic hierarchical coding structure. The total number of opinions expressed by the participants is presented as frequencies in the tables in the findings section. Thus, many participants expressed multiple opinions across different codes. Additionally, the coding categories used to analyze STEM integration levels were directly derived from the typology (disciplinary, multidisciplinary, interdisciplinary, and transdisciplinary) proposed by Drake and Burns (2004).While giving examples of the pre-service teachers' statements, the abbreviation was symbolized with the letter "T" and continued with a number.

Results

The findings were organized to reflect the specific features of the STEM activity, the disciplines needed in STEM integration, and the views on how to relate these disciplines to reveal the participants' conceptualization of STEM. For each question, examples of the pre-service teachers' responses are given and summarized.

Understanding Specific Features of STEM

The opinions of the pre-service teachers about the unique characteristics of a STEM activity were taken to determine their understanding of STEM practices. It was aimed to understand which elements make an activity a STEM activity for them when organizing or implementing. The findings are presented in detail in Table 1.

Table 1. Views on Characteristic Features of a STEM Practice

Themes	Codes	Frequencies
Skill-oriented	Suitability to solve problems	9
	Covering 21st century skills	5
Goal-oriented	Obtaining a product	4
	Relevance to daily life	4
	Appropriate for the purpose/outcome	3
Discipline-oriented	Correct association of disciplines	4
	Having knowledge about different disciplines	2
Student-oriented	Being student-centered	6

According to Table 1, the responses received to identify the specific features of STEM activities were classified as skill-oriented, discipline-oriented, and goal-oriented. Among the particular characteristics of STEM activities, it was concluded that more emphasis was placed on problem-solving. However, it was determined that factors related to daily life and multidimensional thinking were mentioned but not sufficiently explained. As a result it was seen that they defined it as a problem-solving process that takes place in daily life and is in line with an achievement/goal, and a product is obtained. For instance, *"A concrete model should emerge at the end of the activity*" was stated by T12 . It is thought to be the participants used the terms and made explanations which they encountered in the courses. Examples of participants' quotations are given below. For example, T3 said, "*STEM activity is an activity for solving problems in daily life. It is done to make daily life easier*". Also, T11 emphasized STEM as s student-centered activity and discipline-oriented activity explained their views as: "T*he most basic feature of STEM is that the student should be at the center in the activity and should be at the center in order to gain skills through this application. It should also be an interdisciplinary activity*". Moreover, T3 revealed that "*In this process, mathematical knowledge is used in addition to scientific knowledge*" referring to having knowledge about different disciplines. Another view, according to findings, was focusing on being goal-oriented, and it was expressed by T17 as: "*First of all, the purpose and requirements of the activity should be decided. Accordingly, it is decided which dimensions to use*."

Disciplines in STEM Integration

In order to determine the views of pre-service teachers about the role of the relevant disciplines in their conceptualization of STEM, it was tried to find out how many disciplines they think there should be in a STEM activity. The responses obtained are shown in detail in Table 2.

Table 2. Findings related to Views on Disciplines in STEM Activity

Theme	Codes	Frequencies
Disciplines in STEM integration	At least two disciplines should be included	13
	Four disciplines must be included	8
	One discipline should be the focused	6
	STEM and other disciplines	7
	STEAM disciplines	2
	No disciplinary limit	1

According to Table 2, most participants stated there should be at least two disciplines for STEM integration. However, it is seen that many participants thought that four disciplines should be included. At the same time, it was observed that those who said that a single discipline should be at the center made explanations on the axis of the science program, primarily by centering science courses. It was observed that a small number of participants added the art dimension among the disciplines that should be integrated into STEM integration. Only one participant stated that there should be no discipline limitation. Examples of participant statements are given below.

Regarding the need for at least two disciplines, T17 said, "It should include at least two disciplines. The dimensions of these two disciplines should be included in the activity. The common aspects of the two disciplines should be determined". Regarding the need to include all four disciplines, T21 stated, "STEM activity is related to science, mathematics, engineering, and technology. Therefore, I think that these four fields should definitely be included." Regarding the explanations that one discipline should be at the center, T27 stated, "An activity should be done with design skills at the center."

Connections between Disciplines

Pre-service teachers were asked their opinions on how they thought about integrating the disciplines that should be used in STEM integration. They were asked to explain how they should incorporate the disciplines they stated should be included in STEM integration. The responses obtained in this direction are shown in Table 3.

Table 3. Findings related to Connection of Disciplines in STEM Integration

Themes	Codes	Frequencies
Disciplinary	Should be suitable for the objective of the discipline	3
	Discipline-specific skills should be observed	5
Multidisciplinary	Disciplines should be integrated later	6
	Content compatible with the dimensions should be chosen	3
Interdisciplinary	Dimensions should be intertwined	6
	Design and technology should be interrelated	2
Separate disciplines	Dimensions should be evenly focused	1
Other	Irrelevant/Unanswered	11

As shown in Table 3, it was understood that the pre-service teachers' ideas about integrating the disciplines they mentioned were distributed according to disciplinary, multidisciplinary, and interdisciplinary approaches. Still, they did not have a clear vision. Notably, a significant part of the participants left this part unanswered, while some gave irrelevant answers, indicating that they had low STEM background. T34 stated, "*Disciplines should be related to each other with a holistic perspective. Since a single discipline cannot solve the problem, different disciplines should be brought together*." indicating the importance of relating disciplines in an interdisciplinary approach but they could not exemplify or elaborate on their statements.

T29, on the other hand, argued that disciplines should be integrated according to their characteristics and said, "Which part of the activity is related to which discipline and how much it is related to which discipline is first determined. Afterward, the relationship with other disciplines is established where necessary without moving away from the center of the subject". Besides, T4 stated, *"In STEM activities, each discipline should be considered separately and then related to each other. For example, it is necessary to think about what the contribution of engineering skills should be here and how I can connect it with other fields*" as an example for multidisciplinary approach. Although there were statements on different STEM integrations such as at least two disciplines, four disciplines, or more than four disciplines in the previous question, it was seen that how to make a STEM integration was not explained sufficiently in this section in connection with the previous answers. Moreover, many students left this part unanswered, or some wrote general answers, stating that they had low self-efficacy in this subject. For example, T31 "*Disciplines should be interconnected and logically integrated. For this reason, our general knowledge and equipment about disciplines should be high. However, I see myself as weak in developing and implementing STEM activities*".

Discussion

Examining pre-service teachers' thinking about STEM in terms of interdisciplinary teaching, inquiry-based teaching, and hands-on experiences provides a better understanding of the challenges and opportunities to ensure effective STEM teaching and learning. This study aimed to determine in detail what the characteristics of STEM activity are, how they conceptualize STEM, and how they think STEM integration should be done. In this context, one of the findings obtained from this study is pre-service teachers defined STEM activities in terms of their specific characteristics as being focused on the problem-solving process and being related to daily life (Dare et al., 2018; Kloser et al., 2017). They drew attention to the fact that it is a student-centered activity and that STEM disciplines should be correctly associated. These results are consistent with the results of (Dare et al., 2021; Kloser et al., 2017). Real life context and authentic problems are important in terms of STEM learning and developing 21st century skills (Dare et al., 2021). However, it is seen that pre-service teachers could not make their explanations sufficiently (Pimthong & Williams, 2018). It is noteworthy that the participants’ statements, which focus on engineering design and problem-solving, aligned with the science curriculum update implemented by the Ministry of National Education in Turkey in 2018, which explicitly emphasized these skills. However, these statements remained at the conceptual level and did not provide sufficient examples or concrete illustrations. In addition, another result obtained is that among the specific features of the STEM activity, it is also essential to produce a concrete product. Accordingly, pre-service teachers developed largely accurate definitions of the specific features of STEM activities that make them different from other activities, but the same clarity was not found in the explanations.

Another finding obtained from the research is that the view that at least two disciplines should be involved in STEM integration is at the forefront. Although there are views on different types of integration in the literature, another dominant view is that all four disciplines should be included in a balanced way (Dare et al., 2018). This can be said to be since the majority of teachers teach subjects separately and are familiar with such an education system (Dare et al., 2018; Guzey et al., 2019). It is also seen that STEM should be integrated with the arts dimension, albeit in small numbers. In addition, although it was stated that there should be more than four disciplines, sub-disciplines were not mentioned at all.

Related to this, there are results in the literature that indicate that some teachers think there are problems with integrating the technology dimension (Wang et al., 2011). It is essential that technology is not separated from content knowledge or pedagogical knowledge, and good technology integration does not mean simply adding technology to the existing teaching and content area (Harris & Philips, 2018). Similarly, engineering integration cannot be simply open or add-on (Guzey et al., 2019). At the same time, the engineering dimension is the least represented and is not as conceptually prominent as science and mathematics in STEM integration (Kloser et al., 2017). This can be explained by the fact that pre-service teachers do not have an understanding and experience in fundamental engineering knowledge and practices (Aydeniz & Bilican, 2018; Hsu et al., 2011).

The last finding from the research is that pre-service teachers do not have a clear idea about how to relate the disciplines involved in STEM integration (Dare et al.,2019). Although the view that all four dimensions should be tried to be related in an intertwined way was gained, opinions were also shared that the disciplines should be added later according to their characteristics. In this context, the level of responses regarding disciplinary, multidisciplinary, and interdisciplinary understanding is close to each other. However, no response was received regarding the transdisciplinary approach, although it was largely defined as a problem-solving process when describing the characteristics of the STEM activity. This suggests that, although preservice teachers view STEM as a mix of disciplines, they struggle to conceptualize it as a fully integrated, real-world-focused whole in which the boundaries between disciplines have dissolved. However, it is noteworthy that a significant portion of the participants provided unanswered or irrelevant information in this section.

Conclusions

Pre-service science teachers have deficiencies in their STEM conceptualization levels and experience some confusion, although they know various definitions or concepts and had some experience through the course. In addition, although they had correct conceptions about the characteristics of STEM activity, they could not explain them. Although it was stated that there should be two or more disciplines in STEM application, how to relate these disciplines was not clarified. Although the problem-solving method ranked first in defining the STEM activity, the transdisciplinary approach was not mentioned. In the unrelated and unanswered section connecting the disciplines in STEM practice, some pre-service teachers stated that they did not feel competent in STEM integration. Consequently, the findings reveal a significant gap between participants' knowledge of STEM concepts and their ability to explain how these disciplines actually integrate. Despite the emphasis on real-life problems, the study showed that pre-service teachers perceive STEM as a unified teaching approach but struggle with deepening and concretizing these concepts.

Therefore, to get detailed information about associating STEM disciplines and realizing STEM applications, pre-service teachers can be asked to prepare applied activity sheets, worksheets, and lesson plans to obtain more comprehensive information about their deficiencies and needs. Thus, to strengthen STEM conceptualization, the essential components of STEM (science, technology, engineering, mathematics) should be introduced in detail in the lessons, and how these disciplines will be related should be explained with examples. In addition, workshops can be organized where students can experience how the problem-solving process works in STEM. For example, the contribution of different disciplines should be emphasized with practical training that works on a problem together and analyzes, designs, prototypes, and tests, and the role of each discipline in problem-solving in STEM activities should be discussed clearly.

Recommendations

Further research on pre-service teachers' perspectives on STEM would provide an in-depth understanding of

STEM dimensions, providing valuable insights into the types of support and professional development that pre-service teachers may need to effectively integrate into their teaching practice, particularly in areas where they feel less confident. Further research on STEM conceptualization can provide insights into the challenges and opportunities associated with promoting effective STEM teaching and learning and inform the development of policies and initiatives to improve STEM education. In particular, it may be recommended to include engineering design frequently and to create learning environments where they can gain experience. In addition, providing more theoretical and practical learning environments related to STEM integration models can help them become familiar with these concepts and support them in implementing STEM practices when they become teachers easily. Additionally, special training can be given to pre-service science teachers on STEM pedagogy which should address topics such as integration of disciplines, project-based learning, and problem-solving.

Limitations

This study has several limitations. First, the sample size is relatively small and limited to a single state university in Turkey, potentially limiting the generalizability of the results. In addition, the data rely on self-reported opinions via a written form, due to time constraints which may lack a holistic view of pre-service teachers' full competencies.

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