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Understanding School Principals' Perspectives on STEM Education: A Qualitative Study in Turkish Schools *

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Abstract

This study aims to examine the perspectives of school principals working in secondary and high schools regarding STEM education. Employing a phenomenological research design, the study was conducted with 12 school principals, and data were gathered through semi-structured interviews. The collected data were analyzed using content analysis. The findings reveal that although principals' awareness of STEM education has increased, their conceptual understanding remains fragmented. Principals generally perceive STEM as a contemporary pedagogical model that fosters 21st-century skills such as problem solving, analytical thinking, creativity, and collaboration. Nevertheless, significant barriers to effective implementation were identified, including shortages of instructional materials, limited teacher competencies, and time constraints. While technology competitions were acknowledged as enhancing student motivation and supporting more enduring learning, concerns were raised regarding cost and sustainability. Teachers were described as demonstrating positive attitudes toward STEM; however, their limited knowledge and experience were found to restrict effective practice. Furthermore, out-of-school STEM activities were considered valuable for students' academic and social development, yet challenges related to accessibility and continuity were noted. Overall, the study concludes that the institutionalization of STEM education requires strengthening the leadership roles of principals, supporting teachers' professional development, expanding access to out-of-school learning environments, and designing flexible yet standardized implementation plans.

Keywords: School principals, educational management, STEM education, qualitative study

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Introduction

The implementation of educational practices is shaped by how they are understood and managed at the school level (Moore et al., 2024; Spillane et al., 2002). In this process, school principals play a central role in setting goals, guiding instructional practices, and creating conditions that support effective teaching and learning within schools (Hallinger & Murphy, 1985; Leithwood et al., 2008). Through their leadership, principals influence how teachers interpret new approaches, how resources are used, and whether practices are sustained over time (Hallinger, 2005; Robinson et al., 2008). For this reason, school principals play a crucial role in shaping educational practices within schools.

Alongside the growing responsibilities of school principals, the expectations placed on educational practices have also expanded. Education is currently expected to support competencies such as problem solving, critical thinking, collaboration, adaptability, self-regulated learning, and digital literacy. In line with these expectations, education is increasingly shifting away from memorization and toward learning that can be applied to various contexts and situations (OECD, 2023). To meet these expectations, STEM (Science, Technology, Engineering, Mathematics) education has gained attention as an approach that brings different subject areas together in classroom practices (Bybee, 2010; Kennedy & Odell, 2014).

STEM education enables students to acquire knowledge and develop a broad range of skills, particularly in solving real-life problems, conducting scientific inquiry, designing solutions, engaging in entrepreneurial thinking, and collaborating effectively (Akgündüz et al., 2015; Beers, 2011). Evidence from OECD's PISA studies also shows that individuals' ability to develop science-based solutions to the complex problems they encounter is closely linked to success in life (OECD, 2019). In Türkiye, where PISA performance has shown a gradual improvement, the Ministry of National Education (MoNE) has placed greater emphasis on STEM since the 2017 curriculum, encouraging the use of project-based and inquiry-based activities, especially at the secondary school level (MoNE, 2017). More recently, in The Century of Türkiye Education Model (MoNE, 2024), STEM education is implicitly reflected, with related activities structured in line with this emphasis.

The literature emphasises that STEM education should extend beyond classroom-based instruction and be supported through activities such as out-of-school learning environments, competitions, science centres, and community-based projects (English, 2018; Freeman et al., 2014). However, many schools struggle to utilize these opportunities. School administrators often have limited knowledge and awareness of such practices, while practical challenges such as budget constraints, teacher unwillingness, and exam pressure further limit access to STEM-related projects (Güleç Çiftçi & Şentürk, 2024; Hai et al., 2023). These challenges make the role of school principals particularly important in planning STEM practices, supporting teachers, and keeping STEM activities going in schools (Talib et al., 2025).

While teachers' attitudes towards STEM practices have been widely explored in the literature (Biçer et al., 2019; Margot & Kettler, 2019), research that examines how school leaders make sense of STEM and support its implementation within schools remains underdeveloped in comparison (e.g., Geiger et al., 2023). This gap is also visible in Türkiye, where studies directly examining school principals' perspectives on STEM education and their managerial practices related to this process are quite limited. Existing research in the Turkish context indicates that STEM-related practices in schools are constrained by several structural and instructional challenges, including limitations in physical infrastructure, instructional equipment, teacher expertise, and systemic conditions (Ercan, 2020; Güleç Çiftçi & Şentürk, 2024). Within this context, this study aims to fill this gap in the literature, contributing to both theoretical knowledge and practice by revealing school principals' perceptions of STEM education, their leadership roles in this field, the structural and pedagogical obstacles they face, and their reflections on existing practices. Accordingly, the study examines the views of school principals working in secondary and high schools regarding STEM education. Within the scope of the research, answers to the following questions were sought:

1. How are school principals' knowledge levels and conceptual perceptions of the STEM approach?
2. How do school principals evaluate the effects of STEM practices on students' development?
3. What are the evaluations of school principals about the opportunities available for STEM applications in the schools where they work?
4. What are the attitudes of school principals towards technology competitions such as TEKNOFEST, MEB Robot, and FRC?
5. How do school principals evaluate teachers' attitudes towards STEM education and their implementation levels?
6. What are the knowledge and experiences of school principals about STEM activities carried out in out-of-school settings?
7. What are school principals' evaluations of a standardized school plan for STEM practices?

STEM Education: Global Trends and the Turkish context

STEM education has rapidly become a prominent approach worldwide with the aim of equipping individuals with 21st-century skills. International studies highlight that STEM is not limited to science and mathematics but represents an interdisciplinary learning model encompassing engineering, technology, problem-solving, creativity, and collaboration (English, 2018; National Research Council [NRC], 2013; Schweingruber et al., 2014). Reports from international organizations

demonstrate that STEM integration is critical in enhancing scientific literacy and problem-solving competencies (NRC, 2013; Pokropek, 2024). In this regard, STEM is emphasized for its role in improving individual learning outcomes and contributing to national development and innovation processes (Johnson et al., 2015; Kelley & Knowles, 2016).

The development of STEM education in Türkiye gained momentum in the mid-2010s, particularly following the publication of the STEM Education in Türkiye Report by Akgündüz et al. (2015), which made the approach more visible within educational policies. Subsequently, the 2017 Science Curriculum incorporated STEM activities and project-based learning into the national framework (MoNE, 2017). The 2023 Education Vision further emphasized interdisciplinary learning, design-skill workshops, and technology integration (MoNE, 2018). Most recently, “The Century of Türkiye Education Model”, while not explicitly using the term STEM, reflects the fundamental principles of STEM pedagogy through its focus on skill-based, design-oriented, and project-centered learning (MoNE, 2024).

Although research on STEM in Türkiye has increased in recent years, the literature has primarily focused on teachers’ perceptions (Biçer et al., 2019; Margot & Kettler, 2019). Moreover, research in the Turkish context appears to be dominated by quantitative approaches, with relatively fewer studies adopting qualitative perspectives (Ecevit et al., 2022). At the same time, international literature consistently shows that school leadership plays a decisive role in STEM implementation, as administrators are instrumental in supporting teachers’ professional development, shaping school vision, and overcoming structural barriers (Geiger et al., 2023; Robinson et al., 2008; Shernoff et al., 2017). Therefore, investigating school leaders’ perceptions and practices regarding STEM in Türkiye addresses a gap in the literature while contributing to meaningful international comparisons.

National competitions and projects also play a vital role in the dissemination of STEM education. Events such as TEKNOFEST, MEB Robot, and FRC robotics competitions enhance students’ motivation and facilitate the transformation of acquired knowledge into tangible products (Temizhan et al., 2023). Recent international studies further highlight the significance of school leaders’ roles in STEM leadership. For instance, research in Qatari public schools indicates that principals associate STEM leadership with innovation, contextual considerations, and resource-related leadership practices (Omer & Chaaban, 2025). Similarly, studies in Malaysia indicated that school administrators adopt instructional leadership strategies to advance science and mathematics education (Jaafar et al., 2024; Rahman et al., 2025). Research suggests that administrators’ STEM-related strategies include supporting professional development, fostering a positive school culture, improving assessment processes, and strengthening leadership and management practices (e.g., Talib et al., 2025). Moreover, emerging research on high-performing STEM teaching teams underscores the importance of collaboration and planning in curriculum development (Lin et al., 2025). Recent studies also emphasize

the critical role of STEM leaders in building organizational resilience to sustain STEM initiatives (Marshall & Galey-Horn, 2024).

In conclusion, while STEM education in Türkiye has been supported by robust policy documents, competitions, and projects, the leadership roles of school administrators remain crucial for institutionalizing these practices. This study not only expands the limited national literature but also offers a comparative perspective with the international body of research on STEM leadership.

Methodology

Research Design

This study was conducted using a qualitative research method with a phenomenological design. Qualitative research enables an in-depth exploration of individuals' experiences, perceptions, and meaning-making processes (Patton, 2014). Phenomenology, in particular, focuses on examining how individuals experience a specific phenomenon and the meanings they attribute to it (Moustakas, 1994). Accordingly, this study aims to explore school principals' views and lived experiences regarding STEM education from their own perspectives. The phenomenological approach was considered appropriate, as it provides a systematic way to uncover and interpret principals' conceptualizations, experiences, and reflections on STEM education.

Participants

This study included 12 school principals from secondary and high schools in Kastamonu province, located in the northwestern part of Türkiye. The participant identification process continued until significant repetitions were seen in the data and information saturation was reached; finally, 12 school principals were included in the study (Guetterman, 2015). The maximum variation sampling technique, one of the purposeful sampling methods, was used in selecting participants. Rather than generalizing, this sampling method aims to reveal the differences related to the subject being studied and to make various aspects of the phenomenon under study visible (Büyükoztürk et al., 2017).

In this context, to evaluate the views of secondary and high school principals on STEM education from different perspectives, principals with various demographic characteristics (type of school, education level, branch, professional seniority) were included in the study. In selecting the participants, diversity was considered regarding variables such as school type (secondary and high school), tenure, and gender. In order to protect the privacy of the participants during the research process, each principal was assigned a code number (e.g., SP1, SP2, SP3...). Detailed information about the participants is presented in Table 1.

Table 1*Demographic Characteristics of Participants*

<i>No</i>	<i>Education Level</i>	<i>School Type</i>	<i>Management Seniority</i>	<i>Expertise</i>
SP1	Postgraduate	High School	12	Religion Education
SP2	Bachelor's degree	Secondary School	3	English
SP3	Postgraduate	High School	15	History
SP4	Postgraduate	High School	15	Turkish Language
SP5	Bachelor's degree	Secondary School	10	Social Studies
SP6	Postgraduate	High School	7	Mathematics
SP7	Bachelor's degree	Secondary School	9	English
SP8	Postgraduate	High School	17	Religion Education
SP9	Postgraduate	High School	12	Mathematics
SP10	Postgraduate	Secondary School	18	Turkish
SP11	Bachelor's degree	Secondary School	12	Social Studies
SP12	Bachelor's degree	Secondary School	16	Science

Data Collection

In this study, data were collected through semi-structured interviews. This technique allows the participants to convey their own experiences in detail and from their perspectives, while allowing the researcher to conduct a flexible interview process (Wellington & Szczerbinski, 2007). Semi-structured interviews are an important tool for obtaining in-depth and open-ended answers about individuals' experiences, especially in studies conducted with phenomenological design (Van Manen, 2016).

Before the interviews were conducted, it was clearly stated that the participants voluntarily participated, could withdraw from the study at any time, and that the information they provided would only be used for scientific purposes. Identity information was kept confidential to protect participant privacy, and a written consent form was obtained from each participant (Creswell, 2007).

In creating the interview form, a literature review was conducted, and questions were developed to understand principals' views in the context of STEM education in depth. The form consists of two parts: the first part includes the participants' demographic information; the second part includes school principals' knowledge, experience, and evaluations on STEM education. In order to increase the content validity and comprehensibility of the interview form, the opinions of a professor and an associate professor who are experts in the field of educational administration and STEM were taken, and the form was finalized by making necessary arrangements in line with the suggestions of these experts (Miles et al., 2014).

Before the implementation, pilot interviews were conducted with two school principals who had similar characteristics to the research group but were not included in the study, and the

applicability of the form, clarity of the questions, and time management were tested (Maxwell, 2009). After this pilot study, minor corrections were made to the interview form. During the data collection process, one-on-one interviews were planned with each participant, and the interviews were conducted face-to-face by the researchers in the school environment. With the participants' permission, the interviews were audio-recorded, and detailed notes were taken in cases where the audio recording was not approved. The duration of the interviews varied between 30 and 45 minutes. After all interviews were completed, the audio recordings were transcribed and analyzed.

Analysis of Data

In this study, the content analysis method was used to analyze the qualitative data obtained. Content analysis is a technique that enables qualitative data to be analyzed systematically, classified within a specific coding framework, and presented in meaningful categories and themes (Schreier, 2012). This method was preferred because it allows in-depth analysis of school principals' experiences and views on STEM education, while also offering flexibility to capture both anticipated and emergent issues.

The audio recordings obtained through semi-structured interviews were first transcribed into written text in the data analysis process. The transcribed texts were shared with the participants to check their accuracy, and corrections were made when necessary, ensuring the credibility of the data. Then, the researchers analyzed the texts line by line and created codes to preserve the integrity of meaning in the data. During this process, both deductive codes based on the research questions and inductive codes emerging from participants' own expressions were employed. A preliminary codebook was developed to define codes clearly and maintain consistency (Miles et al., 2014).

The codes were categorized according to their similarities, and then these categories were combined under themes based on conceptual similarity. To enhance reliability, two researchers coded part of the data independently, compared their coding, and reached consensus through discussion before applying the agreed coding framework to the entire dataset. Analytic notes were kept throughout the process to document coding decisions and reflections, providing transparency. After the coding and theme formation process, the findings obtained were interpreted by the researchers from a broader perspective. In this interpretation process, the themes obtained were evaluated in the light of the relevant literature and presented comprehensively in the discussion section. In addition, representative quotations from participants were included to illustrate the themes and to ensure that principals' voices were directly reflected in the findings.

Validity and Reliability

In this study, various strategies were employed to ensure the data obtained were valid and reliable. First, the principle of long-term interaction was maintained to enable a deep understanding

of the participants' experiences and opinions, and the interviews were carried out face-to-face and in the most comprehensive manner possible. Thus, participants were encouraged to express their thoughts in detail and to establish a trust-based interaction with the researcher (Yıldırım & Şimşek, 2011).

The context of the study, data collection process, and participant characteristics were described in detail to strengthen the transferability of the study. After the interview records obtained from the participants were transcribed, these records were edited, and participant approval was obtained. In this process, the transcripts were sent to the participants via e-mail, and the accuracy of the content was checked (Creswell, 2007). This practice contributed to ensuring the participants' thoughts were accurately reflected and verifying the data.

In order to ensure the reliability of the research, each stage of the process was documented in detail. Participant consent forms, audio recordings, written transcripts, interview notes, and documents related to the analysis processes were carefully archived. In addition, researcher diversity was used in the data analysis process. The data were analyzed and coded separately by two different researchers. Then, the codes were compared, themes were formed based on the agreed-upon codes, and the analysis process was carried out (Lincoln & Guba, 1985). This practice ensured that differences in interpretation were minimized, and the data were evaluated more objectively.

In addition, to reinforce the reliability of the study, the principle of transparency was adhered to throughout the research process, and the methodological decisions of the research were clearly reported. The authenticity of the findings, the systematicity of the research process, and the integrity in the interpretation of the results support the holistic reliability of the study.

Results

In this section, in line with the purpose of the study, the findings obtained regarding the awareness levels of the principals towards STEM education, their approaches towards implementation, the difficulties they face, and their solution suggestions are presented based on the participants' statements. The findings were structured around themes and sub-themes, and the everyday experiences of school principals were described under each theme.

School Principals' Knowledge Levels and Conceptual Perceptions of STEM

This theme reflects school principals' general knowledge, conceptual understanding, and awareness of STEM education. Participants' perceptions of the role of STEM in education and how they interpreted the concept were analyzed under this theme.

Awareness of the Role of STEM in Education

The study's findings show that many school principals realize that STEM is gaining more importance in the education system. Participants describe STEM as a contemporary approach that contributes to students' future professional lives and problem-solving skills.

Some principals drew attention to the interdisciplinary nature of STEM and emphasized that it allows students to use the knowledge they have holistically acquired in different fields. One participant expressed this view as follows:

"STEM is not just science or math. It enables children to combine what they have learned into a useful product in daily life. In this respect, I think it is an innovative educational approach" (SP2).

Similarly, another principal expressed the importance of STEM in terms of preparing students for the future with the following words:

"In today's world, it is not possible to move forward without knowing technology and engineering. The STEM approach both makes students dream and allows them to concretize those dreams" (SP6).

The study's findings reveal that such statements create a strong awareness of the role of STEM in education among most school principals.

Limited Perceptions of the STEM Concept

The research findings reveal that some school principals perceive STEM in a narrow and limited framework. Some participants identify STEM only with specific activities, especially robotics and coding practices, while awareness of its interdisciplinary, holistic structure remains limited.

A school principal expressed this situation in the following words:

"When we think of STEM, we mostly think of robotics or coding. To be honest, I cannot clarify exactly how engineering and mathematics are involved" (SP3).

Another principal expressed his uncertainty about the scope of STEM as follows:

"The concept of STEM sounds very broad, but in practice, we are usually limited to science activities and some projects. In fact, we do not know exactly how much it covers" (SP7).

The research findings show that such statements indicate that the perceptions of some school principals about the concept of STEM remain fragmented and limited.

School Principals' Views on the Contributions of Stem to Student Development

This theme includes school principals' views on the effects of STEM practices on students' academic, cognitive, social, and affective development.

Contributions of STEM to Students' Academic and Cognitive Development

The study's findings show that many school principals consider STEM applications a positive opportunity for students' academic achievement and cognitive development. Participants emphasized that STEM supports higher-level skills such as problem-solving, analytical thinking, and creativity.

One principal expressed the skills that STEM provides to students in the following words:

“Children try to produce solutions to the problems they encounter in STEM activities. Sometimes they make calculations, sometimes they develop a new idea. In other words, they not only learn knowledge but also how to use that knowledge” (SP4).

Similarly, another participant explained the contribution of STEM to analytical thinking as follows:

“Students no longer proceed by rote, but by questioning. They discuss what and why when conducting an experiment. I think this will affect their views on university and life in the future” (SP9).

The findings of the research reveal that most school principals strongly believe that STEM contributes to the cognitive development of students.

STEM’s Contributions to Students’ Social and Affective Development

The research findings show that STEM practices contribute not only to academic but also to social and affective development. Some participants emphasized that STEM activities support collaboration, self-confidence, and communication skills.

A school principal expressed this contribution with the following statements:

“In STEM activities, students learn to work together. They produce as a team, not alone. In this way, both their communication skills improve and their self-confidence increases” (SP1).

Another principal drew attention to the aspect of STEM that increases students’ motivation:

“When students take an active role in projects, they want to learn more. Even children who are shy in class can show themselves in STEM activities. This also changes their view of school” (SP8).

The research findings reveal that a significant number of school principals consider STEM as a holistic educational approach that supports not only academic but also social and affective skills.

School Principals’ Views on the Opportunities Available for STEM Applications

This theme includes school principals’ views on the physical, institutional, and human resources they have to carry out STEM activities and the constraints they face.

Physical and Institutional Facilities Provided for STEM

The research findings show that some school principals stated that certain opportunities for STEM activities were created in their institutions. Some participants positively evaluated, especially regarding the support of laboratory, workshop, and project-based activities.

A school principal explained this situation with the following statements:

“We have a science laboratory in our school, and a robotics workshop was established with the support of the municipality. Thanks to these opportunities, students can do practical work” (SP6).

Similarly, another participant drew attention to institutional support:

“The Directorate of National Education provides material and project support occasionally. Our teachers also use these opportunities. So we are not in a situation of complete impossibility” (SP2).

The research findings reveal that some school principals think that certain opportunities are provided for STEM, although they do not consider the current conditions sufficient.

Limitations Encountered in STEM Practices

The study findings show that most of the school principals point to significant limitations in disseminating STEM practices. In particular, the prominent problems are lack of materials, teachers' expertise, and time.

One participant expressed this limitation in the following words:

"Robotic materials are costly; we cannot buy all of them. Children are interested, but our opportunities are limited. Therefore, it is difficult to reach every student" (SP5).

Another principal drew attention to the teacher dimension:

"Most of our teachers are enthusiastic but have not received much training on this subject. Therefore, even if they have the materials, they have difficulty practicing" (SP10).

The study findings show that most school principals emphasized that the existing opportunities for STEM practices are insufficient and that the practices are mostly limited to individual efforts.

School Principals' Attitudes Towards Technology Competitions

This theme includes school principals' views on the contributions of technology competitions to student and school development and the difficulties experienced in participating in these competitions.

The Contributions of Competitions to Students and the School

The findings of the study show that a significant number of school principals find technology competitions such as TEKNOFEST, MEB Robot, and FRC valuable for the development of students. Most participants emphasized that such competitions increase students' motivation, enable them to think innovatively, and increase the recognition of schools.

A school principal expressed this contribution in the following words:

"When we prepare our students for TEKNOFEST, both their self-confidence increases and the school's name is recognized. Children have the chance to show themselves on a big stage" (SP8).

Similarly, another participant drew attention to the effect of competitions on learning:

"Participating in competitions allows students to put into practice what they learn in the lessons. They put theory into practice, which makes learning more permanent" (SP1).

The research findings reveal that most school principals consider technology competitions a visible and effective part of the STEM approach.

Limitations Encountered in Participating in Competitions

The study's findings show that some school principals expressed various limitations in participating in technology competitions. In particular, the participants emphasized costs, lack of technical equipment, and the time needed to prepare for the competitions.

A school principal expressed this situation as follows:

“TEKNOFEST requires a serious budget. If we cannot find a sponsor, it is challenging to move forward with our own means. This limits the participation of students” (SP4).

Another principal stated that the process increased the burden on teachers and students with the following words:

“Preparing for competitions is a very intense process. Teachers fall behind in their classes, and students have difficulty balancing these studies with exam preparations” (SP9).

The research findings show that although school principals find technology competitions valuable in general, they face serious obstacles regarding the sustainability of participation.

This theme includes school principals' views on the physical, institutional, and human resources they have to carry out STEM activities and the constraints they face.

Opinions of School Principals on Teachers' Attitudes and Practices towards STEM Education

This theme includes school principals' evaluations of teachers' attitudes towards STEM education, their contributions, and the challenges they face.

Teachers' Contributions to STEM Education

The research findings reveal that a significant number of school principals have positive attitudes towards STEM education and contribute to students' learning processes. Participants stated that young teachers are more prone to STEM applications, open to innovations, and successful in attracting students' interest.

A school principal expressed this situation with the following statements:

“Especially our young teachers are very enthusiastic about STEM. They prepare projects and open clubs. They also influence students and are more motivated to learn” (SP2).

Another participant explained teachers' efforts to integrate STEM into their lessons as follows:

“Our science teachers integrate STEM into their lessons by conducting experiments, and math teachers integrate STEM into their lessons through problem-solving activities. This enables students to gain different perspectives” (SP10).

The study's findings show that teachers' efforts contributed to forming a STEM culture in the school environment and improved students' interdisciplinary thinking skills.

Teachers' Limitations in STEM Practices

The research findings reveal that some school principals pointed out various limitations in teachers' STEM practices. In particular, the participants emphasized that teachers do not have

sufficient knowledge about the STEM approach, lack materials and equipment, and have difficulties with time management.

A school principal expressed this limitation in the following words:

"Most of our teachers support STEM, but their knowledge is limited. We need more seminars and in-service training. Otherwise, practices remain superficial" (SP6).

Similarly, another participant drew attention to the workload of teachers:

"Teachers are already dealing with a busy curriculum. They have difficulty finding additional time for STEM. For this reason, more project-based learning, but a limited number of applications can be done" (SP11).

The research findings show that although teachers have positive attitudes towards STEM, this approach can be implemented at a limited level due to their lack of knowledge and implementation difficulties.

Opinions of School Principals on STEM Activities Carried Out in Out-Of-School Settings

This theme includes the views of school principals on the contributions of out-of-school STEM activities to student development and the limitations experienced in participating in these activities.

Contributions of Out-Of-School STEM Activities

The study's findings show that many school principals find out-of-school STEM activities extremely valuable in terms of students' development. Participants emphasized that these activities increase students' social skills, collaboration skills, self-confidence, and academic knowledge. In addition, STEM activities in out-of-school settings seem to keep students' interest in science and technology alive.

A school principal expressed this contribution as follows:

"Our students learn in a different environment during out-of-school STEM activities. They work as a team and put forward their own ideas. This improves both their self-confidence and problem-solving skills" (SP4).

Another principal emphasized the importance of competitions:

"In events such as TEKNOFEST or science festivals, students come together with different schools. This broadens their vision and allows them to see what they can do in the future" (SP9).

Research findings reveal that out-of-school STEM activities contribute to students' academic and social development and make the learning acquired in the school environment more permanent and motivating.

Limitations of Out-Of-School STEM Activities

The research findings reveal that some school principals pointed out various limitations in implementing out-of-school STEM activities. Participants emphasized that transportation, financial

means, and time management limit students' participation in these activities. In addition, some principals stated that out-of-school activities could not reach all students equally.

One principal expressed this limitation with the following statements:

"The activities are good, but we cannot take every student. Financial means are limited, transportation costs are high. Most of the time, only certain students can participate" (SP7).

Another participant drew attention to the time limitation:

"Out-of-school STEM activities are useful, but students are already under a course load. Therefore, participation can be low or teachers cannot spare time" (SP1).

Research findings reveal that out-of-school STEM activities contribute to the development of students, but they also show limitations in terms of access and continuity.

School Principals' Views on A Standard School Plan for STEM Practices

This theme reflects school principals' views on the contributions and limitations of a standard school plan for planning STEM practices.

Views on the Contributions of Standard Plans

The research findings reveal that a significant portion of school principals think that a standardized school plan is needed for STEM practices to be systematic and sustainable. The participants emphasized that a standardized plan would increase teacher harmony, ensure practices are carried out within a certain framework, and create a shared vision throughout the school.

One principal expressed this situation with the following statements:

"Everyone in the school is trying to do STEM according to their understanding. However, if there were a standard plan, all teachers would work in line with the same goal so that it would be more effective" (SP5).

Another participant drew attention to the long-term contribution of a standardized plan:

"There should be an annual plan for STEM. If it is determined which activities will be done in each class and which achievements will be targeted, things will work more systematically" (SP8).

The findings of the research show that most of the school principals think that standard plans will contribute to the institutionalization of STEM practices and gain a holistic vision.

Views on the Limitations of Standard Plans

The research findings reveal that while some school principals acknowledge the benefits of standardized plans, they are concerned that such plans may reduce flexibility and mechanize practices. Participants expressed that STEM is inherently innovative, student-centered, and experiential, and that standardized plans can limit this dynamism.

One principal expressed this limitation as follows:

"The plan is important, but the spirit of STEM is flexibility. If we tie everything to the plan, teachers' creativity will be limited, and we cannot provide flexibility according to students' interests" (SP2).

Similarly, another school principal used the following statement:

"STEM is a constantly evolving field. A plan prepared today may be insufficient tomorrow. For this reason, flexibility should be included in addition to standard plans" (SP6).

The findings suggest that some principals found the standardized plans helpful, but were also concerned that they might limit flexibility and restrict teachers' creativity.

Discussion, Conclusion and Limitations

This study examined secondary and high school principals' views, implementation experiences, and managerial approaches towards STEM education. The findings revealed that school principals' awareness of STEM has gradually increased, but conceptual, structural, and practical limitations persist. Most principals consider STEM a contemporary and interdisciplinary learning model and emphasize that it contributes significantly to developing 21st-century skills such as problem solving, analytical thinking, creativity, and collaboration. This result aligns with the literature, indicating that STEM supports students' academic, social, and affective development (Cao et al., 2025; Güleç Çiftçi & Şentürk, 2024; Özkan & Kettler, 2022; Yıldırım & Selvi, 2017). However, the fact that some principals perceive STEM as limited to robotics and coding activities shows that conceptual awareness remains fragmented. This finding aligns with studies indicating that the holistic structure of STEM is not sufficiently internalized, especially at the managerial level (Ercan, 2020; Güleç Çiftçi & Şentürk, 2024).

An important finding of the study is that institutional facilities and leadership capacity play a critical role in the sustainability of STEM practices. Although some schools have laboratories and workshops, a lack of materials, limited competencies of teachers, and time pressure cause practices to remain limited to individual efforts. This result shows that STEM in Türkiye is still carried out through project-based and discontinuous practices rather than a systematic model. Similarly, the literature also shows the lack of structural supports and teacher training as an important obstacle in disseminating STEM (Ercan, 2020; Li & Stylianides, 2018). It was also stated that TEKNOFEST and similar technology competitions increase students' self-confidence, make learning concrete, and increase the school's visibility; however, it was emphasized that the sustainability of participation is difficult due to cost, technical equipment, and time pressure. This finding is consistent with previous studies that acknowledged the pedagogical value of competitions but found that their sustainability was weak due to a lack of institutional support (Lachebo, 2024; Pişgin & Pişgin, 2024).

Administrators evaluated teachers' contributions to STEM positively, and it was observed that especially young teachers developed innovative practices. However, their lack of knowledge,

inadequate materials, and intensive curricula cause the practices to remain superficial. This finding aligns with studies emphasizing the need for professional development for teachers in STEM education (Corlu et al., 2014; Shernoff et al., 2017). At this point, the leadership roles of school principals require creating a vision and organizing continuous learning opportunities to support teachers' professional development (Hallinger, 2011; Robinson et al., 2008).

Out-of-school STEM activities were found to be valuable in terms of increasing students' scientific curiosity, developing their social skills, and gaining self-confidence; however, it was stated that not all students could have equal access due to transportation, cost, and time limitations. This result aligns with research showing that out-of-school STEM activities can contribute to positive student outcomes, such as improved attitudes towards STEM (Baran et al., 2019; Kalik & Kırındı, 2022). In addition, opinions on standard school plans revealed that a planned framework is necessary to institutionalize practices; however, STEM's innovative and flexible nature should be preserved. Therefore, a "flexible standard plan" approach is recommended for institutionalizing STEM: Setting the basic vision and goals, but allowing teachers' pedagogical freedom.

Consequently, this research suggests that school principals play a critical role in Türkiye's institutionalization process of STEM education. Leadership capacity, supporting teacher competencies, access to out-of-school learning environments, and promoting competitions at the institutional level directly affect the success of STEM practices. These findings reveal that STEM should be supported with holistic strategies aligned with national policy documents (MoNE, 2024).

Based on the research findings, it is recommended that awareness-raising activities for school administrators, supporting teachers with continuous professional development opportunities, and providing the necessary financial and hardware resources for the sustainability of STEM education at the institutional level be increased. In addition, arrangements should be made to increase the accessibility of out-of-school learning environments, and institutional incentives should be developed to support participation in technology competitions. However, the preparation of plans that both determine the institutional framework and provide flexibility to teachers in accordance with the nature of STEM will contribute to the implementation of practices both systematically and creatively.

This study has some limitations that should be acknowledged. It was conducted with school principals from a single province, and the findings reflect the perspectives of this specific group. The data were gathered through qualitative interviews, representing participants' experiences and interpretations at the time of the study. Future research that includes different stakeholder groups or employs multiple data sources may offer a broader understanding of STEM implementation.

Research and Publication Ethics

In this study, all rules specified in the "Directive on Scientific Research and Publication Ethics of Higher Education Institutions" were followed. None of the actions specified under the second section of the Directive, "Actions Contrary to Scientific Research and Publication Ethics", have been carried out.

Ethics Committee Permission Information

Name of the committee that conducted the ethical assessment: Bartın University Ethics Committee for Social and Human Sciences

Ethics assessment document number: 2025-SBB-0929

Disclosure Statements

1. The authors contributed to the study as follows: The first author led the conceptualization and supervision of the research and prepared the original draft of the manuscript. The second author undertook the formal analysis and contributed to the review and editing processes. The third author was responsible for the methodological design and carried out the data collection. The fourth author contributed by conducting the literature review and assisting with the review and editing of the manuscript.
2. No potential conflict of interest was reported by the authors.

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