

Investigation of the Impact of Robotic Applications on Science Teachers' Perceptions of 21st-Century Skills Competence

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ABSTRACT

This study examines the impact of robotic mBot applications on science teachers' perceptions of their 21st-century skills. The study also addresses issues of efficiency and professional responsibility in science education by examining how robotics training promotes more effective and accountable teaching practices. A mixed method approach was used, combining a quasi-experimental design with in-depth interviews. The study group consisted of 16 science teachers who participated in a two-week training program. Quantitative findings showed significant improvements in teachers' perceptions of their 21st-century skills after the training. Qualitative results indicated that teachers mainly associated these skills with problem-solving, communication, and collaboration, with problem-solving identified as the most prominent. Teachers stressed the importance of possessing such skills to act as role models for students and emphasized professional training as the most effective way to develop them. They also noted that mBot applications help students engage with technology and connect science learning to real-world contexts, despite limited sensor diversity. Overall, integrating robotics into science education appears to enhance teachers' competencies and create meaningful learning opportunities.

KEY WORDS: 21st-century skills, Mbot, robotic application, science teacher

INTRODUCTION

The rapid transformation of technology and education in the 21st century has highlighted the importance of equipping teachers with competencies that extend beyond subject-specific knowledge, encompassing critical thinking, creativity, problem-solving, collaboration, and digital literacy (Güleryüz, 2020; Güney-Manavoğlu, 2022). Kale and Wang (2025) emphasized that computational thinking practices serve as essential cognitive foundations for developing problem-solving and digital literacy skills in future science educators. In this context, educational robotics has been increasingly recognized as a promising tool for fostering such competencies in students and teachers. Prior research has shown that robotics applications not only enhance teachers' and preservice teachers' engagement and motivation (Jaipal-Jamani and Angeli, 2017; Santos et al., 2016), similar to studies that reported positive relationships between teachers' 21st-century skills perceptions and their attitudes toward STEM (Kan and Murat, 2018) but also support the development of problem-solving, creativity, and technological pedagogical knowledge (Avcı, 2017; Erdoğan et al., 2020).

Despite these positive findings, the literature presents mixed results. For example, while some studies have demonstrated significant gains in areas such as problem-solving and creativity (Avcı, 2017; Kanmaz, 2023), others have reported limited or non-substantial improvements in specific competencies like critical thinking (Balıcı, 2021; Silik, 2016). Moreover, much

of the existing research has been conducted with preservice teachers or in early childhood contexts (Bozkurt-Polat and Ulutaş, 2023; Kanmaz, 2023), leaving relatively few studies that directly explore the impact of robotics on the professional skills of in-service science teachers. Recent evidence from Kurt and Anılan (2024) also reveals that, although science teachers hold positive views toward the use of robotics and coding in science education, their classroom implementation remains limited due to time constraints, a lack of equipment, and insufficient training opportunities. This gap is particularly notable given that science teachers play a crucial role in modeling and integrating 21st-century competencies within classrooms. Yet, their own perceptions of these skills in relation to robotics-based professional development remain underexplored.

Science teachers' perceptions of 21st-century skills competencies reveal a nuanced understanding of their importance alongside noticeable gaps in implementation and professional preparedness. Research indicates that science teachers are generally aware of the significance of the "4Cs" communication, collaboration, critical thinking, and creativity, and perceive these competencies as essential for effective teaching and learning in modern educational contexts (Imran et al., 2023). Many preservice and in-service teachers also rate themselves as competent in areas such as information, media, and technology literacy. However, they tend to express lower confidence in learning and innovation skills (LIS)

(Yenel and Selcuk, 2024). Notably, participation in STEM-based laboratory activities and educational interventions has been shown to significantly enhance teachers' perceived competence in 21st-century skills, particularly in problem-solving, critical thinking, and technological proficiency (Oktay et al., 2023; Koculu et al., 2022). However, as Almazroa and Alotaibi (2023) noted in their systematic review, teacher education programs worldwide still face major challenges in effectively translating 21st-century skills frameworks into classroom practice, emphasizing the need for proactive and context sensitive professional development models. Moreover, findings suggest gender-based differences in self-perceived competence, with female teachers often reporting higher levels of competence in life and career skills (LCS), as well as digital literacy, compared to their male counterparts (Kan and Murat, 2018; Yenel and Selcuk, 2024). In addition, a positive correlation exists between teachers' self-efficacy perceptions regarding 21st-century competencies and their attitudes toward STEM education, suggesting that confidence in these skills fosters pedagogical innovation (Sari and Balkas-Yasar, 2024). Despite this, many teachers still report feeling underprepared to effectively integrate 21st-century competencies into their classroom practices, pointing to weaknesses in teacher education programs and professional development opportunities (Ahmar et al., 2023; Bani-Amer, 2022). Institutional support, including access to technological resources and ongoing training, is identified as a crucial factor in strengthening science teachers' capacity to facilitate the development of 21st-century skills in students (Septiana et al., 2023; Sulaiman and Ismail, 2020). Collectively, these findings underscore the importance of embedding structured, practice oriented, and technologically integrated training within teacher education programs to ensure that science educators are well-equipped to cultivate 21st-century competencies in their classrooms.

To address this gap, the present study investigates the impact of robotic mBot applications on science teachers' perceptions of their 21st-century skills competencies. This study interprets robotics-based teacher training as a means of enhancing both the efficiency of instructional practices and the teachers' responsibility in preparing students for 21st-century challenges. By focusing on in-service science teachers, the study contributes to the literature in two key ways: first, it provides empirical evidence on how robotics can serve as a tool for strengthening teachers' professional growth; and second, it highlights the extent to which robotics-based training can influence teachers' self-perceptions of critical 21st-century skills such as problem-solving, collaboration, creativity, and technological literacy. This focus builds on prior research and addresses the pressing need for scalable, practice-oriented strategies to support teacher development in a rapidly evolving educational landscape.

The Importance of the Study

This study is significant as it addresses the gap in understanding of how science teachers can use robotic mBot applications to enhance their 21st-century skills, thereby emphasizing the

potential of such technologies in science education. Its novelty lies in systematically evaluating the effects of robotic mBot applications on teachers' competencies, proposing solutions to identified gaps, and testing their applicability. The training implemented in this research is expected to foster teachers' creative and critical thinking skills, which may positively influence their students. Moreover, the study contributes to the science and teacher education literature by offering insights into instructional strategies and materials that support the effective integration of digital and technological tools in teaching.

The Purpose of the Study

The purpose of this study is to examine the impact of robotic mBot applications on science teachers' perceptions of their 21st-century skills competencies, to identify how such technological tools can support the professional growth of teachers and contribute to the integration of digital practices in science education. The study was structured around two research questions that aligned with this purpose.

- (1) Is there a significant difference between the pretest and posttest scores of science teachers' perceptions of their 21st-century skills competencies?
- (2) What are science teachers' views regarding the impact of robotic mBot applications on their 21st-century skills?

METHODS

Research design

A mixed-methods approach was employed in this study, combining quantitative and qualitative methods. In the quantitative dimension, a quasi-experimental design was used, which is one of the main types of experimental designs (Roger and Öngen, 1993). Fraenkel and Wallen (2003) emphasized that experimental studies necessitate the proper manipulation of independent variables, the comparison of groups, careful sample selection, and the control of extraneous variables. This study adopted a single-group pretest–posttest design, and participants' scores from the pretest and posttest were compared to address the research problem. In the qualitative dimension, a semi-structured interview was employed to gather participants' views on the robotic coding training they attended.

Participants

Convenience sampling was used to select the participants for this study. According to Özen and Gül (2007), convenience sampling involves including individuals in the sample who are easily accessible to the researcher, which provided that they are suitable for the study. The study group consisted of 16 science teachers working at different middle schools in a province in the Black Sea Region of Türkiye. Among the participants, there were eight males and eight females. Their ages ranged from 26 to 43, with a mean age of 33. The participants' teaching experience varied between 1 and 18 years, averaging 7.5 years.

Data Collection Tools

This study used two instruments to collect data: The 21st-Century Skills Competency Perceptions Scale (21CSCPS) and a semi-structured interview form developed by the researcher.

21st-century skills competency perceptions scale

The 21CSCPS was developed by Aksüt (2023). It is a five-point Likert-type scale ranging from (1) strongly disagree to (5) strongly agree, consisting of 44 items grouped into three factors. The first 18 items measure LIS, the following 15 items (19–33) measure LCS, and the final 11 items (34–44) measure Information, Media, and Technology Skills (IMTS). An exploratory factor analysis (EFA) conducted to establish construct validity revealed factor loadings ranging from 0.672 to 0.956, with the three-factor structure explaining 64.43% of the total variance. A confirmatory factor analysis (CFA) further confirmed the three-factor model, with all fit indices meeting acceptable thresholds. Reliability analyses indicated strong internal consistency: Cronbach's alpha values were 0.96 for the EFA group, and for the CFA group 0.90 for LIS, 0.94 for IMTS, 0.84 for LCS, and 0.91 for the overall scale (Aksüt and Ezer, 2025). These results demonstrate that the 21CSCPS is a highly valid and reliable instrument for measuring teachers' perceptions of their 21st-century competencies.

Semi structured interview form

A semi structured interview form was developed by the researchers for use in this study to identify science teachers' views regarding the robotic coding training. The form consisted of 14 items (Appendix). The first five items collected personal information such as age, gender, years of professional experience, undergraduate grade point average, and interest in technology, each requiring short responses. The remaining nine items were open-ended questions designed to elicit participants' opinions on 21st-century skills and the robotic mBot training. The interview questions in the study were first prepared based on the literature, and then content validity was ensured by obtaining expert opinion. There were two experts specialized in mathematics education, while one specialized in educational measurement and evaluation. The experts reviewed the items for appropriateness and comprehensibility and suggested wording changes for three items. Following these revisions, the form was piloted with three teachers. Data obtained from the pilot study were not included in the analysis. After making final adjustments based on the pilot, the interview form was finalized for use in the study.

Data Collection Process

Within the scope of the study, the 21CSCPS was first administered to the participants. Following this, they received a two-week robotic mBot training program consisting of seven sessions. Immediately after the training, the same scale was administered again, and in-depth interviews were conducted individually with each participant. These interviews lasted approximately 15 min, during which the researcher took detailed notes. After the interviews, the notes taken for each participant were transcribed into digital format for further analysis. Information regarding the lesson plan used during the implementation process and the mBot robot kit is presented below. As part of the robotic mBot training, participants attended seven lessons. The training program was adapted

from the how to use mBot section in the Mblock program. Information regarding the learning outcomes of the lessons included in the program is presented in Table 1.

The lesson plan for the robotic mBot training was structured across seven sessions, progressing from introductory knowledge to applied practices. The initial sessions focused on familiarizing participants with mBot, the installation of the mBlock program, and the fundamentals of block-based coding. Subsequent lessons introduced the working principles of distance, line-following, and light-detecting sensors, followed by activities that integrated multiple sensors simultaneously. In the later stages, participants were guided to design applications that could be implemented in science lessons and to conduct and present experiments using the mBot devices that they had designed and coded. This sequential structure ensured a gradual transition from basic operational skills to the practical integration of robotics into science education.

In the final two lessons, the primary learning outcome was for participants to design an application that could be used with mBot in science lessons. To achieve this, the participants were first divided into four groups, each consisting of four members. Each group selected a science topic and determined which mBot sensors would be used for that topic. Subsequently, the mBot was designed and coded. The topics chosen by the groups and the corresponding mBot sensors that they employed are presented in Table 2.

As shown in Table 2, the first group selected the topic of "Detection of environmental obstacles by robots" and, within this scope, utilized a distance sensor and a light sensor. The second group focused on "Pathfinding with line-following

Table 1: Lesson plans for robotic mBot training

Lesson	Learning outcomes
Lesson 1	Recognizes mBot and can install the mBlock program; understands the basic structure of coding and the logic of combining block codes.
Lesson 2	Understands the working principle of distance sensors.
Lesson 3	Understands the working principle of line-following sensors.
Lesson 4	Understands the working principle of light-detecting sensors.
Lesson 5	Uses different sensors on mBot together.
Lesson 6	Designs an application that can be used in science lessons with mBot.
Lesson 7	Conducts and presents an experiment with the mBot they designed and coded.

Table 2: Topics identified by the groups and sensors use

Group	Topic	Sensors used
Group 1	Detection of environmental obstacles by robots	Distance sensor, light sensor
Group 2	Pathfinding with line-following robots	Line-following sensor
Group 3	Solving mazes with line-following robots	Line-following sensor, distance sensor
Group 4	Burglar alarm with mBot	Distance sensor

robots” and employed the line-following sensor. The third group addressed “Solving mazes with line-following robots,” for which they used both the distance sensor and the line-following sensor. The fourth group selected “Burglar alarm with mBot,” and used the distance sensor. In the seventh training session, all participants conducted trials and presented their mBot projects, which they had designed and coded.

To ensure effective group integration during the robotics activities, each group adopted a structured division of roles based on task specialization. In this role distribution, the group included programmers responsible for coding the mBot, a designer who planned the physical setup and sensor configuration, a recorder who documented decisions and coding steps, and a presenter who explained the final product. This division of tasks gave each participant clearly defined responsibilities, thereby promoting individual involvement. Moreover, the groups collaborated to diagnose errors and propose alternative solutions, engaging all members in shared problem-solving cycles. These collaborative mechanisms promoted peer participation, strengthened communication and teamwork skills, and maximized the development of 21st-century competencies such as critical thinking, creativity, and technological fluency. By structuring participation in this way, the training fostered a balanced learning environment in which both individual and collective contributions were visible and meaningful.

Both quantitative and qualitative analyses were conducted in this study. Quantitative data obtained from the 21CSCPS were analyzed using SPSS 20. Pretest and posttest scores were first examined for normality with the Shapiro-Wilk test. Since the data were normally distributed, paired samples t-tests were applied to determine significant differences.

Qualitative data, gathered through semi-structured interviews, were analyzed through coding, categorization, and theme development (Merriam, 1998; Miles and Huberman, 1994). Codes and themes were visualized with frequency tables, and reliability was ensured through intercoder agreement. Following Miles and Huberman's (1994) model, the agreement coefficient was calculated, yielding 85%, which exceeds the 80% threshold commonly accepted as reliable (Patton, 2002). These results indicate that the qualitative findings are valid and trustworthy.

RESULTS

Impact of mBot Training on Science Teachers' Competency Scores

Before testing for significance, the descriptive statistics of the data were examined (Table 3), followed by Shapiro-Wilk tests to assess whether the scores showed a normal distribution.

The results of the Shapiro-Wilk test, conducted to determine whether the scores obtained by the teachers in the study group from the 21CSCPS were normally distributed, are presented in Table 4.

Table 4 presents the Shapiro-Wilk test results for the scores obtained from the 21CSCPS and its subfactors. $p > 0.05$, in the context of a normality test such as the Shapiro-Wilk test, indicates that the data do not significantly deviate from a normally distributed. As shown in Table 4, all p-values were above 0.05, suggesting that the scores were normally distributed. Therefore, a paired samples t-test, which is a parametric test, was conducted to determine whether the difference between the pretest and posttest scores was statistically significant.

According to Table 5, there was a significant difference between the pre-test and post-test scores of science teachers

Table 3: Descriptive statistics of the 21CSCPS

Dimension	Test	N	M	SD	Med	Mode	Min	Max
LIS	Pre	16	69.25	8.8	72	60	55	81
	Post	16	73.81	6.5	75	66	63	83
LCS	Pre	16	58.43	7.1	59	56	43	68
	Post	16	58.75	6.1	58.5	56	46	70
IMTS	Pre	16	41.50	4.6	41.5	38	33	49
	Post	16	45.43	3.5	45	43	39	51
Total	Pre	16	169.18	19	175	175	132	198
	Post	16	178.00	15	181.5	186	151	199

LIS: Learning and innovation skills, LCS: Life and career skills, IMTS: Information, media, and technology skills, 21CSCPS: 21st-Century Skills Competency Perceptions Scale

Table 4: Shapiro-Wilk test results for the 21CSCPS

Dimension	Test	W	df	p
LIS	Pre	0.909	16	0.111
	Post	0.953	16	0.543
LCS	Pre	0.980	16	0.966
	Post	0.919	16	0.165
IMTS	Pre	0.969	16	0.829
	Post	0.962	16	0.707
Total	Pre	0.962	16	0.690
	Post	0.949	16	0.467

LIS: Learning and innovation skills, LCS: Life and career skills, IMTS: Information, media, and technology skills, 21CSCPS: 21st-Century Skills Competency Perceptions Scale

Table 5: Comparison of pre- and post-test scores on the 21CSCPS

Dimension	Test	N	M	Difference	t	p
LIS	Pre	16	69.25	4.56	6.68	0.000
	Post	16	73.81			
LCS	Pre	16	58.43	0.32	0.59	0.564
	Post	16	58.75			
IMTS	Pre	16	41.50	3.93	8.72	0.000
	Post	16	45.43			
Total 21CSCPS	Pre	16	169.18	8.82	6.72	0.000
	Post	16	178.00			

LIS: Learning and innovation skills, LCS: Life and career skills, IMTS: Information, media, and technology skills, 21CSCPS: 21st-Century Skills Competency Perceptions Scale

on the LIS factor ($p < 0.05$). Specifically, the mean post-test score ($M = 73.81$) was significantly higher than the mean pretest score ($M = 69.25$). As shown in the same table, no significant difference was found between the pre-test and post-test scores of teachers on the LCS factor ($p > 0.05$). In contrast, Table 5 indicates a significant difference in the IMTS factor ($p < 0.05$). The mean post-test score ($M = 45.43$) was significantly higher than the mean pre-test score ($M = 41.50$). Finally, Table 5 reveals a significant difference in the overall scores obtained from the 21CSCPS ($p < 0.05$). The mean post-test score ($M = 178.00$) was significantly higher than the mean pre-test score ($M = 169.18$).

Science Teachers' Perspectives on mBot and 21st-Century Skills

This section presents the qualitative findings derived from science teachers' experiences and reflections on the mBot training. The analysis of science teachers' narratives was conducted through thematic coding, resulting in six main themes: Views on 21st-century skills, alignment between the science curriculum and these skills, science teachers' perceptions of 21st-century competencies, teachers' views on robotics after the mBot training, their evaluations of the training itself, and the use of mBot in science lessons.

Theme of views on 21st-century skills

Two categories were identified within the theme of views on 21st-century skills, defining these skills and possessing them, with a total of 18 codes determined (Table 6). In determining these skills, teachers emphasized problem-solving, communication and collaboration, technological literacy, information-seeking, creativity, innovation, critical thinking, adaptability, and social awareness. For instance, one teacher (T14) described problem-solving as enabling students to produce creative solutions, while critical thinking involved questioning and evaluating information. Others highlighted communication and collaboration as essential for achieving common goals (T3) and pointed to technological literacy and information-seeking as indispensable in today's digital world (T8).

In terms of possessing these skills, teachers reflected on their own competencies. One participant (T1) noted that he had technological literacy and planned to apply robotics and coding in his teaching. One participant (T7) stressed communication and collaboration, while others pointed to creativity, innovation, information literacy, and cultural awareness as areas they actively foster in their classrooms (T16, T13). Overall, the findings indicate that teachers view 21st-century skills as a broad set of cognitive and social competencies and recognize the importance of modeling these skills for their students.

Alignment between the science curriculum and 21st-century skills

As presented in Table 7, the theme of alignment between the science curriculum and 21st-century skills included two

Table 6: Theme of views on 21st-century skills

Defining 21 st -century skills	Possessing 21 st -century skills
Problem-solving (f=10)	Problem-solving (f=8)
Communication and collaboration (f=8)	Social and cultural awareness (f=5)
Critical thinking (f=8)	Information literacy (f=4)
Creativity (f=6)	Creativity (f=7)
Technological literacy (f=5)	Communication and collaboration (f=6)
Flexibility and adaptability (f=5)	Technological literacy (f=4)
Learning-to-learn skills (f=4)	Innovativeness (f=3)
Scientific literacy (f=3)	
Social and entrepreneurial skills (f=3)	
Environmental awareness (f=3)	
Innovation (f=2)	
Information-seeking skills (f=2)	

Table 7: Theme: Alignment of science curriculum skills with 21st-century competencies

Category	Codes (with frequency)
Sufficiently aligned	Emphasizes problem-solving (f=12) Frequent references to technology (f=5) Encourages group work (f=4) Guides students' thinking (f=4) Includes questions to foster imagination (f=3)
Not sufficiently aligned	Not adequately aligned with today's world (f=5) Problems remain too theoretical (f=4) Fails to keep up with technological developments (f=3) Principles of scientific inquiry addressed superficially (f=3) Insufficient coverage of life skills (f=2)

categories: Sufficiently aligned and not adequately aligned, under which nine codes were identified. In the first category, teachers emphasized that the curriculum encourages group work, values problem-solving, promotes critical and creative thinking, includes imagination-enhancing questions, and frequently refers to technology. For example, one teacher noted that "the curriculum strongly emphasizes problem-solving, asking students to analyze real-life issues such as environmental problems and propose solutions" (T13). Similarly, group work and project-based activities were highlighted as supportive of communication and collaboration (T8, T2), while opportunities for creativity and innovation were also reported (T4). Teachers further underlined that inquiry-based questions encourage students to think critically and analytically (T1).

Conversely, teachers also identified areas where the curriculum does not sufficiently align with 21st-century skills. Several participants stressed that the curriculum lacks up-to-date technological content and fails to keep pace with innovations such as artificial intelligence, robotics, and coding (T10, T1). Others noted that problems are addressed in an overly theoretical manner, with limited opportunities for students to generate practical solutions (T14). Concerns were also raised regarding

the superficial treatment of scientific research principles, which restricts students' ability to engage in authentic inquiry and data analysis (T7). In addition, teachers reported that life skills such as time management, stress management, and teamwork are not adequately supported, with group activities often dominated by only a few students (T16). Overall, teachers' views indicate that while the science curriculum provides some meaningful support for 21st-century skills, particularly in communication, collaboration, and problem-solving, it remains insufficient in integrating modern technologies, fostering authentic inquiry, and promoting essential life skills.

Science teachers and 21st-century skills

The theme of science teachers and 21st-century skills was divided into two categories: the importance of possessing 21st-century skills and ways to develop them, under which nine codes were identified (Table 8). In the first category, teachers highlighted that possessing these skills is essential for benefiting students, serving as role models, sustaining professional development and motivation, maintaining effective communication with students and parents, and providing quick and practical solutions to problems. For instance, one teacher stressed that "to benefit students truly, teachers need to have digital literacy skills so they can guide learners in using online resources and technology effectively" (T12). Another noted that being a role model in problem-solving and creativity helps students value these competencies (T5). Others emphasized professional growth and motivation, underlining the need to continuously learn new technologies such as robotics and coding (T8). Teachers also pointed to communication skills as crucial for engaging with parents and supporting students through digital platforms (T16). In addition, possessing problem-solving and critical thinking skills was vital for quickly and effectively handling unexpected challenges (T11).

The second category concerned ways of developing 21st-century skills. Teachers emphasized watching online training videos (T14), participating in workshops and seminars (T10), and maintaining openness to continuous learning (T4). One teacher suggested that integrating 21st-century skills into in-service training programs would be particularly beneficial, as such programs could systematically address areas such as digital literacy, problem-solving, critical thinking, and creativity (T6). Overall, teachers perceived 21st-century skills as central to their professional identity and essential for modeling effective practices to students. At the same time, they identified professional development, self-directed learning, and institutional support as key pathways for strengthening these competencies.

Teachers' views on robotics after the mBot training

The theme of teachers' views on robotics after the mBot training consisted of two categories: Positive views and negative views, with nine codes identified (Table 9). In terms of positive views, teachers emphasized that robotics has the potential to broaden students' perspectives, foster technological

Table 8: Science teachers and 21st-century skills

Category	Codes (with frequency)
Importance of possessing 21 st -century skills	To benefit students (f=7)
	To serve as a role model (f=5)
	To provide quick and effective solutions to problems (f=5)
	To ensure professional development (f=3)
	To build healthy communication with students and parents (f=3)
Ways to develop 21 st -century skills	To maintain professional motivation (f=2)
	Participating in training (f=7)
	Including 21 st -century skills in in-service training programs (f=3)
	Watching online videos (f=3)
	Being open to improvement (f=2)

Table 9: Teachers' views on robotics after mBot training

Category	Codes (with frequency)
Positive views	Enhancing students' perspectives (f=3)
	Bringing students closer to technology (f=6)
	Supporting understanding of programming logic (f=4)
	Fostering students' imagination (f=5)
	Making lessons enjoyable (f=8)
	Linking science concepts with real life (f=6)
Negative views	Limited variety of sensors (f=3)
	Difficulty in assembling/disassembling (f=2)
	Coding perceived as difficult (f=2)

engagement, support the understanding of programming logic, stimulate imagination, make lessons more enjoyable, and connect science concepts with real-life applications. For example, one teacher noted that working with robotics helps students strengthen their problem-solving and critical thinking by planning the steps needed for a robot to complete a task (K15). Another emphasized that mBot "allows students to engage more closely with technology, coding, and engineering, increasing their interest in pursuing careers in these areas" (K11). Teachers also pointed to the benefits of block-based coding for understanding software logic (K8), the development of imagination and creativity through designing projects (K16), and the integration of abstract science concepts with real-world contexts such as physics and mathematics (K10). Moreover, robotics was described as making science classes more enjoyable and motivating for students (K13).

Alongside these positive aspects, several limitations were also identified. Teachers mentioned that assembling and disassembling mBot components can be challenging for some students, particularly those with limited technical skills, which may lower motivation (K4). They also pointed out that learning to code, even with block based programming, may be initially difficult and discouraging for students without prior experience (K10). Finally, the limited variety of sensors available in mBot kits was considered a constraint, as it restricts the diversity of projects and students' ability to explore more innovative applications (K17). Overall, teachers' reflections indicate that while robotics offers significant pedagogical benefits for enhancing engagement, creativity, and the application

of scientific knowledge, challenges related to technical complexity, coding difficulty, and hardware limitations need to be addressed to maximize its effectiveness in science education.

Teachers' views on the mBot training

The theme of teachers' views on the mBot training consisted of two categories: Positive views and negative views, with a total of 13 codes identified (Table 10). In the positive category, teachers emphasized that the training contributed to the development of problem-solving, coding, collaboration, imagination, and manual skills, while also increasing their knowledge of robotics, building persistence, raising awareness of the importance of technology in the classroom, and enhancing their confidence in using technology. For example, one teacher highlighted that troubleshooting during the training strengthened their problem-solving skills: "When our mBot failed to move, we identified the reasons, checked the codes and connections, and found a solution. These experiences reinforced analytical thinking" (K10). Another underlined the benefits of learning coding logic through block-based programming (K3). Collaboration was also emphasized: "Working in groups helped us learn how to communicate and divide tasks effectively" (K15). Others noted improvements in imagination and creativity (K16), increased knowledge of sensors and robotics (K11), and the development of fine motor skills through assembly tasks (K1). Teachers further reported gaining persistence through repeated trials (K12) and increased confidence in integrating technology into their classrooms (K5).

Despite these benefits, some limitations were reported. Teachers pointed out that the training was too short and did not allow for sufficient project diversity (K14). Others suggested that focusing solely on mBot restricted opportunities to work with different robotic materials, which would have provided broader perspectives (K2). Similarly, participants noted that the lack of variety in projects and materials limited the program's overall contribution to their 21st-century skills (K4). Overall, teachers' reflections indicate that the mBot training effectively supported multiple dimensions of 21st-century skills, particularly problem-solving, coding, and collaboration. Still, its short duration and narrow focus on a single tool constrained its broader potential.

Use of mBot in science lessons

As shown in Table 11, the theme of using mBot in science lessons included two categories: purposes of use and topics of integration, with 11 codes identified. Teachers identified several purposes for using mBot: Explaining abstract concepts, increasing students' interest in science, demonstrating real-life applications of scientific knowledge, fostering imagination, enhancing technological competence, and building students' self-confidence. For example, one teacher explained: "I plan to use mBot to concretize abstract concepts such as circuits or force and motion through its sensors and motors" (K4). Another highlighted its motivational potential: "Activities with

Table 10: Teachers' views on mBot training

Category	Codes (with frequency)
Positive views	Developing problem-solving skills (f=8)
	Increasing confidence in technology (f=4)
	Enhancing teamwork (f=4)
	Increasing imagination (f=4)
	Improving knowledge of robotics (f=3)
	Raising awareness of classroom technology use (f=3)
	Enhancing manual skills (f=2)
	Learning coding (f=2)
	Instilling persistence (f=1)
Negative views	Limited opportunities for diverse projects (f=3)
	Insufficient number of robotic materials (f=3)
	Lack of other robotic materials beyond mBot (f=2)
	Short duration (f=2)

Table 11: Theme use of mBot in science lessons

Category	Codes (with frequency)
Purposes of use	Explaining abstract concepts (f=3)
	Making students enjoy science (f=8)
	Showing real-life relevance of science knowledge (f=6)
	Enhancing imagination (f=4)
	Increasing technological familiarity (f=6)
	Boosting students' self-confidence (f=3)
Subjects	Force and motion (f=3)
	Simple machines (f=4)
	Life and living things (f=2)
	Electric circuits (f=2)
	Sun, earth, and moon movements (f=1)
	Push and pull (f=3)

mBot make lessons more enjoyable and may help students who dislike science develop interest in the subject" (K15). Teachers also pointed to its role in bridging classroom learning with real life (K2), stimulating imagination and problem-solving (K10), promoting technological literacy (K7), and enhancing students' confidence by completing projects (K5).

Regarding topics, teachers suggested integrating mBot into units such as Force and Motion, Simple Machines, Life and Living Organisms, Electric Circuits, Movements of the Sun, Earth, and Moon, and Push and Pull. For instance, one teacher planned to use mBot to model the relationship between force and motion (K10), while another aimed to demonstrate how levers and pulleys function by adapting mBot (K14). Applications in biology were also mentioned, such as using environmental sensors for monitoring temperature and humidity projects (K12). Other examples included demonstrating electric circuits (K3), simulating astronomical movements (K16), and exploring push and pull through distance sensors (K9).

Overall, teachers' views suggest that mBot has considerable potential to enrich science lessons by connecting abstract concepts to practical experiences, fostering motivation and creativity, and

supporting technological engagement across diverse subject areas. Findings indicate that robotics-based training contributes to instructional efficiency by facilitating active, technology-supported learning environments, while simultaneously fostering teachers' sense of professional responsibility toward continuous skill development and student engagement.

DISCUSSION AND CONCLUSION

The findings of this study indicate that robotic mBot training significantly enhanced teachers' LIS as well as their IMTS. At the same time, no significant improvement was observed in LCS. These results suggest that the training effectively addressed competencies directly linked to problem-solving, creativity, and technological literacy, but is less aligned with broader career oriented competencies. Consistent with Kırbaş and Bulut (2024), who found moderate proficiency in problem-solving, collaboration, and technology use, this study underscores the need for sustained efforts to develop 21st-century skills in teacher education. Similar outcomes have been reported in previous studies, emphasizing the contribution of robotics to creativity, problem-solving, and critical thinking (Özel, 2018; Erdoğan, 2019; Balcı, 2021; Güney-Manavoğlu, 2022; Yun and Crippen, 2024). These results are also consistent with prior systematic reviews, which emphasize the transformative role of robotics in enhancing collaboration, critical thinking, and problem-solving skills in science education (Ramaila, 2024). However, the limited impact on LCS points to a gap highlighted in the literature, where robotics training often focuses on technical and cognitive skills rather than personal or professional development.

Qualitative data further supported these findings. Teachers predominantly defined 21st-century skills as problem-solving, communication, collaboration, and technological literacy, echoing existing frameworks that stress the centrality of these competencies in modern education (Orhani, 2024; Oliinyk et al., 2020). Teachers also emphasized the importance of possessing such skills to act as role models, maintain professional motivation, and foster effective communication with students and parents. Similar to the findings of Barradas et al. (2023), this study highlights that continuous professional development and supportive environments foster teachers' ability to integrate innovation and sustain motivation.

Regarding robotics, teachers noted that mBot activities enhanced problem-solving, coding, creativity, collaboration, and perseverance while fostering confidence in using technology in the classroom. These outcomes are consistent with earlier research demonstrating the role of robotics in strengthening STEM-related skills and 21st-century competencies (Eguchi, 2014; Kanmaz, 2023; Topsakal et al., 2022). Similarly, Dayan and Tsybulsky (2025) demonstrated that digitally mediated professional learning environments enhance teachers' collaboration, creativity, and technological innovation through self-directed and networked engagement. Nonetheless, teachers also reported limitations, including the

short duration of the training, the narrow focus on a single tool, and the lack of sensor variety, which challenges mirror findings from Erdoğan et al. (2020), where participants struggled with coding and hardware constraints. Similar contextual barriers were identified by Kurt and Anılan (2024) who emphasized that challenges related to curriculum intensity and lack of institutional support continue to hinder effective integration into science lessons.

Finally, teachers expressed strong intentions to integrate mBot into science lessons, particularly for teaching abstract concepts such as force and motion, electricity, and astronomical movements, fostering creativity and motivation. This aligns with evidence that robotics bridges theoretical concepts with real world applications, making science more meaningful and engaging (Bozkurt-Polat and Ulutaş, 2023). At the same time, teachers' recognition of programmatic limitations in addressing current technological developments suggests the need for curricula that more systematically integrate robotics and 21st-century skills (Agaoglu and Demir, 2020; Gut, 2010).

In conclusion, this study demonstrates the potential of robotic mBot training to enhance science teachers' 21st-century competencies, particularly in problem-solving, technological literacy, and creativity. However, its limited effect on LCS and structural challenges in training design indicate the necessity of extended, diversified, and curriculum integrated robotics programs. Such initiatives could enable teachers to model and cultivate 21st-century skills in their classrooms, thereby enriching both teaching practices and student learning outcomes. Overall, the study highlights that robotics integrated professional development not only enhances teachers' 21st-century skills but also promotes efficiency and responsibility in science education by fostering reflective, technology-enhanced, and ethically grounded teaching practices.

RECOMMENDATIONS

In the short term, teacher competencies can be strengthened by broadening mBot training to include diverse robotic tools and by offering regular in-service programs focused on problem-solving, critical thinking, collaboration, and digital literacy. Infrastructure investments ensuring classroom access to technology and systematic feedback collection will further enhance teachers' confidence and guide responsive improvements.

In the medium term, sustainability requires aligning science curricula with technological developments by embedding hands-on activities, problem-solving, and digital integration. Institutionalized feedback and sharing effective practices will keep programs current, enabling successful strategies to be scaled across schools.

In the long-term, building an innovative school culture depends on fostering creativity and collaboration through interdisciplinary STEM projects. Teachers and students should co-design problem-based projects that model 21st-century

skills. Scaling success stories within professional learning communities will institutionalize innovation and adaptability across schools.

LIMITATIONS OF THE STUDY

While this study offers valuable insights into the impact of mBot training on science teachers' 21st-century competencies, several limitations should be noted. First, the sample consisted of a delimited group of in-service science teachers who voluntarily participated in the training program. As such, the findings may not be fully generalized to all science teachers or to other subject areas. Second, the mBot training lasted for a relatively short period, which may have constrained participants' opportunities to develop deeper and more sustained changes in their professional competencies, particularly in areas related to LCS. Third, although both quantitative and qualitative data were collected to enhance the validity of the findings, the self-reported nature of the data may create bias regarding social desirability or accuracy in self-assessment. Fourth, there was no follow-up phase to study the longer term impact of the training on science teachers' classroom practices.

STATEMENTS AND DECLARATIONS

This study was approved by the Ethics Committee of University Ondokuz Mayıs, Approval No: 2025-250, Date: 29.03.2024, and all procedures were carried out in accordance with institutional and international ethical standards. The authors declare that no financial support was received for the conduct or publication of this research. The study was conducted independently, without any external funding or sponsorship.

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APPENDIX

Interview Protocol

The following semi structured interview questions were designed to collect qualitative data on participants' demographic characteristics, professional background, and views regarding 21st-century skills and robotics (mBot) applications in science education.

Section I: Demographic Information

Gender: Female Male

Age:

Years of Professional Experience:

Undergraduate GPA (on a 4.00 scale):

Level of Interest in Technology: Low Moderate High

Section II: Open-Ended Questions

How would you define 21st-century skills?

As a teacher, which 21st-century skills do you believe you possess for use in classroom instruction?

To what extent do you think the competencies emphasized in the Science curriculum support 21st-century skills?

For a science teacher, what is the importance of possessing 21st-century skills? Please explain with examples.

What pathways would you recommend for science teachers to acquire or further develop 21st-century skills?

What are your views on robotics applications (in particular, mBot)?

How would you evaluate the training you received on mBot applications in the context of 21st-century skills?

Did the training you received on mBot applications lead to improvements in your 21st-century skills? If yes, which skills improved?

Do you plan to use the knowledge gained from the mBot training in your own classes? If yes, how do you intend to integrate what you learned into your lessons?