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# Investigation of Postgraduate Theses on the Effects of STEM/STEAM and Robotic Coding Applications on 21st-Century Learning and Innovation Skills

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**ABSTRACT**

The aim of this study is to analyse the postgraduate theses that investigated the relationship between STEM/STEAM (STEM+Art) and robotic coding practices and 21st-century learning and innovation skills. For this purpose, the postgraduate theses in the YÖK National Thesis Centre database were classified according to criteria such as thesis type, year, university, institute, research topic, 21st-century learning and innovation skill types, sample type and size, sampling method, research approach, data analysis and findings, and examined within a thematic framework. Out of 237 theses in the sample, 112 (83 master's and 29 doctoral) were identified as suitable for the purpose of the research. They were investigated through systematic analysis, and the data were analysed with descriptive analysis. According to the findings, the studies were most frequently completed in 2019 and 2023, with the majority of the topics focusing on STEM, and problem-solving skills being the most researched. The participants were predominantly secondary school students, and the most commonly used sampling method was convenience sampling. Additionally, the sample size was found to be between 31-100. The study also found that the mixed research design was most preferred methodologically, the effect of STEM/STEAM and robotic coding applications was mostly in the area of problem-solving and creativity, and it also provided positive contributions in terms of cooperation, communication, critical thinking and innovation skills to the learning process. Based on the results obtained from the analysis of the graduate theses , several proposals for new research to be carried out in the future were presented.

# STEM/STEAM ve Robotik Kodlama Uygulamalarının 21. Yüzyıl Öğrenme ve Yenilenme Becerilerine Etkisini İçeren Lisansüstü Tezlerin İncelenmesi

**Makale Bilgisi**

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**ÖZET**

Gerçekleştirilen çalışmada STEM/STEAM (STEM+Art) ve robotik kodlama uygulamalarının 21. Yüzyıl öğrenme ve yenilenme becerileri ile ilişkisini inceleyen lisansüstü tezleri analiz etmek amaçlanmıştır. Bu amaçla, YÖK Ulusal Tez Merkezi veri tabanında yer alan lisansüstü tezler; tez türü, yılı, üniversite, enstitü, araştırma alanı, 21.yüzyıl öğrenme ve yenilenme beceri türü, örneklem türü ve sayısı, örneklem seçimi, araştırma yaklaşımı, veri analizi ve bulgular gibi kriterler temelinde sınıflandırılarak tematik bir çerçevede incelenmiştir. Örneklem kapsamında 237 tez çalışmasından araştırmanın amacına uygun olan 83 yüksek lisans ve 29 doktora olmak üzere toplam 112 tez çalışması sistematik analizle incelenmiş ve veriler betimsel analizle çözümlenmiştir. Bulgulara göre, çalışmaların en fazla 2019 ve 2023 yılında tamamlandığı, konuların en yoğun olarak STEM alanında ele alındığı ve problem çözme becerisinin araştırıldığı, katılımcıların çoğunlukla ortaokul öğrencilerinden oluştuğu, örneklem seçiminde en çok uygun örnekleme metodunun kullanıldığı ve örneklem büyüklüğünün 31-100 arasında olduğu belirlenmiştir. Çalışmada ayrıca yöntemsel olarak çoğunlukla karma araştırma deseninin tercih edildiği, STEM/STEAM ve robotik kodlama uygulamalarının etkisinin en fazla problem çözme ve yaratıcılık alanında olduğu, bununla birlikte öğrenme sürecine yönelik iş birliği, iletişim, eleştirel düşünme ve yenilikçilik becerileri açısından da olumlu katkılar sağladığı belirlenmiştir. Tez çalışmaların analizi kapsamında ulaşılan sonuçlara göre gelecekte yapılması planlanan yeni araştırmalara yönelik çeşitli öneriler sunulmuştur.

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## INTRODUCTION

The 21st-century is recognized as an era of rapidly evolving digital technologies, including smart devices, the Internet, cloud computing, social media, artificial intelligence applications, the Internet of Things, and similar advancements. In this dynamic environment, individuals are expected to possess highly developed skills such as information access, problem-solving, and critical thinking. Therefore, it is crucial for education systems to adopt innovative methods and approaches that align with contemporary needs. Among these innovative approaches, STEM (Science, Technology, Engineering, and Mathematics) and STEAM (STEM integrated with the arts), along with robotics and coding education, stand out as essential practices. These approaches contribute to the development of key 21st-century skills such as analytical thinking, creativity, collaboration, communication, and digital literacy. In fact, technological advancements have led to the widespread use of digital technologies across various fields, accelerating their integration into educational processes (Imaniah, 2023; Özdamar & Aydın, 2022; Qashou, 2021; Talan, 2022; Valverde-Berrocoso et al., 2020). As part of the innovations brought about by digital transformation, many technological tools and resources have become integral to learning activities. However, digital transformation in education is not merely about incorporating digital tools into the process; it is a transformative approach aimed at equipping both learners and educators with national and international competencies, preparing them to be future-ready individuals (Bozkurt et al., 2021). In this regard, learning environments and curricula have been restructured to meet contemporary demands, integrating innovative practices into educational programs. One such educational approach is STEM education, which encompasses interdisciplinary teaching practices from preschool to higher education, fostering the acquisition of 21st-century skills (Fındık et al., 2023). STEM education is recognized for enhancing various competencies, including academic success, problem-solving, creativity, and communication (İdin & Dönmez, 2020). Particularly, robotic coding applications within the STEM framework support the development of creative and systematic thinking, help students understand relationships between events (Güleryüz et al., 2020), and facilitate the acquisition of essential 21st-century skills such as problem-solving, critical thinking, creativity, and collaboration (Arafat et al., 2024). To support these objectives, the Partnership for 21st Century Skills (P21) advocates for educational support systems that involve all stakeholders. These systems include 21st-century standards, assessments, curriculum design, teacher professional development, and learning environments, all aimed at fostering and ensuring the development of essential 21st-century skills in students (Aksoy & Taşkın, 2019; Zhou, 2023).

### 21st Century Skills

Information and communication technologies continue to develop rapidly in recent years. Especially the widespread use of mass media together with the internet has facilitated data sharing and access. Rapid developments in information and communication technologies require the formation of a social structure that can adapt to this progress at a parallel speed (Aktan & Vural, 2016). In line with this necessity, various skills such as creativity, problem-solving, critical thinking, cooperation, communication, learning to learn, entrepreneurship should be effectively taught and learned in order to adapt and contribute to the development process (Önal & Erişen, 2019). These skills are considered within the framework of 21st-century skills (Thornhill-Miller et al., 2023).

Although 21st-century skills do not have a fixed and unchanging definition in the conceptual framework, it refers to the competencies that individuals should have in this century (Coşkun, 2022; Sayın & Seferlioğlu, 2016). In Turkey, Ministry of National Education-MoNE (2023) published the 'Research Report on 21st Century Skills and Values', which contains a systematic analysis and results of national and international research conducted within the framework of 21st-century skills. The report states that 21st-century skills, which are addressed in different frameworks and overlap in many models,

are generally defined as the competencies students need to be successful in their personal, academic and professional lives and include skills such as access to information, critical thinking, problem-solving, effective communication and collaboration. However, in the same report, MoNE (2023) categorised the basic 21st-century skills that students should have under seven main headings: social and emotional skills, language and communication skills, higher-order thinking skills, personal skills, learning skills, study skills and digital skills. This classification suggests that 21st-century skills are addressed in a broad framework. On the other hand, many institutions and organisations at the international level address 21st-century skills with different definitions and classifications (Kuru, 2021). The Partnership for 21st Century Learning (P21) project, which is one of these organisations, provides a comprehensive framework that is well known to the global public and accepted as valid by the authorities (Kılıç, 2022a). For this purpose, a framework for the implementation of 21st-century skills in curriculum and instruction has been developed within the scope of a strategic education project 'Partnership for 21st Century Learning (P21)' implemented in 21 states in the United States and supported by 33 institutions (Gelen, 2017). This framework is organised to ensure that students are ready to work in a more competitive global economy in the 21st- century (Bozkurt, 2021). The education project also offers a broad approach to learning, including areas such as digital literacy, media and technology literacy.

The P21 framework consists of three main components. These are learning and regeneration skills, life and career skills, information, media and technology skills (P21, 2019). Learning and innovation skills, which include creativity, innovation, critical thinking, problem-solving, communication and collaboration skills, are considered to be among the most important skills that individuals should have in academic and daily life (Orak & İnözü, 2021). In the 21st-century, it is emphasized the development of creativity and innovation skills has become increasingly important for success in both academic and business environments (Adeoye & Jimoh, 2023; Akarsu, 2024) and that learning that supports problem-solving skills is effective in the development of creativity skills (Güven & Kavuncuoğlu, 2020; Kashani-Vahid et al., 2017). Life and career skills, which include competencies such as flexibility and adaptability, entrepreneurship and self-direction, leadership and responsibility, social and intercultural skills, productivity and accountability, are also recognised as necessary skills to equip individuals in the 21st-century to anticipate and solve complex problems in living and working environments (Zuwanda et al., 2021). Information, media and technology skills are generally referred to as digital competence, ICT literacy, digital literacy or skills and competences related to the use of digital technologies (Hazar et al., 2021). It is stated that these skills are necessary for personal development and success as well as for social progress as a whole (Zhou, 2023) and that they are necessary for the individual to keep up with the age and to be productive and effective (Özer & Tekin Bozkurt, 2024). The P21 framework has been accepted by the education systems of many countries around the world and has been put into practice through various projects (Gelen, 2017). The P21 framework overlaps with the 21st-century skills in the "21st Century Skills and Values Research Report" published by the MoNE (2023). STEM/STEAM activities, which is a learning approach used to develop these skills in learning environments (Fajrina et al., 2020). STEM and STEAM practices include practices that are put forward to develop various skills such as creativity, critical thinking, collaboration, and communication.

**STEM and STEAM Education**

STEM is an abbreviation formed by combining the initials of the English words science, technology, engineering and mathematics. While it was previously referred to as SMET, it was reorganised as STEM in 2001 by the National Science Foundation of the United States of America and aimed to develop students' interests and competencies by integrating these disciplines into education (Britannica, 2024). STEAM emerged with the inclusion of artistic activities in STEM practices

(Aguilera & Ortiz-Revilla, 2021; Costantino, 2018; Kahya & Özdilek, 2021). It is aimed to develop students' 21st-century skills with the activities carried out by combining STEM and art (Watson, 2020). In addition, STEAM education, which supports STEM education in fields such as art (STEAM), design and humanities, is expressed as an approach that can be used to model learners' innovation, creativity, critical thinking, effective communication and collaboration within the scope of 21st-century skills (Quigley & Herro, 2016). However, STEAM education, which is considered a popular interdisciplinary pedagogical approach to develop students' creativity, problem-solving skills and interest in STEM (Perignat & Katz-Buonincontro, 2019), is being addressed in many countries to develop subjects such as entrepreneurship, critical thinking, interdisciplinary integration and creativity (Chang et al., 2024). In addition, STEM education is also a very effective process in this context, and the interdisciplinary approach to teaching and learning that it offers increases the adaptability to this concept over time (Tytler, 2020). It is stated that this approach improves individuals' personal information literacy, increases competitiveness in the global economy, and forms the basis for conscious and responsible citizenship, including the ethical protection of our world (Maass et al., 2019). In addition, STEM activities help children develop problem-solving skills and scientific thinking processes by awakening their natural curiosity and desire to explore (Erol & İvrendi, 2021; Tippett & Milford, 2017). In particular, STEM-based robotic coding applications can contribute to creative thinking skills by enabling children to apply these skills in concrete projects.

**Robotic Coding**

In the 21st-century, coding, which is accepted as a new literacy, is the process of creating the commands needed for computer programs to work (Sayın & Seferoğlu, 2016). Robotic coding is a type of coding expressed by the combination of mechanical objects and coding (Karataş, 2021). Robotic coding, which gives mobility to objects, is a field of technology used to increase efficiency and productivity in various sectors. Some systems developed in this field offer user-friendly, easy-to-understand interfaces and tools to facilitate the programming of robots. These systems allow robots to be programmed without dealing with complex code-writing processes. Block-based programmes are generally used for robot programming without writing code. With this system, the desired result can be achieved by dragging and dropping predefined code blocks together. With these methods used in robotic coding education, students can actively participate in the process and experience creating a product these applications, especially in the robotic coding process in the primary and secondary school education curriculum, can facilitate the development of students' cooperation, communication and leadership skills (Gratani & Giannandrea, 2022). On the other hand, it is concluded that robotic coding practices support the development of creativity, critical thinking, problem-solving, communication and computational thinking skills, which are among the 21st-century learning and innovation skills (Erdoğan et al., 2020; Kılıç, 2022b).

**Purpose and Problem of the Research**

There are studies in the literature that STEM/STEAM education and robotic coding applications have an impact on the acquisition of 21st-century skills (Eguchi, 2016; Graffin et al., 2022; Güleryüz, 2020; Krüger & Chiappe, 2021; Metin et al., 2023). For example, a meta-analysis study conducted by Saltan and Korkmaz (2024) found that educational robot kits had positive effects on students' problem-solving, academic achievement, and scientific process skills. Similarly, Nazifah and Asrizal (2022) emphasised in their study that STEM-integrated physics e-modules prepared for the development of students' 21st-century skills are used in the learning process. Based on the findings of the studies, it can be stated that STEM/STEAM and robotics coding applications contribute to the development of 21st-century skills. However, it is felt that a comprehensive review of postgraduate dissertations on how these practices work in different contexts and what variables make them more effective will contribute to the

field. To this end, a systematic review of the type, year, university, institute, research topic, 21st-century learning and innovation skill types, sample type and size, sampling method, research approach, data analysis and findings of postgraduate these studies and how they are shaped within the data analysis and findings and what kind of academic tendency they show in this context was undertaken. The main research question of the study is expressed as follows:

What variables are prominent in postgraduate thesis studies examining the effects of STEM/STEAM and robotics coding practices on 21st-century learning and innovation skills such as creativity, innovation, critical thinking, problem-solving, collaboration and communication, and how are these variables distributed? In this context, the following research questions were investigated.

1. What is the distribution of graduate theses on STEM/STEAM and robotic coding applications in terms of type of thesis (master's/doctoral), year, university and institute?

2. What is the distribution of theses on STEM/STEAM and robotic coding applications?

3. What is the distribution of theses incorporating STEM/STEAM and robotic coding applications in relation to 21st-century learning and innovation skills?

4. What is the distribution of the sample types and sample sizes in the theses?

5. What are the sampling methods and research approaches used in the theses?

6. What are the data analysis methods used in the theses?

7. What are the findings of the theses including STEM/STEAM and robotic coding applications on the impact of 21st-century learning and innovation skills?

## METHOD

### Research Model

In this study, the document review method was used to determine the analysis of doctoral and master's theses that examine the effects of robotic coding, STEM and STEAM applications on 21st-century learning and innovation skills. Document review is a research method that is carried out to obtain data by analysing written documents containing information about the facts and events related to the subject of the research (Yıldırım & Şimşek, 2008).

### Population and Sampling

In this study, master's and doctoral theses that were conducted between 2017 and 2024 and found in the YÖK National Thesis Centre database were investigated. As the Ministry of National Education published a framework roadmap for STEM education in 2016 (MoNE, 2016), postgraduate theses conducted since 2017 were included in the study. The search using the keywords "STEM", "STEAM", "FETEMM" and "21st-century skills" retrieved 237 studies and 112 theses (83 master's, 29 doctoral) that met the research criteria formed the sample of the study. "The Impact of STEM/STEAM and Robotics Coding Applications on 21st Century Learning and Innovation Skills" were taken into consideration as criteria in the sample selection of the study and the process progressed according to these criteria.

### Data Collection Process

In this study, a publication classification form containing the relevant themes was used as a data collection tool, using the relevant literature. In developing the publication classification form, the 'Educational Technologies Publication Classification Form' developed by Göktaş et al. (2012) was

revised and used by the researchers according to the scope and objectives of the research.

In the data collection process of the study, searches were conducted using keywords in order to access thesis studies suitable for the research topic from the master's and doctoral theses in the YÖK Thesis Center database. After searching with the keywords "STEM and 21st-century skills", "STEM and creativity", "STEM and innovation", "STEM and collaboration", "STEM and critical thinking", and "STEM and problem solving" in the advanced search section of the YÖK Thesis Center database, the terms "STEAM", "FeTeMM" and "Robotic Coding" were written instead of "STEM" and the master's and doctoral theses were reached. During the data collection process, it was taken into account that the studies accessed as a result of the scan included one of the STEM, STEAM, FeTeMM, robotic coding practices and their impact on 21st-century learning and innovation skills, or one of the sub-dimensions of learning and innovation skills (creativity, innovation, critical thinking, problem-solving, collaboration, communication). The sampling process is shown in Figure 1.

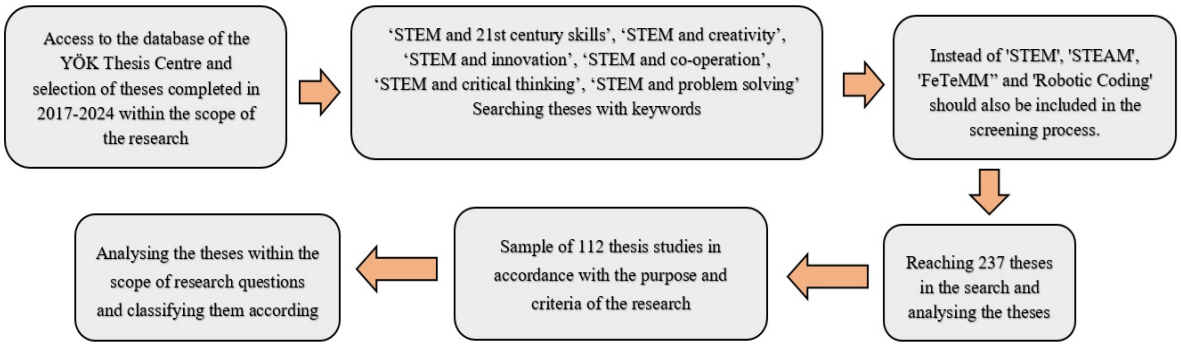


**Figure 1.** Sampling and data collection process

### Analysing the Data

The data of the study were analysed by descriptive analysis method. The aim of descriptive analysis is to reach concepts and relationships that can explain the collected data. Within the scope of descriptive analysis, a framework is created for the analysis, and the data are processed according to the thematic framework, which further illuminates the findings and their interpretations (Yıldırım & Şimşek, 2008). In the study process, master's and doctoral theses were examined one by one and discussed within the scope of publication year, thesis type, university and institute, research topic, 21st-century learning and innovation skill types, sample type and size, sampling method, research approach, data analysis and findings. An example of a thesis analysis is shown in Table 1.

**Table 1**
*Analysis of a sample thesis*

| Thesis No | Year | University Name | Thesis Types | Institute | STEM/STEAM/ Robotic Coding Research Topic | Subject Area of 21st Century Learning and Innovation Skills | Sample Type | Sample Size | Sampling Method | Research Approach | Analysis Methods | The Effect of STEM, STEAM and Robotic Coding Applications on 21st Century Skills |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2019 | Ondokuz Mayıs University | PhD | Institute of Educational Sciences | STEM | Creativity, Innovation, Critical Thinking, Problem Solving, Collaboration, Communication | Primary School | 34 | Convenience Sampling<br>Maximum Variation Sampling | Mixed Method | Quantitative Analysis: ANOVA and t-testi<br>Qualitative Analysis: Descriptive Analysis, Content Analysis | **Positive Effect**<br>Creativity, Innovation, Critical Thinking, Problem Solving, Collaboration, Communication |

The data obtained from the studies were coded and grouped under the themes in the classification form. In order to ensure the consistency of the coding process in the study, a coding study was carried out for the theses analysed with the participation of two researchers. The codes were compared with each other for internal consistency. The reliability formula proposed by Miles and Huberman (1994) was used for comparison. If the result of the reliability formula is above 70%, the study is considered to be reliable. As a result of the coding study, it was seen that the researchers presented consistent codings and the agreement between the codings was 94%. For the codings for which there was no consensus, the researchers came together again and discussed the codings until they reach a consensus.The findings obtained from the study are presented in tables and explanations with frequency values.

## FINDINGS

In this section, the findings obtained as a result of the study are presented. As a result of the research, the information obtained within the framework of the type of postgraduate theses, year of publication, universities and institutes, distribution according to research topic, distribution according to learning and innovation skill types, sample type, sample size, sampling method, research approach, data analysis and findings are presented in tables.

**Table 2**

*Distribution of Thesis Studies by University, Year of Publication, and Thesis Type*

| University | Year | | | | | | | | Total | Thesis Type |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | | |
| Afyon Kocatepe University | | | 1 | | | | 1 | | 2 | MSc |
| Akdeniz University | | | | | | 1 | | | 1 | MSc |
| Alanya Alaaddin Keykubat University | | | 1 | | | 1 | | | 2 | MSc |
| Amasya University | | | 1 | | | | 1 | | 2 | MSc |
| Atatürk University | | | 1 | 2 | | | | | 3 | 1 MSc/2 PhD |
| Aydın Adnan Menderes University | | 1 | 2 | | | | | | 3 | 2 MSc/1 PhD |
| Bahçeşehir University | | | 2 | | | | 1 | | 3 | MSc |
| Bayburt University | | | 1 | | | | | | 1 | MSc |
| Bolu Abant İzzet Baysal University | | | 1 | | | | | | 1 | MSc |
| Çanakkale Onsekiz Mart University | | | | | | | 1 | | 1 | MSc |
| Çukurova University | | | | 1 | | 1 | | | 2 | PhD |
| Dokuz Eylül University | | | | | | | 1 | 1 | 1 | 1 MSc/1 PhD |
| Düzce University | | | | | | 2 | | | 2 | MSc |
| Ege University | | | | | | 1 | | | 1 | MSc |
| Erciyes University | | | | 1 | 2 | | 1 | | 4 | 2 MSc/2 PhD |
| Erzincan Binali Yıldırım University | | 3 | | 1 | | 1 | | | 5 | MSc |
| Eskişehir Anadolu University | | | | | | 1 | | | 1 | MSc |
| Eskişehir Osmangazi University | | | | | | | | | 1 | MSc |
| Fırat University | | 1 | 2 | | 1 | | 3 | | 7 | 6 MSc/1 PhD |
| Gazi University | 1 | 2 | 1 | 1 | 1 | | 2 | 1 | 9 | 3 MSc/6 PhD |
| Giresun University | | | | | | | 2 | | 2 | MSc |
| Hacettepe University | | | | | 1 | | 1 | | 2 | PhD |
| Hatay Mustafa Kemal | | 1 | 1 | 1 | | | | | 3 | MSc |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| University | | | | | | | | | | |
| İnönü University | | | | | | 1 | | | 1 | MSc |
| İstanbul Aydın University | 1 | | | 1 | | | | | 2 | MSc |
| İstanbul University | | 1 | 1 | | | | | | 2 | 1 MSc/1 PhD |
| Kafkas University | | | | | | | 1 | | 1 | MSc |
| Kahramanmaraş Sütçü İmam University | | | | | | | 1 | | 1 | MSc |
| Karamanoğlu Mehmetbey University | | | | | | 2 | | | 2 | MSc |
| Kastamonu University | | | | | 1 | | | | 1 | MSc |
| Kırıkkale University | | 1 | | | | 1 | | | 2 | MSc |
| Kırşehir Ahi Evran University | | | 1 | | 1 | | | | 2 | MSc |
| Kütahya Dumlupınar University | | | 1 | | | | | | 1 | MSc |
| Marmara University | 1 | 1 | 2 | | | | 1 | | 5 | MSc |
| Mersin University | | | | 1 | | 1 | | | 2 | 1 MSc/1 PhD |
| Muğla Sıtkı Koçman University | | | | | | | 2 | | 2 | MSc |
| Muş Alparslan University | | 1 | | | | | | | 1 | MSc |
| Necmettin Erbakan University | | | 2 | | | | 1 | | 3 | 2 MSc/1 PhD |
| Nevşehir Hacı Bektaş Veli University | | | | | | | 1 | | 1 | PhD |
| Niğde Ömer Halisdemir University | | | | | 1 | | | | 1 | MSc |
| Ondokuz Mayıs University | | 1 | 1 | | 1 | | | | 3 | PhD |
| Ordu University | | | | | | | 1 | | 1 | PhD |
| Pamukkale University | | | | 1 | | | | | 1 | PhD |
| Recep Tayyip Erdoğan University | | 1 | | 1 | | | | | 2 | MSc |
| Sakarya University | | | | | | | 1 | | 1 | PhD |
| Siirt University | | | | | | | 1 | | 1 | MSc |
| Sivas Cumhuriyet University | | | | | | | 1 | | 1 | MSc |
| Süleyman Demirel University | | | | | | | | 1 | 1 | MSc |
| Tokat Gaziosmanpaşa University | | | 1 | | | | | | 1 | MSc |
| Trabzon University | | | | | 1 | | | | 1 | PhD |
| Trakya University | | | | | 2 | | | | 2 | MSc |
| Uşak University | | 1 | | | | | | | 1 | MSc |
| Van Yüzüncüyıl University | | | | | 1 | | | | 1 | MSc |
| Yıldız Teknik University | | | 2 | | 1 | 1 | | | 4 | 3 MSc/1 PhD |
| Zonguldak Bülent Ecevit University | | | 1 | | | | 1 | | 2 | MSc |
| Toplam | 3 | 15 | 26 | 11 | 14 | 14 | 26 | 3 | 112 | 83 MSc<br>29 PhD |

**MSc:** Master's Degree **PhD:** Doctorate

Table 2 shows the distribution of master's (f=83, 74.11%) and doctoral (f=29, 24.89%) thesis studies conducted in 55 universities between 2017-2024. Gazi University (f=9, 8.04%) is the university with the highest number of thesis studies, followed by Fırat University (f=7, 6.25%), Erzincan Binali Yıldırım University and Marmara University (f=5, 4.46%), and then Erciyes University and Yıldız

Technical University (f=4, 3.57%). When the distribution by years is analysed, the most studies were conducted in 2019 and 2023 (f=26, 23.21%), followed by 2018 (f=15, 13.40%) and 2021 and 2022 (f=14, 12.50%).

**Table 3**
*Distribution of Thesis Studies by Institute and Thesis Type*

| Institutes | Thesis Type | | Total |
|---|---|---|---|
| | Master's Degree | Doctorate | |
| Institute of Educational Sciences | 44 | 23 | 67 |
| Institute of Natural and Applied Sciences | 27 | 3 | 30 |
| Institute of Social Sciences | 12 | 3 | 15 |
| Total | 83 | 29 | 112 |

When the distribution of thesis studies in Table 3 according to the institutes, the institutes where the most studies were conducted are Institutes of Educational Sciences (f=67, 59.82%), followed by Institutes of Natural and Applied Sciences (f=30, 26.79%) and Institutes of Social Sciences (f=15, 13.39%). 44 master's (f=44, 53.01%), 23 doctorate (f=23, 79.31%) thesis studies were conducted in Institutes of Educational Sciences, 27 master's (f=27, 32.53%), 3 doctorate (f=3, 10.34%) thesis studies were conducted in Institutes of Natural and Applied Sciences and 12 master's (f=12, 14.46%), 3 doctorate (f=3, 10.34%) thesis studies were conducted in Institutes of Social Sciences.

**Table 4**
*Distribution of Thesis Studies by Subject Area*

| Theme | f | Master's Degree | Doctorate |
|---|---|---|---|
| STEM | 90 | 67 | 23 |
| STEAM | 4 | 2 | 2 |
| Robotic Coding | 18 | 14 | 4 |
| Total | 112 | 83 | 29 |

When the distribution of studies according to their subject area is examined in Table 4, it is seen that the most studied theme is STEM (F=90, 80.36%), followed by robotic coding (f=18, 16.07%) and STEAM (f=4, 3.57%).

**Table 5**
*Distribution of Thesis Studies by Subject Area of 21st-Century Learning and Innovation Skills*

| 21st-Century Skills | STEM | STEAM | Robotic Coding | Total |
|---|---|---|---|---|
| Creativity | 58 | 4 | 9 | 71 |
| Innovation | 21 | 1 | 6 | 28 |
| Critical Thinking | 45 | 2 | 7 | 54 |
| Problem Solving | 62 | 3 | 15 | 80 |
| Collaboration | 32 | 1 | 8 | 41 |
| Communication | 30 | 1 | 6 | 37 |
| Total | 248 | 12 | 51 | 311 |

Table 5 shows the distribution of 21st-century learning and innovation skills in the studies according to subject area. Accordingly, problem-solving skill (f=80, 71.43%) is the most commonly

used skill, followed by creativity skill (f=71, 63.39%) and critical thinking skill (f=54, 48.21%). When the studies are examined within their themes, problem-solving skill emerging in 80 theses is mostly handled with STEM applications (f=62, 77.50%), followed by robotic coding (f=15, 18.75%) and STEAM (f=3, 3.7.35%). Creativity skill, which was included in a total of 71 studies, was also studied mostly with STEM (f=58, 81.69%), and was included with robotic coding (f=9, 12.68%) and STEAM (f=4, 5.63%), respectively. Critical thinking skill was also addressed in a total of 54 studies and studied mostly with STEM (f=45, 83.33%), followed by robotic coding (f=7, 12.96%) and finally with STEAM (f=2, 3.70%).

**Table 6**
*Distribution of Thesis Studies by Sample Type and Sample Size*

| Sample Type | f | Sample Size | f |
|---|---|---|---|
| Preschool | 15 | 1-10 | 6 |
| Primary School | 21 | 11-30 | 28 |
| Middle School | 45 | 31-100 | 65 |
| High School | 2 | 101-300 | 7 |
| Undergraduate | 22 | 301-1000 | 5 |
| Teacher | 7 | 1001 and above | 1 |
| Total | 112 | Total | 112 |

Table 6 shows the distribution of sample levels and sample sizes in thesis studies. The sample level was mostly taken from secondary school students (f=45, 41.16%), followed by sample groups consisting of undergraduate students (f=22, 19.64%). When the sample sizes are examined, it is seen that 31-100 (f=65, 58.04%) is preferred the most.

**Table 7**
*Distribution of Thesis Studies by Sampling Method and Research Approach*

| Sampling Method | f | Research Approach | f |
|---|---|---|---|
| Criterion sampling | 20 | Mixed | 61 |
| Maximum variation sampling | 10 | Quantitative | 37 |
| Homogeneous sampling | 8 | Qualitative | 14 |
| Typical case sampling | 1 | | |
| Convenience sampling | 73 | | |
| Simple random sampling | 8 | | |
| Total | 124 | Total | 112 |

Table 7 shows the sampling method and research approach used in the studies. Convenience sampling stood out as the most preferred one (f=73, 65.18%). In addition, since some studies included more than one sample type due to their structure, it is seen that the total value (f=124) is more than the total of the research (f=112). When the research method is examined, it is seen that the most mixed research is (f=61, 54.46%).

**Table 8**
*Distribution of Thesis Studies by Data Analysis Methods*

| Quantitative Data Analysis | f | Qualitative Data Analysis | f |
|---|---|---|---|
| t-test | 66 | Content analysis | 60 |
| ANOVA/ANCOVA | 33 | Descriptive analysis | 40 |
| MANOVA/MANCOVA | 5 | | |
| Correlation | 8 | | |

| | | | |
|---|---|---|---|
| Regression | 2 | | |
| Mann Whitney U | 27 | | |
| Kruskal Wallis | 6 | | |
| Confirmatory Factor Analysis (CFA) | 2 | | |
| Total | 149 | Total | 100 |

In Table 8 the distribution of the data obtained in the studies according to their analysis is presented. The results revealed that in the analysis of quantitative data, the t-test was used the most (f=66, 58.93%) whereas the qualitative data was mostly analysed through the content analysis (f=60, 53.57%).

**Table 9**

*Distribution of STEM, STEAM, and Robotic Coding Applications in Thesis Studies by Their Effects on 21st-Century Skills*

| 21st-Century Skills | STEM | | STEAM | | Robotic Coding | |
|---|---|---|---|---|---|---|
| | Effective | No effect | Effective | No effect | Effective | No effect |
| Creativity | 57 | 1 | 4 | - | 9 | 1 |
| Innovation | 20 | 1 | 1 | - | 6 | - |
| Critical Thinking | 44 | 1 | 2 | - | 7 | - |
| Problem Solving | 58 | 4 | 3 | - | 15 | - |
| Collaboration | 31 | 1 | 1 | - | 8 | - |
| Communication | 29 | 1 | 1 | - | 6 | - |

In Table 9, STEM, STEAM and robotic coding applications are generally effective in the development of 21st-century learning and innovation skills. According to the findings of the theses studies, STEM/STEAM and robotics coding training are particularly effective in developing creativity and problem-solving skills. In addition, many theses found that these courses contributed positively to the development of critical thinking, innovation, collaboration and communication skills. On the other hand, in addition to the finding that STEM education has no significant effect on problem- solving skills, there are also findings that it has no significant effect on creativity, innovation, critical thinking, cooperation and communication skills. Another study found that training in robotics programming had no significant effect on creativity skills.

## DISCUSSION

In this study, 21st-century skills and their components, including learning and innovation skills along with STEM, STEAM and robotic coding concepts are discussed. By reviewing the literature on these concepts, definitions in line with the data obtained from many academic studies and various findings obtained in the studies were mentioned. For the purpose of this study, the studies on the effect of STEM, STEAM and robotic coding applications on 21st-century learning and innovation skills were analysed from the master's and doctoral theses conducted in Turkey between 2017 and 2024 in the YÖK National Thesis Centre database. According to the data obtained, there are 112 thesis studies in 55 universities, 83 of which are master's theses and 29 of which are doctoral theses. The findings that the studies were mainly conducted at the master's level overlap with the results of the meta-analysis study conducted by Kazu and Kaplan (2024) and Çavaş et al. (2020), which examined the impact of STEM education. An analysis of the distribution of postgraduate theses by year reveals that the highest number of studies was conducted in 2019 and 2023, with 26 theses in each year. In particular, the increase in the number of studies on STEM applications after 2018 is noteworthy. This finding aligns with the fact that STEM education has been included in the curricula in Turkey since 2018 (Uluyol & Pehlivan, 2019). Çavaş et al. (2020) also stated that there were no postgraduate theses on STEM in Turkey before 2014

and that this issue was addressed in the following years. Similarly, in the study conducted by Ecevit et al. (2022), which analysed research on STEM education in Turkey, it was found that the research was mostly concentrated in 2019.

The distribution of studies by university shows that Gazi University had the highest number of 9 studies, followed by Fırat University with 7 studies and then Erzincan Binali Yıldırım University and Marmara University, each with 5 studies, and Erciyes University and Yıldız Technical University, each with 4 studies. Kaya and Ok (2020), in their research on the graduate thesis studies carried out in the field of STEM education in Turkey, found that most of the dissertations in the field of STEM were carried out at Gazi University, and Erzincan Binali Yıldırım University was one of the higher education institutions with the highest number of dissertations in the field of STEM. This can be interpreted as an indication that the study has consistent findings with similar studies. When the distribution of thesis studies according to the institutes in which they were carried out was analyzed, it was found that the most studies were carried out in the Institutes of Educational Sciences with 67 studies, then in the Institutes of Natural and Applied Sciences with 30 studies and in the Institutes of Social Sciences with 15 studies, respectively. These studies are distributed as 44 master's and 23 doctoral theses in the Institutes of Educational Sciences, 27 master's and 3 doctoral theses in the Institutes of Natural and Applied Sciences, and 12 master's and 3 doctoral theses in the Institutes of Social Sciences. Similarly, in the content analysis study conducted by Çalışkan and Okuşuk (2021) on postgraduate theses conducted within the framework of STEM education, it was observed that most of the theses were conducted in the Institutes of Educational Sciences. The prevalence of studies conducted in the Institute of Educational Sciences can be attributed to the recognition of STEM as a contemporary and global educational approach. Looking at the distribution of theses studies on teaching activities, it can be seen that 90 studies mostly addressed the effect of STEM education on 21st-century skills. Ichsan et al. (2023) stated that STEM approach is especially important for 4C skills (Creativity, Colaboration, Critical Thinking and Communication) among 21st-century skills and emphasised the need for a STEM approach that will encourage these skills for Generation Z. This may be due to the fact that STEM education is a more general approach and educational policy that can be used at all levels of education (Akarsu et al., 2020; Arslan & Arastaman, 2021; Ay & Seferoğlu, 2021).

Among the STEM/STEAM and robotics coding applications, the effect of STEM activities on problem-solving, one of the 21st-century learning and innovation skills, was examined and a total of 62 studies were found to cover this area. Then, the relationship between STEM applications and creativity in 58 studies, critical thinking in 45 studies, collaboration in 32 studies, communication in 30 studies and innovation skills in 21 studies was investigated. Among the 51 studies addressing the theme of robotic coding, the impact on problem-solving skills was the most frequently explored, with 15 studies focusing on this aspect. Additionally, creativity was explored in 9 studies, collaboration in 8 studies, critical thinking in 7 studies, and communication and innovation skills in 6 studies. In studies focusing on the STEAM theme, creativity emerged as the most frequently addressed skill in four studies, followed by problem-solving in 3 studies, critical thinking in 2 studies, and innovation, collaboration, and communication skills in one study each. These findings highlight a predominant emphasis on problem-solving and creativity skills. Duran and Sarı (2021), in their research analyzing graduate thesis studies on STEM education in the 4th and 5th grades of primary education, found that problem-solving skills were the primary focus when examining the outcomes related to the acquisition of STEM education skills. Similarly, numerous national and international studies in the literature highlight the impact of STEM education on problem-solving skills (Acar et al., 2020; Astuti et al., 2021; Doğan et al., 2020; Shongwe, 2024).

In terms of sample types of the thesis studies in the study, it is observed that 45 studies included middle school students, 22 studies included undergraduate students, and 21 studies included primary

school students. Considering the findings obtained in similar studies conducted in Turkey in the literature, it is seen that secondary school level is generally preferred as the sample group (Çalışkan & Okuşuk, 2021; Çavaş et al., 2020; Daşdemir et al., 2018; Herdem & Ünal, 2018; Kazu & Kaplan, 2024). Regarding study group sizes, there are 65 thesis studies with a maximum size between 31-100. Similarly, Zağlı et al. (2022) found that the most common sample size used in their document analysis of character education theses was less than 100. The preference for a study group of less than 100 people may be due to concerns about keeping the sample under control (Özgür et al., 2018).

Within the scope of sample selection method, convenient/easily accessible sampling was preferred in 73 thesis studies, followed by criterion sampling in 20 studies, maximum variation sampling in 10 studies, affinity sampling and simple random sampling in 8 studies each, and typical case sampling in 1 study. The reason why convenient/easily accessible sampling type is mostly preferred in the studies may be due to the ease of access to the participants in the research and it's advantageous in terms of time (Evci & Yeşiltaş, 2023) and cost (Baltacı, 2018). When the distribution of the studies according to their methods was examined, the mixed method was preferred in 61 studies, followed by the quantitative method in 37 studies and the qualitative method in 14 studies. In a similar study conducted by Kaya and Ok (2020), the fact that the most preferred method was the mixed method is consistent with the results obtained. In the analysis of the data was evaluated, it was concluded that 60 content analyzes and 40 descriptive analyzes were used in qualitative research methods, while 66 t-tests and 33 ANOVA/ANCOVA tests were applied in quantitative research methods. It can be interpreted that content analysis is the most preferred method among qualitative research methods because it enables researchers to obtain in-depth information about a specific purpose or topic in their studies (Alanka, 2024). In addition, the preference for parametric tests such as t-test and ANOVA/ANCOVA in quantitative data is thought to be due to the normal distribution of study groups and the fact that these tests are effective and powerful statistical methods for assessing differences between group means.

When the thesis studies are analysed, according to the general findings on the effects of STEM, STEAM and robotic coding applications on 21st-century learning and innovation skills, it is concluded that STEM applications are effective in 58 studies in thesis studies where the effect of STEM applications on problem-solving skills is discussed, while there is no effect in 4 studies. In the literature, here are many studies demonstrating that STEM applications generally have a positive effect on students' problem-solving skills (Erden & Yalçın, 2021; Güven et al., 2021; Kartini et al., 2021; Muzana et al., 2021). However, some studies include findings STEM education has a low effect on problem-solving skills. For example; in the study conducted by Açışlı Çelik (2022), it was stated that STEM education integrated with the 5E learning model did not create a significant difference in students' problem-solving skills, but an increase was observed in general. In Asigigan and Samur (2021), the effect of gamified STEM applications on students' problem-solving skills was investigated and it was emphasized that there was no significant difference between the experimental and control groups. Upon reviewing theses on coding applications for robots, it was observed that all studies on problem-solving skills contributed to the development of these skills. Similarly, in the studies on STEAM activities, it was found that creativity skills were most often investigated and that STEAM activities contributed to 21st-century skills in all studies.

## CONCLUSION AND SUGGESTIONS

As a result, within the scope of the findings obtained from master's and doctoral theses studies, it can be stated that STEM, STEAM and robotic coding education contributes to the development of students' 21st-century skills and these practices are more prevalent in secondary school education levels. There are many national and international studies conducted in this area in the literature (Arafat et al.,

2024; Bircan & Çalışıcı, 2022; Hadinugrahaningsih et al., 2017; Haymana & Özalp, 2020; Nazifah & Asrizal, 2022; Zainil et al., 2023) and their findings overlap with the findings of this study. Therefore, although the instructional activities conducted in the context of STEM/STEAM and robotics coding contribute to creativity, innovation, critical thinking, problem-solving, cooperation and communication skills among the 21st-century learning and innovation skills, it can be interpreted that the positive effect on especially problem-solving and creativity skills is predominant. In addition, in line with the findings of this study, which was carried out to analyse postgraduate theses, including the impact of these practices on 21st-century learning and innovation skills, various suggestions can be made for further studies to be carried out.

1. Since this study was conducted at the national level, future studies can examine global studies on the effects of STEM/STEAM and robotic coding practices on 21st-century skills. Comparisons can be made by considering the differences in implementation between countries.
2. Studies on the effects of STEM/STEAM and robotic coding practices on 21st-century life and career skills and information, media and technology skills can be addressed.
3. By comparing different new-generation educational approaches (e.g. project-based learning, flipped learning, game-based learning), the effects of these approaches on 21st-century skills can be examined.
4. Studies can be conducted on the effects of STEM/STEAM and robotic coding practices on 21st-century skills according to demographic differences.
5. As theses research tends to focus on problem-solving and creativity skills, the impact of the practices on innovation, critical thinking, collaboration and communication skills can be explored.
6. As the majority of the sample groups favoured in the thesis studies were middle school students, this situation can be taken into account in future studies and research can be conducted for different age groups and social contexts.
7. The number of studies on STEAM and the relationship between this subject and different teaching areas and skills can be increased in the graduate thesis studies to be carried out.

**Author Contributions**

Research Design (CRediT 1) Author 1 (%50) – Author 2 (%50)

Data Collection (CRediT 2) Author 1 (%50) – Author 2 (%50)

Research - Data analysis - Validation (CRediT 3-4-6-11) Author 1 (%50) – Author 2 (%50)

Writing the Article (CRediT 12-13) Author 1 (%50) – Author 2 (%50)

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**Conflict of Interest**

There is no conflict of interest to declare.

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