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Enhancing 21st-Century Skills, STEM Attitudes, and Career Interests Through STEM-Based Teaching: A Primary School Intervention Study

STEM Temelli Öğretim Yoluyla 21. Yüzyıl Becerilerinin, STEM Tutumlarının ve Kariyer İlgilerinin Geliştirilmesi: Bir İlkokul Uygulama Çalışması

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Abstract: This study aims to explore the impact of STEM-based teaching on students' 21st-century skills and attitudes towards STEM, and career interests in STEM fields. The research employed an experimental design with a one-group pretest-posttest approach, involving 34 students enrolled in the 4th grade of a primary school. To evaluate the outcomes, several assessment tools were used: the Multidimensional 21st-Century Skills Scale, the STEM Attitude Scale, and the Science, Technology, Engineering, and Mathematics Career Interest Survey (STEM-CIS). The study was conducted over a period of 7 weeks, during which STEM activities were implemented and assessments were carried out. The collected data were analyzed using paired sample t-tests and repeated measures ANOVA to identify any significant changes between the pretest and posttest scores. The results of the study indicated a significant improvement in the students' 21st-century skills, attitudes towards STEM, and interest in STEM careers following the intervention. Specifically, the posttest scores showed that students exhibited higher levels of career awareness compared to other skill areas such as critical thinking and problem-solving, entrepreneurship and innovation, as well as social responsibility and leadership. Moreover, the findings highlighted that students' information and technology literacy skills were more developed compared to their social responsibility and leadership skills. These results suggest that STEM-based teaching is effective in enhancing students' skills and attitudes, thereby increasing their interest in pursuing careers in STEM fields. The study underscores the potential of STEM education in preparing students for future careers by developing crucial skills and fostering positive attitudes towards STEM disciplines.

Key Words: STEM, 21st-century skills, attitude, career interest, primary school

Özet: Bu çalışma, STEM temelli öğretimin öğrencilerin 21. yüzyıl becerileri, STEM'e yönelik tutumları ve STEM alanlarındaki kariyer ilgileri üzerindeki etkisini araştırmayı amaçlamaktadır. Araştırma, bir ilkokulun 4. sınıfına kayıtlı 34 öğrencinin katıldığı tek grup ön test-son test yaklaşımlı deneysel bir tasarım kullanmıştır. Sonuçları değerlendirmek için çeşitli değerlendirme araçları kullanılmıştır: Çok Boyutlu 21. Yüzyıl Becerileri Ölçeği, STEM Tutum Ölçeği ve Fen, Teknoloji, Mühendislik ve Matematik Kariyer İlgi Anketi (STEM-CIS). Çalışma, STEM etkinliklerinin uygulandığı ve değerlendirmelerin yapıldığı 7 haftalık bir süre boyunca yürütülmüştür. Toplanan veriler, ön test ve son test puanları arasındaki önemli değişiklikleri belirlemek için eşleştirilmiş örneklem t-testleri ve tekrarlanan ölçümler ANOVA kullanılarak analiz edilmiştir. Çalışmanın sonuçları, müdahalenin ardından öğrencilerin 21. yüzyıl becerilerinde, STEM'e yönelik tutumlarında ve STEM kariyerlerine olan ilgilerinde önemli bir gelişme olduğunu göstermiştir. Özellikle, son test puanları, öğrencilerin eleştirel düşünme ve problem çözme, girişimcilik ve yenilikçilik ile sosyal sorumluluk ve liderlik gibi diğer beceri alanlarına kıyasla daha yüksek düzeyde kariyer bilinci sergilediklerini göstermiştir. Ayrıca bulgular, öğrencilerin bilgi ve teknoloji okuryazarlığı becerilerinin sosyal sorumluluk ve liderlik becerilerine kıyasla daha gelişmiş olduğunu vurgulamıştır. Bu sonuçlar, STEM temelli öğretimin öğrencilerin beceri ve tutumlarını geliştirmede etkili olduğunu ve böylece STEM alanlarında kariyer yapmaya olan ilgilerini artırdığını göstermektedir. Çalışma, STEM eğitiminin önemli beceriler geliştirerek ve STEM disiplinlerine yönelik olumlu tutumları teşvik ederek öğrencileri gelecekteki kariyerlerine hazırlama potansiyelinin altını çizmektedir.

Anahtar Kelimeler: STEM, 21. yüzyıl becerileri, tutum, kariyer ilgisi, ilkokul

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Introduction

In the 21st century, often heralded as the information age, society is witnessing unprecedented technological and engineering advancements. This era is marked by a significant shift from interactions with the natural environment to increased engagement with technology. Such changes, driven by the current era's demands, have profound implications for individual lives and societies at large. The swift progress in science and technology has reshaped societal needs and transformed the roles individuals play within social contexts. Yet, this century's rapid changes and technological developments have spotlighted the importance of skills and competencies collectively termed as 21st-century skills. These encompass creative thinking, critical thinking, problem-solving, collaboration, effective communication, responsibility, productivity, and leadership (Trilling & Fadel, 2009). With evolving roles in both business and social contexts, there is an increasing demand for educational curricula to adopt innovative approaches, preparing individuals for a changing business landscape profoundly influenced by ongoing technological advancements. Consequently, the educational sector has embarked on a quest for innovative methodologies, with STEM (Science, Technology, Engineering, and Mathematics) education emerging as a pivotal strategy to equip individuals with the requisite skills for the 21st-century business world. Characterized by interdisciplinary integration, STEM education enhances connections between academic subjects and their real-world applications, effectively transforming knowledge into practical skills (Bullock, 2017).

The acquisition of 21st-century skills enables individuals to adapt to changing circumstances, solve complex problems effectively, and communicate with diverse populations. STEM-based teaching, with its focus on interdisciplinary approaches and real-world applications, plays a crucial role in developing these skills which are vital for addressing contemporary challenges (Aydeniz & Bilican, 2017; Bybee, 2013; Huang et al., 2022; Sanders, 2009). Additionally, the use of hands-on, project-based learning within STEM education not only boosts student engagement and retention but also deepens understanding, cultivating essential skills for future success (English, 2016). Beyond the integration of multiple disciplines, STEM education also emphasizes elements such as attitude, belief, and motivation (Açıkay et al., 2023; Lin et al., 2021; Vennix et al., 2018; Yazıcı et al., 2023). The positive impact of STEM-based teaching significantly affects students' attitudes towards STEM fields. Engaging students in STEM activities from an early age promotes interest and cultivates positive dispositions towards science, technology, engineering, and mathematics, which are vital for their academic and career choices (Archer et al., 2012; Tytler & Osborne, 2012). Furthermore, positive attitudes towards STEM education are instrumental in guiding career orientation within STEM disciplines (Christensen et al., 2015). A study by Maltese and Tai (2011) demonstrates that early experiences with STEM significantly impact students' decisions to pursue STEM careers, highlighting the critical role of STEM education in shaping career paths. This assertion is supported by Aschbacher et. al., (2010), who discovered that students' perceptions of their abilities and the relevance of STEM to their lives are pivotal in developing interests in STEM-related careers. Therefore, it is imperative to promote STEM education to not only increase the number of students entering STEM fields but also to encourage women's participation in these areas and enhance students' scientific and STEM literacy (National Research Council [NRC], 2011).

Moreover, STEM education addresses the skills gap prevalent in many countries, where employers find it challenging to locate individuals with the necessary technical abilities. Effective STEM education prepares students not only for the complexities of future workplaces and societies but also meets the economic and societal demands for a workforce proficient in these essential skills and disciplines (Van Tuijl & van der Molen, 2016; Wang & Degol, 2013). Thus, by advocating for STEM education, schools and universities can prepare students for careers in expanding industries and provide them with the skills required to succeed in the workforce. Additionally, engaging students in STEM activities throughout their educational journey increases their interest in STEM professions (Bindis, 2020; Dabney et al., 2012; Huang et al. 2022; Gossen, 2024; McMaster et al., 2023; Yazici et al., 2023). Indeed, early STEM experiences significantly influence students' decisions to pursue careers in these fields, with students' perceptions of their abilities and the relevance of STEM to their lives playing a crucial role in this process (Archer et al., 2012; Tytler & Osborne, 2012; Maltese & Tai, 2011; Aschbacher et. al., 2010). Careers in STEM fields have a substantial impact on jobs requiring technical knowledge and skills within the respective disciplines, leading to increased scientific studies, innovations, and technological advancements (Cover et al., 2011). The attraction to STEM disciplines is often motivated by the belief that these fields can enhance one's quality of life, further reinforcing their appeal for STEM careers (Douglas & Strobel, 2014). Additionally, it is anticipated that future professions will be closely linked to STEM disciplines. The expected rates of STEM graduates in higher education among OECD and G20 countries have shown an upward trend, as highlighted in the OECD's "Education Indication in Focus" report (OECD, 2015). Consequently, STEM education has become increasingly significant in European countries and an integral part of school curricula at all educational levels, from preschool to high school (Akgündüz et al., 2015).

Despite its importance, STEM education faces challenges, particularly at the K-12 level, where science and mathematics often overshadow technology and engineering due to resource constraints (Miaoulis, 2011). This imbalance necessitates a comprehensive educational restructuring to fully integrate STEM education, preparing students for modern world demands (Myers and Berkowicz, 2015). In sum, STEM education's emphasis on interdisciplinary learning, critical thinking, problem-solving, creativity, and technological literacy is essential for equipping students with 21st-century skills. This approach significantly contributes to their personal development, career aspirations, and societal contributions. (e.g., Benek & Akcay, 2022; Bircan & Çalışıcı, 2022; Gülhan & Şahin, 2016; Khanlari, 2013; Leavy et al., 2023; Schmidthaler, et al., 2023).

In sum, the aforementioned literature suggests that STEM-based pedagogy assumes paramount importance in shaping the 21st-century competencies, STEM orientations, and vocational inclinations of students. Introducing STEM education at the primary school level is crucial as it lays the foundation for future learning and career interests. Early exposure to STEM concepts can spark curiosity and foster a positive attitude towards these fields, encouraging students to pursue STEM-related studies and careers. Furthermore, developing 21st-century skills from a young age prepares students to navigate and succeed in a rapidly evolving technological world. Moreover, the necessity to conduct this study arises from the crucial requirement for evidence-based methodologies in integrating STEM education into pedagogical frameworks. Despite the theoretical insights provided by existing literature on STEM education, a noticeable gap remains due to the limited availability of empirical studies. This research aims to address this gap by focusing on the practical aspects of STEM-based teaching, with the primary goal of establishing its effectiveness and impact on students' 21st-century skills, attitudes, and career aspirations. The absence of empirical evidence hinders a comprehensive understanding of the advantages and potential challenges associated with the integration of STEM education. Thus, this study plays a pivotal role in enhancing the body of empirical research, offering robust evidence that has the potential to guide educational policies and practices related to STEM education. The investigation also aligns with broader educational objectives by seeking to identify best practices in STEM education, providing valuable insights applicable in educational settings and guiding stakeholders, including educators, policymakers, and curriculum developers, in designing and implementing effective STEM programs. Consequently, the study not only targets to fill existing gaps in empirical research but also significantly contributes to the ongoing discourse on the pedagogical relevance and application of STEM education in fostering a comprehensive and future-oriented educational environment. As part of this pursuit, this study aims to investigate the effects of STEM-based teaching on 21st-century skills, attitudes towards STEM, and career interests in STEM professions among fourth-grade primary school students. To achieve this objective, the study seeks to address the following research questions:

- Do STEM-based teaching have an effect on the 21st-century skills of primary school 4th grade students?
- Do STEM-based teaching have an effect on the attitudes towards STEM of primary school 4th grade students?
- Do STEM-based teaching have an effect on the career interests in STEM fields of primary school 4th grade students?
- Is there a difference among students’ 21st-century skills after the implementation?

Method

In this study, only an experimental group was utilized without a control group because there were not enough classes available. Therefore, one-group pretest-posttest experimental design, which is one of the weak experimental designs, was used. In this design, the effect of an implementation is determined by comparing the before and after measurements (Fraenkel & Wallen, 2009). Hence, instruments were applied to the participants before and after the implementation.

Sample

This study was conducted in a small town in western Türkiye. The study group consists of 34 students (21 girls, 13 boys, mean age = 10.63) attending the 4th grade of a primary school. A convenient sampling method was used due to the accessibility of the participants.

Instruments

Multidimensional 21st-Century Skills Scale

The "Multidimensional 21st-Century Skills Scale" developed by Çevik and Şentürk (2019) was used to measure students' 21st-century skills. The 5-point Likert-type (from strongly agree to strongly disagree) scale consists of information and technology literacy skills, critical thinking and problem-solving skills, entrepreneurship and innovation skills, social responsibility and leadership skills, and career consciousness sub-scales. The reliability coefficients were presented at Table 1.

STEM Attitude Scale

The "STEM Attitude Scale" developed by Güzey et al. (2014) and adapted into Turkish by Aydın et al. (2017) was used to measure students' attitudes towards STEM. The scale is a 5-point Likert-type (from strongly agree to strongly disagree) scale. The reliability coefficient was displayed at Table 1.

Science, Technology, Engineering, and Mathematics Career Interest Survey (STEM-CIS)

In order to measure the students' interest in STEM professions, the "Science, Technology, Engineering, and Mathematics Career Interest Survey (STEM-CIS)" which was developed by Kier et al. (2013) adapted by Koyunlu Ünlü et al., (2016) was used. The 5-point Likert-type (from strongly agree to strongly disagree) scale consists of sub-scales. The reliability coefficients were showed at Table 1.

Table 1. The reliability coefficients

Scales	Sub-scales	Cronbach alpha
Multidimensional 21st-century skills scale	Information and technology literacy skills	.84
	Critical thinking and problem-solving skills	.79
	Entrepreneurship and innovation skills	.76
	Social responsibility and leadership skills	.73
	Career consciousness	.75
STEM attitude scale	STEM attitude scale	.94
STEM-CIS	Science	.86
	Mathematics	.88
	Technology	.94
	Engineering	.90

The Implementation Process

The implementation process lasted for 7 weeks, including the implementation of the tests in the first and the last week, and the implementation of the activities for 5 weeks. A total of 5 STEM activities were carried out during the application process. These activities were selected in accordance with the objectives in the curriculum. The objectives and the activities were presented at Table 2. At the beginning of every application, questions related to daily life were included following the activities and it was ensured that the students were motivated against the course. These questions helped to determine the students' prior knowledge of the subjects. Per the activities planned to be implemented, videos were shown to the students. Later, worksheets containing case studies requiring problem-solving related to

STEM activities were distributed to the students. The students first created their designs by doing individual work on the problem situation. Then, following the steps of the engineering cycle, they turned their designs into products. After the STEM activities, the students were given a pretest "Multidimensional 21st-Century Skills Scale", "Interest Scale for STEM Professions" and "STEM Attitude Scale" scales were reapplied to 34 students as the posttest.

Table 2. The objectives and the activities

Week	STEM Activity	Science and Mathematics Objectives (MoNE, 2018)	Engineering and Technology Objectives (MoNE, 2018)
1	The activity of designing a newspaper tower in which s/he can notice the effects of the force and make use of standard units of length measurement.	The student conducts experiments aimed at the effect of force on the movement of objects and changing the shape of objects. The student estimates a length that they can measure directly with the most appropriate unit of length measurement and checks their estimate by measuring.	The student identifies a real-life design problem that can be solved through the development of a product, tool, process, or system. The student limits the problem by considering the measure of material, time and cost. The student develops solutions to the problem according to the determined limitations and criteria and compares the suggestions developed with each other. The student evaluates and tests the solution proposals determined for the solution of the problem according to the criteria determined in advance.
2	The activity to create a catapult assembly to be able to throw an object the farthest away by taking advantage of the pushing and pulling effect of force.	The student conducts experiments aimed at the effect of force on the movement of objects and changing the shape of objects. The student estimates a length that it can measure directly with the most appropriate unit of length measurement and checks its estimate by measuring.	The student uses existing technological products. The student knows why technological tools are used.
3	The activity of designing a car in which the accelerating and deflecting effect of force can be noticed.	The student conducts experiments aimed at the effect of force on the movement of objects and changing the shape of objects. The student estimates a length that it can measure directly with the most appropriate unit of length measurement and checks its estimate by measuring.	The student demonstrates the ability to select, use, and troubleshoot existing technologies.
4	The activity of creating a solid boat with aluminium foil in line with the concepts of buoyancy force and density of water.	The student explains the basic properties that characterize matter by using the five sense organs. The student measures and compares the masses and volumes of different substances. The student estimates the amount of liquid in a container, in units of litres and millilitres, and checks its estimate by measuring. The student estimates a length that it can measure directly with the most appropriate unit of length measurement and checks its estimate by measuring.	
5	The activity of designing a recycling machine by trying different methods, such as magnets or air blows.	The student chooses the appropriate one of the methods that can be used to separate the mixtures they encounter in everyday life. The student discusses the separation of mixtures in terms of their contribution to the country's economy and the effective use of resources. The student estimates a length that it can measure directly with the most appropriate unit of length measurement and checks its estimate by measuring.	

Ethics Committee Approval

The research proposal was reviewed and approved by the University Ethics Commission.

Data Analysis

The assumptions were tested to statistically examine the 21st-century skills, interests in STEM professions and attitudes of primary school 4th grade students towards STEM. The normality assumption was examined, and the skewness and kurtosis values are presented in Table 3.

Table 3. Skewness and Kurtosis values

	Skewness		**Kurtosis**	
Variables	**Pretest**	**Posttest**	**Pretest**	**Posttest**
Information and technology literacy skills	-.203	-1.873	-.468	6.925
Critical thinking and problem-solving skills	-.895	-1.246	.325	.832
Entrepreneurship and innovation skills	.900	-.937	.662	2.162
Social responsibility and leadership skills	.721	-.202	.550	1.258
Career consciousness	-.136	-.731	.140	.719
Attitude	-.332	-.683	.439	.874
Science	-.460	-.394	1.631	-.369
Mathematics	-.931	-.878	1.786	.568
Technology	-.999	-1.172	1.544	.778
Engineering	.096	-.250	1.126	-.070

The skewness and kurtosis coefficients between [-2, +2] indicate that the data are normal (George & Mallery, 2010). As seen in Table 4, the post-test kurtosis coefficients of information and technology literacy skills and entrepreneurship and innovation skills are outside the acceptable values. However, the histogram and Q-Q plot graphs of these sub-scales show that the values can be considered normal. Therefore, during the examination of pretest-posttest results pertaining to 21st-century skills, attitude, and career interest, the paired sample t-test, a parametric statistical analysis, was employed, assuming the fulfillment of the normality assumption.

One-way repeated measure ANOVA was conducted to examine mean differences in the level of students' 21st-century skills after the implementation. Because the number of the items is not equal for the sub-scales (e.g. 15 items for information and technology literacy skills, and 4 items for social responsibility and leadership skills) mean scores were calculated for each sub-scales based on the number of items before this analysis.

Results

STEM-Based Teaching Effects

The series of paired sample t-tests were run to determine whether students' 21st-century skills, attitudes, and career interest changed after the implementation. The findings of each paired sample t-test were presented respectively.

Table 4. Paired sample t-test result of students' multidimensional 21st-century skills scores

Sub-scales	**Test**	**N**	***M***	***SD***	***t***	***p***	***d***
Information and technology literacy skills	Pretest	34	53.73	10.41	-6.827	.000	1.17
	Posttest	34	64.35	8.78			
Critical thinking and problem-solving skills	Pretest	34	19.09	5.30	-3.449	.002	.59
	Posttest	34	22.29	6.77			
Entrepreneurship and innovation skills	Pretest	34	34.50	9.16	-3.587	.001	.62
	Posttest	34	40.53	6.04			
Social responsibility and leadership skills	Pretest	34	13.71	2.24	-3.985	.000	.68
	Posttest	34	15.53	2.29			
Career consciousness	Pretest	34	23.50	2.91	-4.683	.000	.80
	Posttest	34	26.79	3.98			

Table 4 displays that a significant difference was found between pretest and posttest in terms of the information and technology literacy skills (t = -6.827, p<0.05, d = 1.17), critical thinking and problem-solving skills (t = -3.449, p<0.05, d = .59), entrepreneurship and innovation skills (t = -3.587, p<0.05, d = .62), social responsibility and leadership skills (t = -3.985, p<0.05, d = .68), and career consciousness (t = -4.683, p<0.05, d = .80) scores of primary school 4th grade students. This significant difference is in favor of the posttests. According to Cohen (1988) criteria, the magnitude of the difference is medium for critical thinking and problem-solving skills, entrepreneurship and innovation skills, and social responsibility and leadership skills whereas it is large for information and technology literacy skills, and career consciousness.

Table 5. Paired sample t-test result of the students' attitude scores

Test	N	*M*	*SD*	*t*	*p*	*d*
Pretest	34	103.44	14.28	-11.326	.000	1.94
Posttest	34	122.82	9.39			

As Table 5 shows a significant difference was found between pretest and posttest in favour of posttest in primary school 4th grade students' attitudes towards STEM with a large effect size (t = -11.326, p<0.05, d = 1.94).

Table 6. Paired sample t-test result of the students' interest scores

Sub-scales	Test	N	*M*	*SD*	*t*	*p*	*d*
Science	Pretest	34	36.76	5.55	-6.737	.000	1.16
	Posttest	34	41.62	5.18			
Mathematics	Pretest	34	40.50	6.09	-3.875	.000	.66
	Posttest	34	44.15	5.26			
Technology	Pretest	34	36.29	7.91	-3.184	.003	.55
	Posttest	34	43.26	7.19			
Engineering	Pretest	34	32.41	8.32	-4.997	.000	.86
	Posttest	34	39.82	6.49			

Table 6 indicates that a significant difference was found between pretest and posttest in terms of the science (t = -6.737, p<0.05, d = 1.16), mathematics (t = -3.875, p<0.05, d = .66), technology (t = -3.184, p<0.05, d = .55), and engineering (t =-4.997, p<0.05, d = .86) scores of primary school 4th grade students. This significant difference was in favour of the posttests with a large effect size for science, and engineering as well as with a medium effect size for mathematics, and engineering.

Changes in Students' 21st-Century Skills

Repeated measures ANOVA was conducted to examine whether the level of students' 21st-century skills differ. Results showed a statistically significant difference in means among five dimensions (Wilk's Lambda = .497, F (4, 30) = 7.583, p = .000, η^2 = .503). The multivariate $\eta 2$ = .63 indicated that magnitude of the difference in means is large. To determine which means differ from each other significantly, pairwise comparisons were conducted following Holm's sequential Bonferroni procedure. Examination of the pairwise comparisons revealed that students have significantly higher levels of career consciousness (M = 4.47, SD = .49) compared to critical thinking and problem-solving skills (M = 3.72, SD = 1.13), entrepreneurship and innovation skills (M = 4.05, SD = .60), and social responsibility and leadership skills (M = 3.88, SD = .57). Additionally, students' information and technology literacy skills (M = 4.29, SD = .59) was found to be at higher levels than social responsibility and leadership skills (M = 3.88, SD = .57).

Discussion

This study aimed to investigate the effects of STEM-based teaching on the 21st-century skills of primary school 4th-grade students, as well as their attitudes towards STEM and interests in STEM professions. The findings indicate a positive impact of incorporating STEM activities on students' acquisition of these essential skills. Assessments conducted before and after engaging in these activities reveal noteworthy improvements across various sub-scales. These observed improvements align with the findings of previous studies (Bircan & Çalışıcı, 2022; Gülhan & Şahin, 2016; Khanlari, 2013). That also emphasized the effectiveness of STEM education in fostering these competencies. Moreover, Şahin et al. (2014) argued that STEM activities not only promote 21st-century skills but also facilitate collaborative learning, contributing to a broader understanding of STEM education's efficacy. The consistent findings across these various studies strengthen the robustness of the current research, reaffirming that STEM-based teaching is valuable for developing the skills needed for success in today's rapidly evolving world. By nurturing competencies such as critical thinking, problem-solving, creativity, and communication, STEM education equips students with the foundational skills necessary to thrive in a technology-driven and interconnected global society. As these skills become increasingly vital in various professional and personal contexts, the integration of STEM activities in primary school education holds immense promise for equipping students with the tools they need to meet the challenges of the future.

Furthermore, the assessment of students' attitudes toward STEM following their engagement in STEM activities revealed a significant positive change in their attitudes. This finding is consistent with the research conducted by Bircan and Çalışıcı (2022), which also demonstrated a positive impact of STEM-based teaching on students' attitudes toward STEM. Emir (2021) further contributed to this understanding by conducting a study with third-grade students in primary school, integrating STEM education with values, and finding a positive increase in students' attitudes toward STEM, which also correlated with enhanced academic success in science courses.

Moreover, the assessment of students' interest in STEM professions, utilizing the "Interest Scale for STEM Professions," demonstrated a notable increase in the sub-scales of the scale. This aligns with the findings of previous research. Dou et al. (2019) found that various elements of STEM education, such as curriculum, pedagogy, and extracurricular activities, positively influenced students' preferences for pursuing careers in STEM fields. Maltese and Tai (2011) also concluded that engagement in STEM education, including participation in science fairs, had a positive impact on students' interests in STEM professions. Additionally, Archer et al. (2010) and Hiğde and Aktamış (2022) demonstrated the positive effects of STEM-based activities on students' knowledge, skills, and interest in STEM professions.

The findings further indicate that students exhibit significantly higher levels of career consciousness compared to other skills such as critical thinking, problem-solving, entrepreneurship, innovation, social responsibility, and leadership. This finding suggests that students prioritize their career awareness and aspirations over other essential skills, indicating a potential gap or imbalance in the development of these skills among the students. This prioritization of career consciousness aligns with the research conducted by Fenyes et al. (2021), which supports the finding of higher career consciousness among students. They (2021) argue that the current education system often places significant emphasis on career-oriented goals and preparing students for future employment. As a result, students may tend to prioritize their career aspirations and goals over the development of other skill areas. While the emphasis on career consciousness can be beneficial in motivating students and preparing them for their future professional lives, it is essential to consider the broader spectrum of 21st-century skills that are equally crucial for their holistic development. Critical thinking, problem-solving, entrepreneurship, innovation, social responsibility, and leadership are indispensable skills that enable students to navigate various challenges and contribute positively to society. Addressing the potential imbalance in skill development requires the incorporation of targeted interventions and instructional approaches. These should aim to foster a comprehensive development of 21st-century skills while simultaneously enhancing career consciousness. Implementing interdisciplinary activities, project-based learning, and problem-solving scenarios can create opportunities for students to enhance their critical thinking, innovation, and social responsibility skills in conjunction with their career-oriented pursuits. Additionally, the study's findings provide valuable insights into the proficiency levels of students in various 21st-century skills domains, particularly information and technology literacy skills, social responsibility, and leadership skills.

The results reveal significant disparity, with students demonstrating higher levels of information and technology literacy skills compared to their social responsibility and leadership skills. Information and technology literacy skills encompass the ability to effectively access, evaluate, and utilize information and navigate digital technologies to gather and communicate information. In the context of today's digital age, where information and technology play a central role in various aspects of life, these skills have become increasingly vital for individuals to thrive in both academic and professional settings. The observed higher proficiency in information and technology literacy skills among students can be attributed to their widespread exposure to technology and digital resources in their daily lives, including in education, entertainment, and social interactions. The ubiquity of technology has facilitated the development of these skills in students, as they regularly engage with digital platforms, search engines, and social media for various purposes. However, the findings also raise concerns about the relatively lower proficiency levels in social responsibility and leadership skills. These skills encompass the ability to work collaboratively, demonstrate ethical behavior, and assume leadership roles to address societal challenges effectively. Given the importance of these skills in fostering active citizenship and contributing to the betterment of society, it is imperative to address this disparity in skill development among students. To bridge this gap, educational institutions should consider implementing targeted strategies to foster the development of critical thinking, problem-solving, entrepreneurship, innovation, social responsibility, and leadership skills in students. Integrating these skills into the curriculum, providing relevant projects and activities that encourage teamwork and community engagement, and promoting experiential learning opportunities can be effective approaches to promote the holistic development of students' skill sets.

Conclusion

This comprehensive discussion underscores the significant positive influence of STEM activities on students' acquisition of 21st-century skills, evident from notable improvements observed across various skill sub-scales. The consistency of these findings with prior research reinforces the effectiveness of STEM education in fostering essential competencies for students. The implications of these results are far-reaching, emphasizing the importance of integrating STEM-based teaching practices into primary school curricula to better equip students for the demands of the modern world. Moreover, further research in this domain promises to contribute to refining and enhancing STEM education approaches, ultimately benefiting both students and societies. Additionally, the findings from the assessment of students' attitudes toward STEM and their interest in STEM professions confirm the positive impact of engaging in STEM activities on these aspects. Nevertheless, the observed prioritization of career consciousness over other critical skills highlights the necessity for a balanced educational approach that fosters a comprehensive set of 21st-century skills in students. By incorporating diverse pedagogical strategies encompassing both career-oriented objectives and broader skill development, educators can better prepare students to confront multifaceted future challenges while nurturing their career aspirations. Future research in this area should explore effective instructional methods that achieve this essential balance and contribute to students' holistic growth and success in an ever-evolving society. Ultimately, the study's findings emphasize the positive impact of implementing STEM activities on students' 21st-century skills, attitudes toward STEM, and interest in STEM professions. The observed discrepancy in proficiency levels between information and technology literacy skills and social responsibility and leadership skills calls for a comprehensive approach to skill development. By integrating these implications and suggestions into educational practices, educators, policymakers, and curriculum developers can harness the potential of STEM education to equip students with a well-rounded skill set, empowering them to thrive in an increasingly complex and interconnected world.

It is crucial to note that the effectiveness of STEM education may be influenced by various factors, such as the quality of instructional design, teacher expertise, and the availability of resources. To further enhance the efficacy of STEM education, future research should explore the specific elements and practices within STEM-based teaching that yield the most significant impact on 21st-century skill development. Additionally, investigating the longitudinal effects of STEM education on students' skills and attitudes over extended periods could provide further insights into the long-term benefits of such interventions. Moreover, further research and evaluation are essential to strengthen the evidence base surrounding STEM education's efficacy and its impact on students' skill development. By conducting rigorous research, educational stakeholders can identify best practices, assess the long-term effects of STEM interventions, and continuously refine their approaches to maximize the benefits of STEM education.

Furthermore, the study's implications extend beyond the classroom and into the broader realm of STEM education. Policymakers and curriculum developers should focus on designing comprehensive educational programs that encompass not only the acquisition of technical knowledge but also the cultivation of essential 21st-century skills. By nurturing positive attitudes toward STEM and fostering interest in STEM professions from an early age, educational institutions can encourage more students to pursue careers in STEM fields, addressing the existing skills gap and ensuring a steady supply of skilled professionals in these critical sectors. Continuous professional development for educators is also crucial in ensuring the successful implementation of STEM education. Teachers must be equipped with the knowledge and skills required to effectively integrate STEM activities into their teaching practices, thus creating an enriching and engaging learning environment that supports skill development in students.

References

Acikay, N. Bircan, M. A., & Karakas, H. (2023). The effect of STEM activities on primary school students' attitudes towards STEM. *International Journal of Research in Teacher Education, 14*(2), 19-35.

Akgunduz, D., Aydeniz, M., Cakmakci, G., Cavas, B., Corlu, M. S., Oner, T., & Ozdemir, S. (2015). *STEM eğitimi Türkiye raporu: Günün modası mı yoksa gereksinim mi? [A report on STEM Education in Türkiye: A provisional agenda or a necessity?]*. İstanbul Aydin University

Archer, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B., & Wong, B. (2010). "Doing" science versus "being" a scientist: Examining 10/11-year-old schoolchildren's constructions of science through the lens of identity. *Science Education, 94*(4), 617-639.

Archer, L., Dewitt, J., Osborne, J., Dillon, J., Willis, B., & Wong, B. (2012). Balancing acts: Elementary school girls' negotiations of femininity, achievement, and science. *Science Education, 96*(6), 967–989. doi:10.1002/sce.21031.

Aschbacher, P. R., Li, E., & Roth, E. J. (2010). Is science me? high school students' identities, participation and aspirations in science, engineering, and medicine. *Journal of Research in Science Teaching, 47*(5), 564–582.

Aydeniz, M., & Bilican, K. (2017). STEM eğitiminde global gelişmeler ve Türkiye için çıkarımlar [Global developments in STEM education and implications for Türkiye]. In Salih Cepni. (Ed.), *Kuramdan Uygulamaya STEM+A+E Eğitimi* (pp.69-90). Pegem Akademi.

Aydin, G., Saka, M., & Güzey, S. (2017). Science, technology, engineering, mathematic (STEM) attitude levels in grades 4th - 8th. *Mersin University Journal of the Faculty of Education, 13*(2),787-802.

Benek, I. & Akcay, B. (2022). The effects of socio-scientific stem activities on 21st century skills

of middle school students. *Participatory Educational Research, 9*(2), 25–52.

Bindis, M. (2020). "I Love Science": Opinions of secondary school females toward science and science careers. *International Journal of Science and Mathematics Education, 18*(8), 1655–1671.

Bircan, M. A., & Calisici, H. (2022). The effects of STEM education activities on fourth grade students' attitudes to STEM, 21st-century skills and mathematics success. *Education and Science, 47*(211), 87-119.

Bullock E. C. (2017). Only STEM can save us? Examining race, place, and STEM education as property. *Educational Studies, 53*(6), 628–641.

Bybee, R. W. (2013). *The case for STEM Education: Challenges and opportunities*. National Science Teachers Association.

Cevik, G., & Senturk, E. (2019). Multidimensional 21st century skills scale: Validity and reliability study. *Cypriot Journal of Educational Sciences, 14*(1), 11-28.

Christensen, R., Knezek, G., & Tyler-Wood, T. (2015). A retrospective analysis of STEM career interest among mathematics and science academy students. *International Journal of Learning, Teaching and Educational Research, 10*(1), 45-58.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences (2nd ed.).* Lawrence Erlbaum Associates, Publishers

Cover, B., Jones, J. I., & Watson, A. (2011). Science, technology, engineering and mathematics (STEM) occupations: A visual essay. *Monthly Labor Review, 134*(5), 3-15.

Dabney, K. P., Tai, R. H., Almarode, J. T., Miller-Friedmann, J. L., Sonnert, G., Sadler, P. M., & Hazari, Z. (2012). Out-of-school time science activities and their association with career interest in STEM. *International Journal of Science Education, 34*(17), 2735-2773.

Dou, R., Hazari, Z., Dabney, K., Sonnert, G., & Sadler, P. (2019). Early informal STEM experiences and STEM identity: The importance of talking science. *Science Education, 103*(3), 623–637. https://doi.org/10.1002/sce.21499

Douglas, K. A., & Strobel, J. (2014). Hopes and goals survey for use in STEM elementary education. *International Journal of Technology and Design Education, 25*(2), 245-259.

Emir, Z. A. (2021). *Integrating values into STEM education: The effects of values-based STEM education on primary school students' academic achievement in science courses and on STEM attitudes*. (Unpublished master's thesis). Hatay Mustafa Kemal University, Hatay.

English, L. D. (2016). STEM education K-12: Perspectives on integration. *International Journal of STEM Education, 3*(1), 1-8.

Fenyes, H., Mohacsi, M., & Pallay, K. (2021). Career consciousness and commitment to graduation among higher education students in Central and Eastern Europe. *Economics and Sociology, 14*(1), 61-75.

Fraenkel, J. R., & Wallen, N. E. (2009). *How to design and evaluate research in education (7th ed.).* McGraw-Hill.

George, D., & Mallery, P. (2010). *SPSS for Windows step by step: A simple guide and reference, 17.0 update (10a ed.).* Pearson.

Gossen, D. (2024). It says STEM so it must work for everyone: Experiences, beliefs, and career choices across the STEM disciplines. *International Journal of Education in Mathematics, Science, and Technology (IJEMST), 12*(3), 660-681. https://doi.org/10.46328/ijemst.3450

Gulhan, F., & Sahin, C. (2016). The effects of science-technology-engineering-math (STEM) integration on 5th grade students' perceptions and attitudes towards these areas. *Journal of Human Sciences, 13*(1), 602–620.

Guzey, S. S., Harwell, M., &Moore, T. (2014). Development of an instrument to assess attitudes toward science, technology, engineering, and mathematics (STEM). *School Science and Mathematics, 114*(6), 271-279.

Higde, E., & Aktamis, H. (2022). The effects of STEM activities on students' STEM career interests, motivation, science process skills, science achievement and views. *Thinking Skills and Creativity, 43*, 101000.

Huang B., Jong MS-Y., King R. B., Chai C-S., & Jiang MY-C. (2022). Promoting secondary students' twenty-first century skills and STEM career interests through a crossover program of STEM and community service education. *Frontiers Psychology, 13*(903252). doi: 10.3389/fpsyg.2022.903252

Khanlari, A. (2013). Effects of robotics on 21st century skills. *European Scientific Journal, 9*(27), 26-36.

Kier, M. W., Blanchard, M. R., Osborne, J. W., & Albert, J. L. (2013). The development of the STEM career interest survey (STEM-CIS*). Research in Science Education, 44*(3), 461-481.

Koyunlu Unlu, Z., Dokme, I., & Unlu, V. (2016). Adaptation of the science, technology, engineering, and mathematics career interest survey (STEM-CIS) into Turkish. *Eurasian Journal of Educational Research, 63*, 21-36.

Leavy, A., Dick, Maria Meletiou-Mavrotheris, Efi Paparistodemou & Elena Stylianou. (2023) The prevalence and use of emerging technologies in STEAM education: A systematic review of the literature. *Journal of Computer Assisted Learning, 39*(4), 1039-1395.

Lin, K. Y., Lu, S. C., Hsiao, H. H., Kao, C. P., & Williams, P. J. (2021). Developing student imagination and career interest through a STEM project using 3D printing with repetitive modeling. *Interactive Learning Environments, 31*(5), 2884–2898. https://doi.org/10.1080/10494820.2021.1913607

Maltese, A. V., & Tai, R. H. (2011). Pipeline persistence: Examining the association of educational experiences with earned degrees in STEM among U.S. students. *Science Education, 95*(5), 877-907.

McMaster, N., Carey, M., Martin, D., & Martin, J. (2023). Raising primary school boys' and girls' awareness and interest in STEM-related activities, subjects, and careers: An exploratory case study. *Journal of New Approaches in Educational Research, 12(*1), 1-18. doi:https://doi.org/10.7821/naer.2023.1.1135

Miaoulis, I. (2011, December). *Museums Key to STEM Success.* U.S. News & World Report.

Ministry of National Education (MoNE). (2018). *Fen bilimleri dersi (3, 4, 5, 6, 7 ve 8. sınıflar) öğretim programı [Science course (3, 4, 5, 6, 7 and 8th grades) curriculum].* http://mufredat.meb.gov.tr/Programlar.aspx

Myers, B., & Berkowicz, J. (2015). *The STEM shift: A guide for school leaders.* Thousand Oaks, CA: Corwin Press.

National Research Council (NRC). (2011). *Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics.* National Academies Press.

OECD (2015), "How is the global talent pool changing (2013, 2030)?", *Education Indicators in Focus*, No. 31, OECD Publishing, Paris, https://doi.org/10.1787/5js33lf9jk41-en.

Sahin, A., Ayar, C. M., & Adiguzel, T. (2014). STEM Related After-School Program Activities and Associated Outcomes on Student Learning. *Educational Sciences: Theory & Practice, 14*(1), 309-322.

Sanders, M. (2009). STEM, STEM education, STEM Mania. *Technology Teacher, 68*(4), 20-26.

https://doi.org/10.17763/haer.57.1.j463w79r56455411

Schmidthaler E., Anđic B., Schmollmüller M., Sabitzer B., Lavicza Z. (2023). Mobile augmented reality in biological education: Perceptions of Austrian secondary school teachers', *Journal on Efficiency and Responsibility in Education and Science, 16*(2), 113-127.

Trilling, B., & Fadel, C. (2009). *21st century skills: Learning for Life in Our Times*. John Wiley & Sons.

Tytler, R., & Osborne, J. (2012). Student attitudes and aspirations towards science. In B. J. Fraser & C. J. McRobbie (Eds.), *Second international handbook of science education* (pp. 597–625). Springer

Vennix, J., den Brok, P., & Taconis, R. (2018). Do outreach activities in secondary STEM education motivate students and improve their attitudes towards STEM? *International Journal of Science Education, 40*(11), 1263-1283.

van Tuijl C., & van der Molen J. H. W. (2016). Study choice and career development in STEM fields: An overview and integration of the research. *International Journal of Technology and Design Education, 26*(2), 159–183. https://doi.org/10.1007/s10798-015-9308-1

Wang, M., & Degol, J. (2013). Motivational pathways to STEM career choices: Using expectancy–value perspective to understand individual and gender differences in STEM fields. *Developmental Review, 33*(4), 1-37.

Yazici, Y.Y., Hacıioglu, Y. & Sarı, U. (2023). Entrepreneurship, STEM attitude, and career interest development through 6E learning byDeSIGN™ model based STEM education. *International Journal of Technology and Design Education, 33*, 1525–1545.