JOURNAL OF BALTIC SCIENCE EDUCATION

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

MODELING THE FACTORS INFLUENCING SECONDARY STUDENTS' PERFORMANCE IN STEM SUBJECTS

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Abstract. *STEM education plays a key role in influencing and orienting students' interests towards STEM fields and careers. This influence is multifaceted, involving not only STEM content and experiences but also teachers, schools, and personal factors. The purpose of this study is to explore the factors impacting the academic performance of 951 tenth grade students in STEM subjects (physics, chemistry, biology, mathematics, and information technologies) who are attending public and private schools in two provinces of Turkey. Using a correlational research model, the study assessed how students' personal characteristics, teacher effectiveness and school characteristics affect achievement in STEM courses. Data were collected using the 'Factors Affecting STEM Achievement Questionnaire (FA-STEM-A)', a 20-item questionnaire divided into three sub-dimensions. Analyses focused on the relationships between student characteristics, teaching quality, school infrastructure and STEM performance. Structural equation modelling revealed that positive student characteristics, especially fondness for STEM subjects and confidence in STEM abilities, moderately increase achievement. In contrast, negative factors attributed to teachers and schools, such as inadequate classroom activities, lack of educator expertise, inadequate technological resources, and large class sizes, hindered student performance. These findings emphasize the important influence of both inherent student qualities and external educational conditions in determining STEM education.*
Keywords: *STEM achievement, secondary students, STEM subjects, structural equation modeling*

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Introduction

Governments and educators view STEM education as a means of preparing the kinds of students who will be necessary for the future, which has an impact on how nations like the United States and Canada prepare their citizens through educational policies (Hansen & González, 2014). The strategic significance of STEM at the global level is progressively growing due to the technology-driven economic model, which is essential for countries to stay abreast of advancing technologies (Mansour et al., 2024). Research highlights the significance of STEM (science, technology, engineering, and mathematics) in obtaining a competitive edge in a progressively globalized economy (National Research Council [NRC], 2013). Academics, researchers, and government officials in both emerging and established nations who acknowledge the significance of STEM are promoting student enthusiasm and success in STEM subjects (Freeman et al., 2019). Government and institutional strategies are crucial in attracting and retaining students in STEM fields by recruiting volunteers and enhancing international student satisfaction (Chang et al., 2022). To further emphasize the importance of STEM, many educational institutions have launched cohesive initiatives that promote research and innovation through STEM-oriented clubs and activities, integrated within both academic curricula and extracurricular programs (Han et al., 2021).

Despite extensive efforts by educational institutions, programs, and government initiatives to enhance STEM education through cohesive initiatives such as STEM-oriented clubs and activities within academic and extracurricular programming, a concerning decline in student success and engagement in STEM subjects persists (Mansour & EL-Deghaidy, 2021; Murphy et al., 2019). Moreover, there is often a misalignment between the skills taught in these programs and the demands of the STEM workforce (Almeda et al., 2020). As technology and scientific understanding advance, educational programs may struggle to keep pace with the needs of the industry, leaving students unprepared for the rigors of STEM careers. In this sense, a solid grounding in STEM is essential for all students, not just those pursuing careers as scientists or engineers, and is considered a key part of being prepared for postsecondary education and careers (Hoeg & Bencze, 2017). Academic-preparedness

https://doi.org/10.33225/jbse/24.23.518

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

diversity within small learning groups in STEM university courses is generally linked to positive learning outcomes, particularly benefiting students who are less academically prepared (Micari et al., 2016).

To boost STEM achievement in Turkey, curriculum reforms have included daily life-related and achievement-oriented activities. Academic foundations and interest in STEM are critical for long-term success in these fields. However, the Ministry of National Education (MoNE) has not mandated the necessary integration into the 2017 curriculum to guarantee success in STEM. In addition to policy efforts, science and mathematics teachers often struggle with collaborative and project-based approaches, both inside and outside the classroom, which are essential for STEM success. According to Çevik and Abdioğlu (2020), project-based studies and science camps have a positive impact on STEM achievement. Nonetheless, teachers are frequently underprepared, particularly in accountability-based approaches like STEM. Moreover, infrastructural shortcomings in Turkish schools (PISA 2016) and overcrowded classrooms (OECD, 2017) also hinder progress in STEM achievement. Considering the impact of these factors, the situation regarding STEM education in Turkey remains complex and unclear. It is imperative to investigate the effects of the three major educational components on STEM achievement.

This paradox highlights several underlying challenges, among which the role of student personality traits and the intricate relationships between student characteristics, teacher effectiveness, and school features are particularly significant. Therefore, exploring the relationships between student characteristics, teacher effectiveness, and school features, and their collective impact on academic performance in STEM subjects is crucial. This holistic understanding can provide insights into the reasons behind the declining enrollment in STEM subjects. For instance, the effectiveness of STEM teachers and the environmental features of schools can significantly amplify or mitigate the influences of student personality traits on their academic outcomes. Effective teachers and supportive school environments can enhance students' self-efficacy and reduce the negative impacts of anxiety on learning, thereby encouraging more students to pursue and persist in STEM subjects. Achievement in STEM subjects is increasingly recognized as a crucial component of preparedness for school and future careers. The correlation between STEM learning principles and student achievement, as well as the impact of academic preparedness on performance, has been the subject of various studies. Classroom practices that involve using technology and engaging in experiments or projects are positively correlated with student gains in math and science achievement (Maranto & McShane, 2012).

This interaction of the relationships between student characteristics, teacher effectiveness, and school features provides a more comprehensive picture of educational outcomes in STEM subjects. Recognizing how these variables interact allows for the development of nuanced interventions that address multiple aspects of the educational experience, leading to more effective improvements in student achievement. Furthermore, interventions can be better targeted when it is known how these factors influence each other. For example, a school with highly effective teachers might still struggle with student performance if the students' personal challenges or the school's structural deficiencies are not addressed. Insights into the interactions between students' personal traits, teacher qualities, and school characteristics enable educators to refine teaching methods and administrative policies (Kim et al., 2017). Knowing that student engagement is boosted not only by teacher supportiveness but also by a conducive school atmosphere can lead to integrated strategies that foster both, enhancing the overall educational experience and outcomes.

Factors Impact on Student STEM Success

Studies suggest that various personality traits can greatly influence a student's likelihood to enroll in and succeed in STEM subjects (Chen & Simpson, 2015; Coenen et al., 2021; Deshler et al., 2019). The impact of student personality on success in STEM subjects is complex and significant, influencing everything from academic engagement and self-efficacy to career choices in science, technology, engineering, and mathematics (Mansour & EL-Deghaidy, 2021). Research indicates that students with high levels of anxiety often have reduced success and lower grades in mathematics, which can diminish their sense of belonging and self-efficacy within STEM fields (Deshler et al., 2019). Personality types also play a pivotal role; for example, students with investigative personalities are more likely to enroll in STEM majors, whereas those with artistic or enterprising traits are less inclined to pursue these fields. Additionally, the presence of social personality traits can influence STEM major selection in a gender-dependent manner (Chen & Simpson, 2015). Key personality traits such as Openness to Experience, Extraversion, and Agreeableness significantly relate to student preferences for STEM studies, although cognitive skills often exert a more substantial influence on actual educational decisions (Coenen et al., 2021). The development of a science identity, a crucial social psychological process, has been shown to enhance the

https://doi.org/10.33225/jbse/24.23.518

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

likelihood of students pursuing science careers and can mediate other factors impacting educational success (Stets et al., 2017).

Teacher-related factors exert a profound influence on student success in STEM subjects, shaping their motivation, engagement, and overall achievement and developing students' science identity. Teachers' professional backgrounds, their motivational beliefs, and instructional practices are pivotal (Mansour & EL-Deghaidy, 2021; Mansour et al., 2024). For example, Ekmekci and Serrano (2022) have emphasized how these elements significantly affect students' motivation, retention, and success in STEM subjects. Furthermore, programs that enhance teachers' content and pedagogical knowledge invariably lead to better student outcomes (Lynch et al., 2019). In this sense, Professional development tailored to integrate STEM effectively into teaching practices not only bolsters teachers' attitudes but also their ability to make science personally relevant to students. However, this positive influence can be somewhat offset by factors such as extensive teaching or mathematics experience, which might entrench less flexible attitudes toward innovative, integrated STEM education (Thibaut et al., 2018).

The classroom environment itself, enriched by technology and hands-on experiments, plays a crucial role (Terzi & Kırılmazkaya, 2020; Wang, 2013). Hansen and González (2014) found that technology use and experimental activities in class are positively correlated with gains in math and science achievement. Additionally, the way teachers motivate—particularly through providing structure—can significantly enhance student engagement in STEM (Loof et al., 2019). The concepts of teacher self-efficacy and outcome expectancy are also critical, directly and indirectly affecting students' STEM knowledge achievements. These teacher beliefs influence student attitudes towards STEM and their development of 21st-century skills, which are essential for navigating future careers in these fields (Han et al., 2021).

High-quality teaching and effective pedagogical practices are indispensable for maintaining student interest and achievement in STEM. These factors directly affect students' motivation and their potential interest in STEM careers (Demirkol et al., 2022; McDonald, 2016). Moreover, teachers' acceptance of STEM teaching is influenced by their performance expectancy, the social influence they experience, and their effort expectancy, which collectively impact how they implement STEM curricula (Zhou et al., 2022). Even seemingly minor teacher classroom practices, such as the arrangement of seating and student note-taking habits, can significantly influence learning outcomes in STEM, suggesting that many aspects of the educational environment can be strategically manipulated to enhance student performance (Dagtas, 2014). Overall, understanding and enhancing the myriad teacher-related factors in STEM education can lead to substantially improved educational outcomes, better preparing students for complex future careers in these critical fields. This holistic approach to teacher development in STEM not only fosters a better educational environment but also equips students with the necessary skills and motivations to pursue these subjects further (Ekmekci & Serrano, 2022; Han et al., 2021)

The impact of school factors on student success in STEM subjects is profound and multifaceted, reflecting a complex interplay between individual, family, and educational elements that shape student engagement and achievement. Research has highlighted several critical factors that schools influence, which are pivotal for fostering interest and proficiency in STEM. Secondary school math achievement and early exposure to math and science subjects, alongside math self-efficacy beliefs, are crucial for developing students' intent to major in STEM. Early achievements and attitudes toward math significantly anchor these intentions (Wang, 2013). Interestingly, attending a secondary school with a specialized STEM program does not significantly affect college STEM success when prior STEM-related academic and extracurricular experiences are accounted for, suggesting that the foundation laid in earlier educational experiences may be more influential than the specific secondary school program attended (Bottia et al., 2018). Moreover, factors extending beyond the school environment, such as parental education, attitudes towards STEM, and demographic factors like socioeconomic status, play a significant role in shaping academic achievement in STEM (Terzi & Kırılmazkaya, 2020).

Student aspirations for STEM careers are also influenced by broader socio-cultural factors including cultural capital, gender, and parental occupation in STEM, alongside prior achievement in foundational skills like reading and numeracy (Holmes et al., 2018). These aspirations are further shaped by both academic and social factors during their education, such as interactions with faculty and perceptions as a transfer student, which are pivotal for community college students transferring to 4-year institutions (López & Jones, 2017). Furthermore, the choice to major in STEM fields in higher education is affected by individual factors such as race and academic preparation, as well as institutional factors including the selectivity of the college attended (Engberg & Wolniak, 2013). Secondary school subject taking in science and performance on standardized tests, along with individual-level factors such as gender, race, and income level, also impact interest in STEM majors (Lichtenberger & George-Jackson, 2012).

https://doi.org/10.33225/jbse/24.23.518

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

The early focus on effective pedagogical practices in junior secondary schooling and the development of high-quality teachers are identified as key to engaging and achieving success in STEM education (McDonald, 2016). In conclusion, while foundational school experiences such as secondary school math achievement and exposure to STEM are critical, the overall effectiveness of specialized STEM programs is nuanced. A comprehensive approach that considers individual, family, and school factors is essential to fully support and enhance student success in STEM subjects. This approach must not only bolster foundational academic skills but also address the broader social and institutional contexts that influence educational pathways.

In sum, the interaction between student characteristics, teacher effectiveness, and school features forms a dynamic matrix that significantly impacts educational outcomes in STEM subjects. This holistic approach is essential for fostering environments where every student has the opportunity to succeed, particularly in challenging fields like STEM. By refining our understanding and strategies based on these interactions, the educational achievement in STEM subjects can be improved and students can get prepared well for future challenges and career in STEM fields. Moreover, this understanding is key to promoting equity in STEM education. Different students come with varied backgrounds and personal characteristics that may affect how they benefit from certain teaching styles or school environments. By considering these factors together, educators can tailor their approaches to meet the diverse needs of all students, thereby reducing educational disparities and promoting inclusivity (Bedford, 1988).

Research Aim and Research Questions

STEM education plays a pivotal role in influencing students' career interests, with positive effects on their orientation towards STEM fields (Holmes et al., 2018). This influence is multifaceted, involving not only educational content and experiences (Hazari et al., 2017) but also social factors and personal interests (Chachashvili-Bolotin et al., 2016). Engaging students early and continuously in STEM and providing supportive communication and role models are key strategies for fostering a sustained interest in STEM careers (Sarı et al., 2018). According to Wang (2013), it is emphasized that the years spent in secondary school and middle school are crucial for students to develop an interest in STEM areas and enhance their achievements in these fields.

This study aimed to explore the multifaceted impact of student characteristics, teacher effectiveness, and school features on academic performance in STEM subjects, amid concerns about declining enrollment and success rates. The significance of this study is emphasized by the strategic global importance of STEM education, crucial for maintaining competitive advantages in a technology-driven economy. By examining how student personalities, teacher-related factors such as professional development and motivational style, and school environments characterized by their STEM program offerings and pedagogical practices support or hinder student achievements, this study provides insights into why certain students excel while others do not. Addressing these topics not only elucidates the direct impacts of these factors but also how they interact to shape educational outcomes, essential for developing targeted interventions that address the root causes of challenges in STEM education and for preparing students for a globally competitive workforce.

1. What personal characteristics of students influence their performance in STEM subjects?
2. Which teacher-related factors influence students' performance in STEM subjects?
3. What school features influence the academic success of students in STEM subjects?

Research Methodology

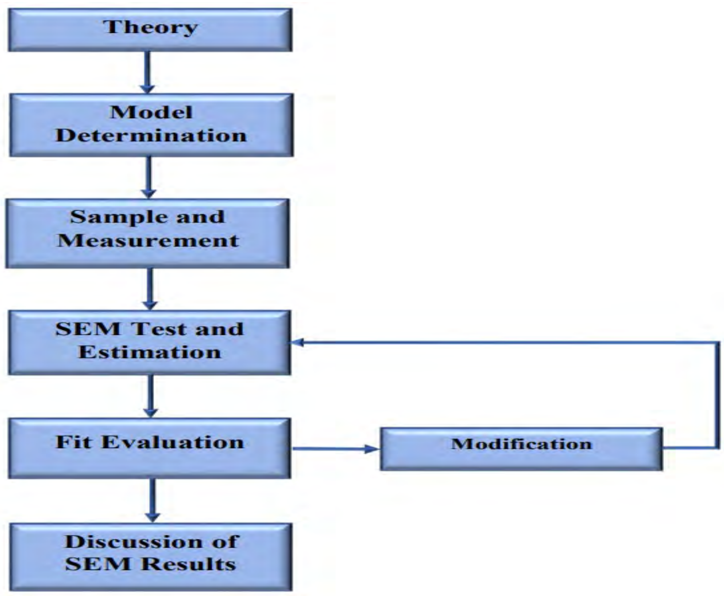
Research Design

This study used a correlational research model to examine the relationships among student personal characteristics, teacher effectiveness, and school features, as well as their collective impact on the academic performance of 10th-grade students in STEM subjects in Turkiye. Structural Equation Modelling (SEM) was employed to delineate the predicted correlations between these variables. Figure 1 provides a comprehensive visualization of the SEM application used in this analysis.

https://doi.org/10.33225/jbse/24.23.518

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

Figure 1
Structural Equation Modeling (SEM)



Sample

This study's population consisted of 6.5 million students studying in Turkey's public and private secondary schools (MoNE,2022). For the sample, the convenience sampling method, which is one of the non-probability sampling methods, was preferred. Since convenience sampling involves using a sample that is readily accessible to researchers, it can be applied to almost any research (Creswell, 2013). However, researchers only employ this method when they have the ability to select participants from a wide range of populations and research areas (Koerber & McMichael, 2008). Schools in two southern regions of Turkiye that were easily accessible and willing to participate were selected for the study. From these schools, 10th graders were selected. In Turkiye, secondary school students in the 10th grade begin to decide on their educational pathways or domains (STEM or other fields). This specialization serves as a crucial determinant of their future in STEM fields. Hence, accurate prognostications of achievement for students studying in Turkiye are a pivotal determinant that has the potential to profoundly alter our destiny. Consequently, at the secondary level, the curricula for 9th and 10th grade include mathematics, physics, chemistry, and biology as compulsory subjects. In order to forecast the academic accomplishment of the students in the study, the year-end grades of the 9th grade STEM subjects were used. Table 1 provides more details regarding the characteristics of the subjects who willingly participated in the study.

Table 1
Descriptive Information on the Participants of the Study

Variables	Category	*n*	$\bar{X}$
Gender	Female	417	44
	Male	534	56
School Type	Government	874	92
	Private	77	8
Inquisitiveness in STEM subjects	Yes	533	56
	No	418	44

https://doi.org/10.33225/jbse/24.23.518

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Variables	Category		n	$\bar{X}$
Materials belonging to the student at home	Own desk	Yes	801	84
	No	150	16	
	Bookcase	Yes	636	67
	No	315	33	
	Computer	Yes	556	58
	No	395	42	
Education level of the mother	Literate		25	3
	Primary School		559	59
	Secondary School		252	26
	University		115	12
Education level of the father	Literate		15	2
	Primary School		438	46
	Secondary School		342	36
	University		156	16
Academic achievement in STEM subjects*	Informatics	Successful	734	77
		Unsuccessful	217	23
	Biology	Successful	836	88
		Unsuccessful	115	12
	Physics	Successful	733	77
		Unsuccessful	218	23
	Chemistry	Successful	814	86
		Unsuccessful	137	14
	Mathematics	Successful	695	73
		Unsuccessful	256	27

*50 points, which is the success threshold in the Turkish education system, has been taken as the criterion.

Out of the 951 students involved in the study, 417 (44%) were female and 534 (56%) were male. The sample group, chosen through convenience sampling, comprised 874 (92%) students from government secondary schools and 77 (2%) students from private secondary schools. Out of the students involved in the study, 533 (56%) expressed their curiosity about STEM subjects, while 413 (44%) indicated otherwise. 395 participants, making up 42% of the group, did not own computers. Most of the students involved in the study had parents who were literate. Specifically, it is evident that the fathers had better literacy levels compared to the mothers. Out of the STEM subjects, 77% of informatics students were successful (734 students), while 23% were unsuccessful (217 students). In biology, 88% of students were successful (836 students), while 12% were unsuccessful (115 students). In physics, 77% of students were successful (733 students), while 23% were unsuccessful (218 students). In chemistry, 86% of students were successful (814 students), while 14% were unsuccessful (137 students). Lastly, in mathematics, 73% of students were successful (695 students), while 27% were unsuccessful (256 students).

This is a unique research study that tries to establish the elements that influence the academic accomplishment of private and public secondary school students in STEM subjects in two regions of Turkiye. It is unique since it incorporates the classification performance of the SEM method. Within this particular framework, the grade point averages of students in the subjects of physics, chemistry, biology, and computer technology from the preceding year were considered. The researcher obtained the necessary permissions to administer the data collection tools to 951 students. This included obtaining permissions for the use of the tools and conducting interviews with school administrators to obtain data collection permissions for the research. The survey was conducted in person in the classroom using a traditional pen-and-paper format and had an average duration of 20 minutes.

https://doi.org/10.33225/jbse/24.23.518

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Instrument and Procedures

The data were gathered via the "Factors Affecting STEM Achievement Questionnaire (FA-STEM-A)". In light of the literature, the researchers developed the questionnaire. During the process of formulating the survey questions, a collection of relevant literature (Kaya & Rice, 2010) was utilized to generate a pool of resources. The questionnaire consisted of 30 questions and was formatted with binary response options of "yes" and "no." After a thorough evaluation conducted by a science expert, two STEM experts, and a measurement expert, five questions were removed from the questionnaire. These experts were chosen for their substantial experience and authoritative expertise in their respective areas—science education, STEM curriculum design, and educational measurement. The purpose of their review was to refine the questionnaire by ensuring that each question was crucial and directly related to the study's goals. The questions that were eliminated were found to be redundant, overlapping with other items, or not directly relevant to the primary focus of the research. Therefore, the questionnaire's content validity was guaranteed. Exploratory factor analysis was used to construct the validity of the questionnaire. KMO value calculated as a result of factor analysis of the data: .70, Bartlett's test value: .00, chi-square value: 1342.41, and these values indicate that item analysis can be started. For item factor analysis, five questions with item loadings below .30 were removed from the questionnaire. The eigenvalues of the remaining 20 items were greater than 1 and categorized under 3 dimensions. The three dimensions explain 48% of the total variance. The factor loadings of the items belonging to the sub-dimensions ranged between.37 and.82. In order to determine the reliability of the questionnaire, the KR20 (Kuder-Richardson) reliability coefficient was calculated and found to be.84. The questionnaire consisted of 20 questions and was divided into three sub-dimensions: "Students' Personal Characteristics," "Teacher Effect," and "School Feature."

Students' Personal Characteristics

The dimension of student personal characteristics, which is thought to affect STEM achievement and was created with the support of the literature, consists of a total of eight questions and five sub-factors. These factors are: liking STEM subjects (LSC) (English, 2017), self-confidence in STEM subjects (SCS) (Kaya & Rice, 2010), taking an active role in applied STEM (APS) (Gökbayrak & Karışan, 2017), regular study habits (RSH) (Hora & Oleson, 2017), and preferring STEM professions (PSC) (Kırkıç & Uludağ, 2021).

Teacher Effect

This dimension of the questionnaire consists of a total of five questions and three sub-dimensions. These are: implementing activities in the classroom (CA) (Kelley et al., 2020); using different teaching methods (UDM) (Autenrieth et al., 2018); and having sufficient experience (SE) (Nadelson et al., 2012) in the related sector.

School Feature

This dimension of the questionnaire consists of a total of seven questions and three sub-dimensions. These are: the curriculum (C) (Holmlund et al., 2018), the school's technology infrastructure (STI) (Konstantopoulos, 2006), and class size (CS) (Kara et al., 2020).

Each dimension consists of 8, 5, and 7 questions, respectively. Additionally, there is a demographic component that inquires about students' academic accomplishments in STEM subjects throughout the preceding year. This section was obtained from the participants with consent from the school authorities. In addition, the grade point averages of students in physics, chemistry, biology, and computer technology from the preceding year were considered. The researcher obtained the necessary permissions to administer the data collection tools to 951 students. The survey was conducted in person in the classroom using a traditional pen-and-paper format and had an average duration of 20 minutes.

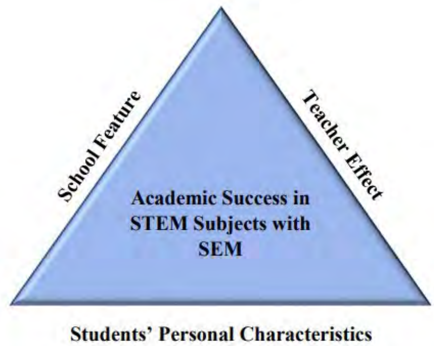
Data Analysis

A systematic plan was established to uncover the connection between these three characteristics using Structural Equation Modeling (SEM) as shown in Figure 2.

https://doi.org/10.33225/jbse/24.23.518

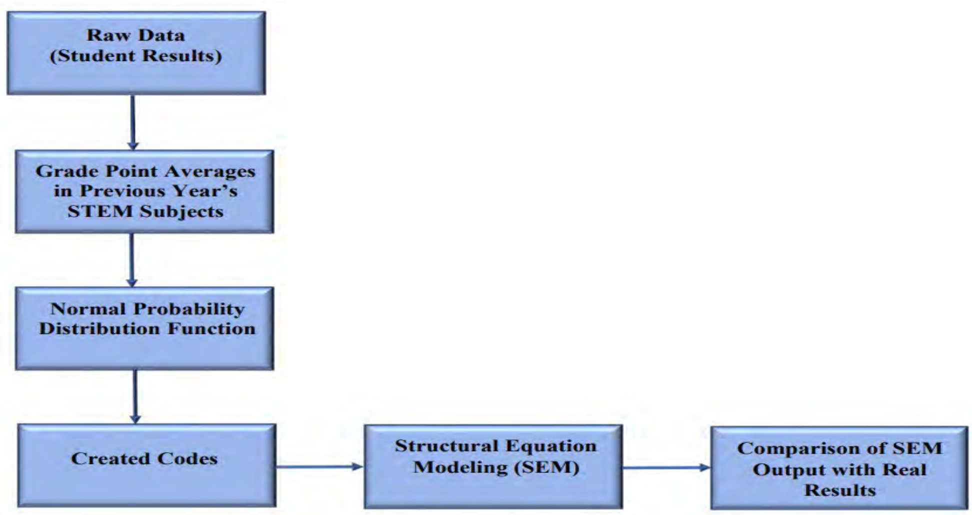
ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Figure 2
Structural Model of the Research



In order to prepare the data for analysis, the researchers organized and examined the collected data and removed any missing data. The data was analyzed using a statistical tool specifically designed for structural equation modeling (SEM). Figure 3 provides a visual representation of the procedures involved in data processing.

Figure 3
Data Analysis Process Steps



Exploratory Factor Analysis

The questionnaire's construct validity was evaluated through the use of exploratory factor analysis. Factor analysis requires the evaluation of data suitability through the Kaiser-Meyer-Olkin (KMO) coefficient and the Bartlett's test. The KMO coefficient should be at least .60, and the Bartlett's test should yield a significant result (Chou & Talalay, 2005). The factor analysis of the data yielded a KMO value of .70, a Bartlett's test value of .00, and a Chi-square value of 1342.41. These results suggest that item analysis can be performed. We eliminated nine questions from the questionnaire that had factor loadings below .30. Out of the remaining 11 things, there were eigenvalues that exceeded 1, and these items were categorized into three dimensions. The combination of these three dimensions accounted for 48% of the overall variance. The components in the sub-dimensions had factor loadings ranging from .37 to .82. The questionnaire's reliability was assessed using the Kuder-Richardson (KR20) reliability coefficient, which yielded a value of .84. Based on a theory, the study used principal component analysis with promax rotation to find three latent variables that were thought to be linked to how well students did in STEM classes. The discovered variables were modeled using the SEM (Structural Equation Modeling) model, which was constructed using

https://doi.org/10.33225/jbse/24.23.518

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

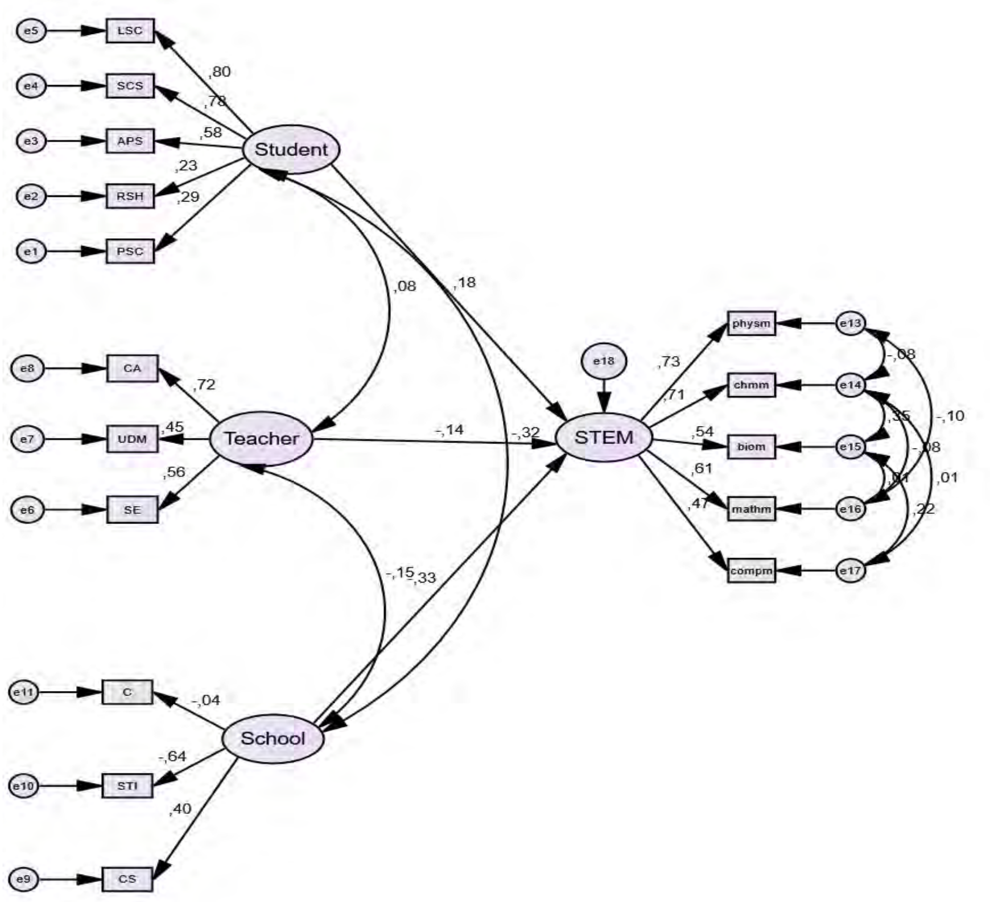
Amos 21.0 software. Structural equation modeling (SEM) is a robust statistical method employed to examine and evaluate the causal and correlational connections between observed and unobserved variables (Hoyle, 1995). The rationale for employing this approach is that the suggested novel framework (see Figure 2) in the study encompasses several independent variables that are interconnected with several dependent variables. Consequently, it is imperative to evaluate the complete model as a cohesive unit within a single procedure. Moreover, the lack of SEM research pertaining to the topic matter is significant for the distinctiveness of the work.

Research Results

The initial stage of Structural Equation Modeling (SEM) involved conducting confirmatory factor analysis on the measurement model. The model was tested at a significance threshold of < .05 using the robust maximum likelihood technique. Missing values in the data were addressed using the listwise deletion approach. The model's fit was evaluated by analyzing the goodness-of-fit indices generated through AMOS 21.0 software. The fit indices considered included "*χ2*", "*df*" (degrees of freedom), "*χ2/df*", "GFI" (Goodness of Fit Index), "CFI" (Comparative Fit Index), "NFI" (Normed Fit Index), "TLI" (Tucker-Lewis Index), "SRMR" (Standardized Root Mean Square Residual), and "RMSEA" (Root Mean Square Error of Approximation). These indices provided insights into the overall fit of the model to the observed data.

Figure 4

**Structural Equation Model for STEM Achievement (Standardized Coefficients)*



*Note:
Student Effect's predictors include: LSC "Liking STEM Course"; SCS "Self-Confidence in STEM"; APS "Active Participation in STEM"; RSH "Regular Study Habits"; PSC "Preference for STEM Careers".
Teacher Effect' predictors include: CA "Conducting Activities"; UDM: "Using Different Methods"; SE "Sufficient Expertise". School Effect's predictors include: C "Curriculum"; STI: School's Technological Infrastructure"; CS "Class Size"

https://doi.org/10.33225/jbse/24.23.518

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Upon examination of the Structural Equation Model (SEM) depicted in Figure 4, it is evident that three latent variables—namely "Students' Personal Characteristics (Student)," "Teacher Effect (Teacher)," and "School Feature (School)"—are defined as independent latent variables. An analysis was conducted on the fit indices of the model, including "$\chi 2$," "RMSEA," "AGFI," "GFI," "CFI," "NFI," and "NNFI." It was determined that the model was statistically significant at a significance level of < .05.

Upon evaluating the model fit indices, it becomes apparent that the "$\chi 2$ = 227.61, p = .00)" value is statistically significant. The $\chi 2$ value is typically noteworthy as it is highly responsive to changes in the sample size (Hair & Sarstedt, 2019). As the sample size increases, the $\chi 2$ value consistently exhibits statistical significance (Kline, 2023). The ratio of χ2 to degrees of freedom, which is 2.27, is smaller than 3.00. This value falls within the acceptable range for goodness-of-fit (Hair & Sarstedt, 2019).

Once again, the "RMSEA value," which is a significant indicator of Confirmatory Factor Analysis (CFA), was calculated to be .040. An RMSEA value of ≤ .05 is considered a reliable indicator of perfect fit (Kline, 2023). The measurement model's GFI value is .91, indicating an excellent fit as per Byrne's (2001) classification. Additionally, the NFI value of .92 and the CFI value of .95 were discovered. An NFI index value beyond .90 signifies a satisfactory fit, while a CFI value surpassing .95 indicates an exceptional fit (Thompson, 2004). Upon evaluating the goodness-of-fit index values, the model's pathways and parameter estimations were reviewed. Consequently, there is no path in the tested structural model that is deemed statistically unimportant. The structural model's parameter estimates, which include unstandardized and standardized regression coefficients as well as t-values, are displayed in Table 2.

Table 2
Parameter Estimates for the Structural Model

Path***	Unstandardized Regression **Coefficient**	Standardized Regression **Coefficient**	*t*
STEM → Student	.38	.18	3.30*
STEM → Teacher	-.17	-.14	2.89**
STEM → School	-.52	-.33	4.57**
LSC→ Student	2.70	.80	7.88**
SCS→ Student	2.68	.78	7.88**
APS→ Student	2.01	.58	7.54**
RSH→ Student	.75	.23	5.16**
PSC→ Student	1.00	.29	-----
CA→ Teacher	1.26	.72	8.19**
UDM→ Teacher	.76	.45	9.09**
SE→ Teacher	1.00	.56	-----
C→ School	-.10	-.04	-.86**
STI→ School	-1.63	.64	4.96**
CS→ School	1.06	.40	-----

*p < .05 **p < .01
***Note:
Student Effect's predictors include: LSC "Liking STEM Course"; SCS "Self-Confidence in STEM"; APS "Active Participation in STEM"; RSH "Regular Study Habits"; PSC "Preference for STEM Careers".
Teacher Effect' predictors include: CA "Conducting Activities"; UDM: "Using Different Methods"; SE "Sufficient Expertise". School Effect's predictors include: C "Curriculum"; STI: School's Technological Infrastructure"; CS "Class Size"

The parameter estimates presented in Table 2 were examined in detail, including both the unstandardized and standardized regression coefficients (pathways), as well as the t-values obtained for the established model. As shown in Table 2, the factors with the greatest impact on students' achievement in STEM subjects were their affinity for STEM subjects and their self-confidence in these areas. It was revealed that among the teacher traits, which acted as another predictor, the elements most affecting STEM achievement were teachers' engagement in classroom activities and their possession of adequate expertise. Among school features, the school's technological

https://doi.org/10.33225/jbse/24.23.518

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

infrastructure and class size were identified as significant predictors that substantially influenced STEM success. The study ultimately evaluated the combined, direct, and indirect impacts to ascertain the predictive influence of the variables in the model. Table 3 displays these combined, direct, and indirect effects.

Table 3
The Effects Values of the Structural Model

Predictable	Predictive	Effect Values			
		Total	Direct	*t*	*SE*
STEM	Students' Personal Characteristics	.37	.18	1.10	3.30*
STEM	Teacher Effect	-.21	-.14	.76	-2.89**
STEM	School Feature	-.52	-.33	.11	-4.57**
Students	LSC	2.70	.79	.14	4.10*
Students	SCS	2.68	.77	.26	5.16**
Students	APS	2.01	.57	.34	7.54**
Students	RSH	.74	.23	.34	7.88**
Students	PSC	1.0	.28	---	7.89**
Teacher	CA	1.65	.72	.10	4.20*
Teacher	UDM	1.31	.55	.20	9.09**
Teacher	SE	1.0	.45	---	8.08**
School	C	-1.0	-.039	.10	-1.10*
School	STI	-1.63	-.645	.32	-4.96**
School	CS	-1.0	.404	---	-.89*

*$p < .05$. **$p < .01$

The results presented in Table 3 indicate that students' personal qualities had a significant positive direct influence (*ß* = .37, p < .01) on STEM achievement. Conversely, the teacher effect (*ß* = -.16, *p* < .01) and school feature (*ß* = -.52, *p* < .01) exerted direct negative effects on STEM achievement. The model revealed that the variable representing students' personal characteristics had a total effect of *d* = .37 on STEM success, while the teacher effect variable contributed a total effect of *d* = .16 to STEM achievement. Moreover, the school feature variable significantly negatively impacted STEM achievement, with a coefficient of *d* = -.52.

Of the sub-dimensions of the student effect variable, the LSC variable had the most substantial effect on the student effect variable (*ß* = .79, *p* < .01). Conversely, the RSH variable, representing regular study habits, had the least effect (*ß* = .23, *p* < .01). In terms of teacher influences, the most impactful sub-dimension was CA 'Conducting Activities,' which entails the implementation of activities in the classroom (*ß* = .72, *p* < .05). The least impactful was SE 'Sufficient Expertise,' indicating adequate proficiency in the subject matter (*ß* = .45, *p* < .01). Furthermore, the STI, 'School Technological Infrastructure,' emerged as the most significant factor influencing the school variable, another determinant of STEM achievement (*ß* = .64, *p* < .01). The least influential factor was the curriculum (*ß* = .03, p < .01).

Cohen (1988) defines effect sizes as follows: values of $d \leq .2$ indicate a small effect size, values of $.2 < d < .8$ indicate a medium effect size, and values of $d \geq .8$ indicate a large effect size. The effect size quantifies the proportion of the total variance in the dependent variable that is attributable to an independent variable or factor, measured on a scale from .00 to 1.00. Within this particular framework, it can be asserted that the attributes of students and the characteristics of schools exert a moderate impact on STEM performance, while the influence of teachers can be considered modest. Furthermore, Table 3 shows that the combination of students' personal traits, teacher influence, and school attributes accounts for 42% of the overall variation in STEM achievement (R^2 = 42%).

https://doi.org/10.33225/jbse/24.23.518

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Discussion

This study utilized Structural Equation Modeling (SEM) to elucidate the factors influencing the academic performance of secondary school students in STEM subjects—namely, physics, chemistry, biology, mathematics, and information technology—in Turkiye. According to Turkiye's Ministry of National Education's mandate (MoNE, 2020), the participants were students in the 10th grade who had concentrated on these five particular subjects during the previous year (9th grade). Throughout the 9th and 10th grades, all schools within the Turkish education system required students to study the same STEM subjects. Within this particular context, the subjects that were favored for assessing achievement in STEM subjects included physics, chemistry, biology, mathematics, and information technology.

Students' Personal Characteristics

The study's findings revealed that students' personal characteristics significantly, positively, and moderately predicted STEM achievement. Notably, students' interest in STEM subjects and their self-confidence in those subjects emerged as the most influential factors among personal characteristics (Chachashvili-Bolotin et al., 2016; Lichtenberger et al., 2012).. This aligns with research in the literature that indicates students who excel in STEM also exhibit favorable views and a keen interest in STEM subjects (Şahin et al., 2017; Toker, 2017). A study by Cromley et al. (2016) emphasized that cognition and motivation, including study skills, self-efficacy, continuing interest, and effort control, are related to both grades and retention in STEM majors. In addition, Alhadabi (2021) identified the constructive role of science self-efficacy in STEM achievement by showing that science self-efficacy has direct positive effects on science identity and science achievement and emphasized that these abilities directly affect STEM achievement.

Self-confidence in STEM subjects is an intrinsic factor that has a significant influence. According to Bybee (2010), the qualities necessary for STEM education include flexibility, sociability, social skills, non-standard problem solving, self-management, systematic thinking, and decision-making. This aligns with the conclusions drawn from the study. According to Bandura et al. (2001), students' self-esteem plays a crucial role in their motivation. When students lack confidence in their ability to accomplish desired outcomes, they are less motivated to overcome challenges.

Students' self-confidence has an impact on their motivation. According to Singh et al. (2002), students' sense of achievement, which is in turn directly related to their self-esteem, influences their motivation to study. This relationship has a direct impact on their active engagement in the lesson and ultimately their academic performance in STEM subjects (Cromley et al., 2016; Şahin et al., 2017). Another aspect that influences STEM accomplishment is the active participation of individuals in STEM subjects. The participants' consistent study habits and inclination towards one of the STEM professions are other factors that influence STEM accomplishment. Other primary determinants for students in selecting a university department are their interest in the subject, academic achievement, work-relevant experiences, and the availability of job opportunities (Lent et al., 2002). The study concluded that among the student characteristics impacting STEM success, regular study habits (RS) were the least effective (Gandhi-Lee et al., 2015). To enhance achievement in STEM fields, it is crucial to foster interest, curiosity, and motivation among students.

Teacher Effect

Surprisingly, the findings of the study indicated that teachers had a significant negative and low-level predictive effect on students' STEM achievement. It was revealed that the characteristics that most negatively affected teachers' impact on STEM achievement were "organizing in-class activities and involving students" and "having sufficient expertise." In essence, Turkish secondary school students' success in STEM subjects is somewhat limited by their STEM teachers. This unexpected outcome could potentially be attributed to the teachers' lack of experience with STEM education in Turkiye, a nation where STEM education is still in its early stages of development (Yilmaz et al., 2018).

Moreover, among the sub-factors contributing to this underlying variable, the teachers' lack of engagement in doing experiments or activities in their classes had the most significant adverse effect on STEM achievement. These findings, in line with studies by Loof et al. (2019) and Gasiewski et al. (2011), highlight the importance of teacher engagement and the provision of supportive and structured learning environments in promoting student motivation and engagement in STEM education. These findings imply that to improve STEM achievement, edu-

https://doi.org/10.33225/jbse/24.23.518

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

cational initiatives should focus on enhancing teachers' motivating styles and creating classroom contexts that encourage student interaction and support. This can also be construed as science and math educators affording diminished occasions for active student engagement through a reduced provision of in-class exercises. Multiple investigations undertaken in Turkiye have yielded comparable findings (Aktepe & Aktepe, 2009). According to Çevik et al. (2024), achieving success in the STEM approach, which incorporates a comprehensive, engineering-focused strategy, relies on both in-class and out-of-class applications. Implementing low-resource applications contributes to the acquisition of STEM benefits (Temiz & Çevik, 2023). According to EL-Deghaidy et al. (2017), the absence of necessary equipment for teachers to apply STEM applications and the insufficient emphasis on engineering are the primary reasons for the lack of such applications. This, in turn, has a detrimental impact on the success of STEM education. Teachers' willingness to include STEM applications in their subjects may be hindered by both internal and external restraints, which can have a detrimental impact. For instance, the absence of student engagement, inadequate time allocation, or insufficient pedagogical expertise in STEM. may cause instructors to be inclined to shun STEM activities and revert to a conventional teacher-centered approach due to external obstacles such as limited resources, institutional issues, including an ill-suited curriculum for STEM activities, and time constraints (Mansour, 2010; 2013).

The study identified "teacher's sufficient expertise" as the least impactful sub-dimension of the teacher factor affecting STEM achievement. Despite this, the findings underscore a significant concern: STEM teachers' lack of proficiency markedly impairs Turkish students' success in STEM fields. This deficiency is particularly pronounced in teachers' ability to integrate their specialized knowledge or the subjects they teach with other STEM components (Han et al., 2021. Given that STEM is a multidisciplinary approach, it is crucial for STEM teachers to possess sufficient competence in the specific STEM activities they will carry out (Kelley et al., 2020). Science educators who embrace innovation are anticipated to cultivate students that possess a similar disposition towards innovation, exhibit scientific inquisitiveness, and demonstrate proficiency in conducting research and inquiry (Sarıoğlu et al., 2022). When examining the study's findings, Siew et al. (2015) identify a variety of difficulties, such as a lack of resources, time, and subject-matter expertise. These challenges are significant factors to consider in Turkiye, particularly in the field of STEM education. Prior to commencing the implementation of STEM education, it is advisable to engage in talks with teachers regarding the definition and potential benefits of STEM education in order to enhance teachers' awareness (Çevik et al., 2017). Another teacher attribute that predicts success in STEM subjects is the implementation of diverse instructional approaches in the classroom. Teachers must employ several instructional strategies to ensure their students excel in various domains. Implementing project-based or collaborative techniques in STEM education, as well as including argumentation, has been shown to have a significant impact on students' achievement in STEM subjects (Çevik, 2018).

School Related Factors

Interestingly, the findings revealed that the school characteristic variable had a significant, moderately negative effect on students' STEM achievement. Among the school characteristics influencing students' STEM achievement, two crucial latent variables are the school's technology infrastructure and class size. The technology infrastructure of schools has the most significant influence among the various aspects comprising school variables. According to Bell and Bull (2008), it is recommended to leverage technology in the classroom to facilitate students' acquisition and analysis of data, enhance their creativity, and foster their scientific perspectives. Given that technology is a focal point in the original research of STEM professionals, including a wide range of tools from basic measuring instruments to advanced supercomputers (Fernandez et al., 2021), it is imperative for schools or classrooms to provide students with rapid exposure to the present-day technological landscape (Seward & Nguyen, 2019). The incorporation of STEM-specific tools or technologies is necessary to facilitate students' genuine engagement and involvement in STEM activities (Guzey & Roehrig, 2009). Since Turkiye is a developing country, the technical infrastructure of some schools may not be adequately prepared for STEM education. This finding helps explain the negative effects of teachers on STEM achievement. The pedagogical, technological, or scientific development of teachers may also be influenced by factors such as schools or curriculum, or, in other words, the level of development of the country (Hennessy et al., 2022).

The absence of technology infrastructure in the educational settings (such as schools or classrooms) where STEM applications are implemented might have a detrimental impact on STEM education. Given that the schools included in the research had a typical socioeconomic status, the inadequate technology resources in the classroom may have hindered the effectiveness of STEM education. In Turkiye, the socioeconomic situation, equipment, and

https://doi.org/10.33225/jbse/24.23.518

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

quality of human resources in schools are determinants that influence the academic achievement of students (PISA, 2016). These findings reiterate the significance of schools having access to high-quality resources, a subject that has been the focus of discussion for many years. To attain success in STEM education, it is necessary to adapt current learning settings to be conducive to STEM education. Enhancing technology infrastructure holds significant importance. These challenges encompass the provision of laboratory equipment, internet access, workshops on diverse topics such as artificial intelligence, robotics, coding, and digital games, as well as the supply of necessary technological tools and equipment for classrooms (Ortiz Rojas et al., 2017).

Class size is another influential element in determining STEM achievement in schools. The average class size in secondary schools in Turkiye is 30 or above, according to the OECD in 2017. This scenario will provide a significant obstacle to attaining the intended success in STEM education. Furthermore, Fraser (1998) has highlighted the significance of the classroom or learning environment in shaping student accomplishments and attitudes. The curriculum is one of the school elements in Turkiye that has a detrimental impact on the success of secondary school students in STEM subjects. However, it is a factor that has the least effect as found in the study. Given that STEM is a comprehensive educational approach, it is necessary for the curriculum to be designed in a cohesive and hierarchical manner. Nevertheless, in Turkiye, the curriculum for each STEM subject is distinct and autonomous (MoNE, 2017). This circumstance hinders the attainment of the anticipated achievement in education implemented through multidisciplinary techniques such as STEM.

Conclusions and Implications

This study employed structural equation modelling (SEM) to investigate the determinants of secondary school students' academic performance in STEM subjects, encompassing physics, chemistry, biology, mathematics, and information technology, within the Turkish educational context. The study delved into the personal characteristics of students, teacher effects, and school features. The findings emphasize the pivotal role of students' personal characteristics, particularly their interest and self-confidence in STEM subjects, in predicting STEM achievement. Conversely, the study revealed that teachers have a surprisingly negative impact on STEM achievement, attributed to factors such as inadequate engagement in classroom activities and insufficient expertise. Additionally, school-related factors, notably the technological infrastructure and class size, emerged as significant predictors of STEM success. The model elucidated the intricate interplay of these variables, shedding light on the multifaceted nature of STEM achievement among secondary school students in Turkiye.

The findings of this study carry significant implications for educational policy and practice in Turkiye. To enhance STEM achievement among secondary school students, interventions should focus on fostering students' interest and self-confidence in STEM subjects, as well as cultivating consistent study habits and a positive orientation towards STEM careers. Teachers play a critical role in this process and should be supported in acquiring the necessary expertise and implementing diverse instructional approaches to promote student engagement and success in STEM education. Additionally, there is a pressing need to revamp the curriculum to align with STEM education principles and foster interdisciplinary learning. In the future, researchers could look into the specific ways that these factors affect STEM achievement and come up with new ways to deal with the problems that have been identified. This would help us learn more about how to teach STEM effectively in Turkiye and beyond.

Ethical Approval

The ethics committee of Karamanoglu Mehmetbey Üniversitesi approved the data collection and research methods, the ethical approval number: E.21495

Funding

The authors express their gratitude to Princess Nourah bint Abdulrahman University Researchers Supporting Project number (PNURSP2024R583), Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia.

Declaration of Interest

The authors declare no competing interest.

https://doi.org/10.33225/jbse/24.23.518

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Received: *March 14, 2024* Revised: *April 30, 2024* Accepted: *May 17, 2024*

Cite as: Mansour, N., Cevik, M., Yağci, A., Alotaibi, S. B. M., & EL-Deghaidy, H. (2024). Modeling the factors influencing secondary students' performance in STEM subjects. *Journal of Baltic Science Education*, *23*(3), 518–535. https://doi.org/10.33225/jbse/24.23.518

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