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Integrating STEM and Mathematical Modeling in Middle School: An Investigation of Students' Motivation, Attitudes, and Modeling Competence

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Abstract: The purpose of this study is to investigate the effects of integrating STEM and an interdisciplinary modeling-oriented environment (IMOE) in middle school on students' modeling competence, motivation, and attitudes toward STEM learning. Using an explanatory sequential mixed-methods design, 64 eighth-grade students were assigned to three groups: control, STEM, and STEM with mathematical modeling. Data were collected through the STEM attitude and motivation scales, a modeling activities rubric, and semi-structured interviews. The results indicate that IMOE has a significant and positive impact on students' attitudes toward the mathematics sub-dimension of STEM and their motivation in science, engineering, and mathematics. Students' modeling competencies improved, and qualitative findings revealed increased interest in real-world applications of mathematics, with students emphasizing the nature and challenges of the problems, supportive learning factors, and encountered constraints. The study suggests that integrating IMOE into mathematics education can effectively enhance students' attitudes and motivation, particularly regarding the mathematics component of STEM.

Keywords: STEM Education, Mathematical Modeling, Eighth-Grade Students, Motivation, Attitudes

Ortaokulda STEM ve Matematiksel Modellemenin Entegrasyonu: Öğrencilerin Motivasyon, Tutum ve Modelleme Yeterliklerinin İncelenmesi

Öz: Bu çalışma, disiplinler arası modelleme odaklı bir ortamda STEM eğitiminin entegrasyonunun, ortaokul öğrencilerinin modelleme yeterlikleri, motivasyonları ve STEM öğrenmeye yönelik tutumları üzerindeki etkilerini araştırmayı amaçlamaktadır. Araştırmada açıklayıcı sıralı karma yöntem deseni kullanılmış ve 64 sekizinci sınıf öğrencisi üç gruba ayrılmıştır: kontrol, STEM ve matematiksel modelleme ile birleştirilmiş STEM grubu. Veriler STEM tutum ve motivasyon ölçekleri, modelleme etkinlikleri rubriği ve yarı yapılandırılmış görüşmeler aracılığıyla toplanmıştır. Nicel bulgular, disiplinler arası modelleme odaklı bir ortamda etkinliklere katılımın öğrencilerin STEM'in matematik boyutuna yönelik tutumlarını ve fen, mühendislik ve matematiğe yönelik motivasyonlarını anlamlı biçimde artırdığını göstermiştir. Ayrıca öğrencilerin modelleme yeterliklerinde de belirgin gelişmeler gözlenmiştir. Nitel bulgular ise öğrencilerin matematiğin gerçek yaşamla ilişkisine yönelik ilgilerinin arttığını; problem doğası ve zorlukları, destekleyici öğrenme koşulları ve süreçte karşılaşılan sınırlılıklar gibi unsurları vurguladıklarını ortaya koymuştur. Genel olarak, disiplinler arası modelleme odaklı bir ortamda matematik öğretimi entegrasyonunun, özellikle STEM'in matematik bileşenine yönelik tutum ve motivasyonu etkili biçimde geliştirebileceği sonucuna ulaşılmıştır.

Anahtar Sözcükler: STEM Eğitimi, Matematiksel Modelleme, Sekizinci Sınıf Öğrencileri, Motivasyon, Tutum

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The accelerating pace of scientific and technological advancement in the 21st century has fundamentally reshaped the skills required for both individual and societal success. Higher-order competencies such as problem solving, critical thinking, and collaboration are increasingly recognized as indispensable for national competitiveness and sustainable development (Bybee, 2013; National Research Council, 2014). As schools work to prepare students for the complexities of the modern world, STEM (Science, Technology, Engineering, and Mathematics) education has emerged as a globally recognized interdisciplinary approach that cultivates these essential skills (Moore et al., 2014; Moore & Smith, 2014).

Current research consistently demonstrates STEM education's wide-ranging benefits, including not only improved academic achievement but also increased motivation, interest, and sustained engagement with science-related careers (Christensen et al., 2015; Eccles & Wigfield, 2002; Ling et al., 2019; Wang et al., 2020). These effects are particularly notable during the middle school years—a critical period for the development of STEM attitudes and interests (Knezek et al., 2013; Maltese & Tai, 2011). Engagement in STEM activities in the middle grades can positively influence students' perceptions, reasoning skills, and inclination toward science-related fields, especially when interdisciplinary integration and culturally responsive pedagogy are emphasized (English, 2023; English & Gainsburg, 2016; Knezek et al., 2013; Moore et al., 2014).

Within the STEM paradigm, mathematics occupies a unique and foundational role. It serves as both a conceptual framework and a representational language that unifies the disciplines and enables the formulation and solution of complex problems (English, 2016; Stillman et al., 2020). Ironically, despite its centrality, mathematics is often marginalized in integrated STEM instruction, reduced to procedural calculations without substantive conceptual engagement or authentic context (English, 2016; Maass et al., 2019). This superficial treatment risks diminishing both the discipline and learners' opportunities to appreciate its power for interpreting the world (English, 2023; Tytler, 2020).

Literature Review

Integrating STEM and Mathematical Modeling

Embedding mathematical modeling (MM) within STEM learning contexts offers a promising way to counteract this tendency (Czocher et al., 2020; Doğan et al., 2019; Kertil & Gurel, 2016), as it cultivates deeper conceptual understanding (Cevikbas et al., 2025), strengthens higher-order problem-solving skills (Stillman et al., 2017; Wang et al., 2023), and fosters interdisciplinary connections essential for preparing students for real-world challenges (Czocher et al., 2020; English, 2016; Gamboa et al., 2021; Hallström & Schönborn, 2019). In this context, considering that the development of such competencies is cumulative, it is crucial to incorporate mathematical-modeling-based STEM practices into curricula beginning at an early age (Genç & Karataş, 2017; Ozturk & Cinar, 2022).

MM has increasingly been recognized as a pedagogical innovation capable of bridging these gaps. It allows students to express, analyze, and interpret real-life phenomena using mathematical structures, thereby enabling deeper interdisciplinary connections (Ärlebäck & Albarracín, 2019, 2024; Blum & Leiss, 2007; Borromeo Ferri, 2018). Modeling-based learning strengthens students' analytical and interpretive skills through engagement with reality-based scenarios, promoting not only cognitive development but also increased motivation and meaningful participation (Imaduddin et al., 2020; Rhodes & Lancaster, 2020; Wang et al., 2020; Yanar & Ergene, 2024). When rooted in authentic, culturally relevant contexts, MM supports both the cognitive and affective domains of STEM learning (Anhalt et al., 2018; Bolat & Gülcü, 2022; Turner et al., 2022).

Despite the growing theoretical and practical recognition of MM's value in STEM education, empirical research at the middle-school level remains limited and inconsistent. Many studies focus on science or engineering contexts, neglecting robust mathematical engagement and the developmental progression of modeling competence (Akarsu et al., 2020; Anhalt et al., 2018; English & King, 2019; Wang et al., 2023). Notably, Deniz and Kurt (2022), one of the few process-oriented studies in this domain, showed that eighth-grade students faced challenges in STEM-based activities related to group management and key modeling phases such as understanding the problem, establishing a model, and verification. Furthermore, systematic reviews reveal that motivational outcomes receive disproportionate attention, while the critical mathematical reasoning processes underpinning these outcomes are rarely examined in depth (Bayanova et al., 2023; English, 2023; Schuchardt & Roehrig, 2024). Turkish studies, in particular, have focused primarily on preservice teachers rather than secondary or middle-school students, leaving a significant research gap concerning students' experiences and affective development within modeling-based STEM activities (Armutcu & Bal, 2023; Gök & Demir, 2021; Kertil & Gurel, 2016).

Recent international events, such as the COVID-19 pandemic, have highlighted the societal importance of mathematical problem solving and modeling, underscoring the urgent need for educational approaches that foster critical mathematical literacy and adaptive innovation (Bakker & Wagner, 2020; Rhodes & Lancaster, 2020). MM not only supports the transfer and application of formal knowledge to complex, real-world problems, but also cultivates critical, systems, and design-based thinking that are viewed as cornerstone competencies for the twenty-first century (English, 2016, 2023; Slavit et al., 2021). However, research shows that when students cannot perceive meaningful links between mathematics and other STEM domains, both their interest and achievement may decline (Kelley & Knowles, 2016; Roberts et al., 2022).

To better understand and address these challenges, contemporary STEM and mathematics education research increasingly draws on complementary theoretical frameworks that bridge cognitive, pedagogical, and motivational perspectives. Such integration enables the development of a multi-layered and cohesive theoretical foundation for modeling-based STEM instruction—one that views learning not merely as knowledge acquisition but as a process involving positive expectancy beliefs, perceived task value, and meaningful affective engagement (English, 2016, 2023; Moore et al., 2014). This type of framework not only helps address persistent empirical gaps, particularly at the middle-school level, but also offers a blueprint for innovative instructional design, curriculum reform, and future research aimed at fostering both competence and engagement in STEM learning.

Theoretical Framework

In STEM learning, cognition and affect are intertwined; instructional quality depends not only on design but also on students' motivation and the meanings they attribute to tasks (Bayanova et al., 2023; Shankar et al., 2025). This study integrates three complementary perspectives—Borromeo Ferri's (2006) modeling cycle, the 5E Learning Model (Bybee et al., 2006), and Expectancy–Value Theory (EVT; Eccles & Wigfield, 2002)—to explain how students think, how they learn, and why they persist in modeling-based STEM activities.

In our integrated model, the modeling cycle serves as the cognitive backbone: it structures task design and performance assessment by organizing students' movement between real-world contexts and mathematical representations (Ärlebäck & Albarracín, 2019; Borromeo Ferri, 2018). Empirical work shows that using this cycle strengthens reasoning, problem solving, and modeling competencies by linking abstract ideas to concrete STEM phenomena (Arslan & İnan-Sonakalan, 2022).

The 5E model provides the pedagogical orchestration for this cognitive work. It sequences inquiry so that the modeling cycle can be embedded where students extend earlier explorations to address authentic problems—most prominently in the Elaborate phase (Bybee et al., 2006). In STEM contexts, this alignment fosters the progressive construction of interdisciplinary concepts and applications (Deng et al., 2025; Johnson et al., 2015), enabling students to apply abstract mathematics meaningfully (Moore et al., 2014).

EVT anchors the motivational pathway that sustains participation. Within this model, engagement in MM directly strengthens mathematics self-efficacy (expectancy) and indirectly elevates task value (usefulness and interest), thereby supporting persistence (Eccles & Wigfield, 2002; Wigfield et al., 2021). Prior research links high expectancy–value profiles to sustained STEM engagement and career intentions (Andersen & Ward, 2013; Perez et al., 2019) and shows that mathematics expectancy–value patterns predict cognitive effort, modeling engagement, and STEM attitudes (Adler et al., 2024; Mayerhofer et al., 2024).

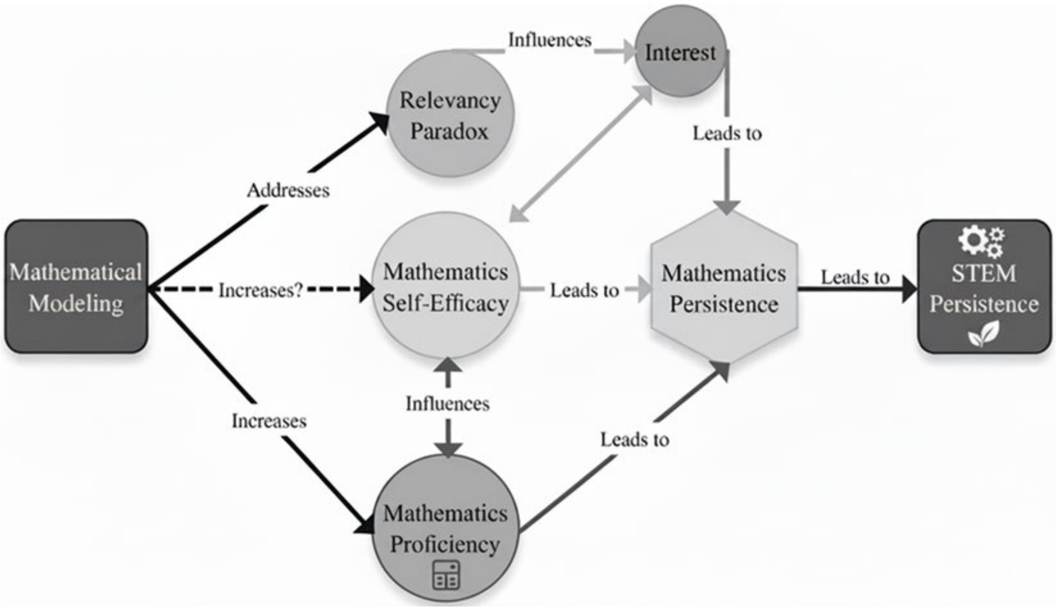

Figure 1. Conceptual model of relationships among MM, cognitive–affective factors, and STEM persistence (adapted from Czocher et al., 2020)

Figure 1 synthesizes these relations. MM exerts a direct effect on self-efficacy and an indirect effect on interest and persistence, culminating in mathematics persistence and, ultimately, STEM persistence. This pathway also addresses the relevancy paradox by positioning mathematics as useful and connected to real-world contexts, thereby elevating both expectancy and value.

Together, these components form a coherent integration model: the modeling cycle provides the cognitive engine, the 5E framework structures the instructional trajectory, and EVT explains the motivational dynamics that sustain engagement. This integrated framework underpins our analysis of how modeling-based STEM instruction strengthens middle-school students' cognitive competencies and affective engagement.

The Present Study

This study aims to examine the effects of interdisciplinary modeling-based STEM activities on eighth-grade students' modeling competence, motivation, and attitudes toward STEM learning. It seeks to bridge the cognitive depth of mathematics with the affective engagement fostered by STEM activities, thereby providing empirical evidence on how modeling processes can connect these two dimensions within a unified learning framework. Accordingly, the study addressed the following research questions:

1. Is there a statistically significant difference between the pretest and posttest scores of the Control, STEM, and STEM + MM groups regarding students' attitudes toward STEM learning?
2. Is there a statistically significant difference between the pretest and posttest scores of the Control, STEM, and STEM + MM groups regarding students' STEM motivation levels?
3. How do students in the STEM + MM group demonstrate their modeling competencies during the learning process, and how do they perceive these activities in the transition toward STEM education?

Method

Research Design

This study employed an explanatory sequential mixed-methods design (Creswell & Clark, 2017) to investigate the impact of STEM and MM interventions on middle school students' attitudes and motivation. The initial quantitative phase used a quasi-experimental pretest–posttest control group design, with participants randomly assigned to three groups: Control, STEM, and STEM+MM. The instructional flow for the experimental groups was guided by the 5E learning model (Bybee, 1997), providing a scaffold for inquiry-based learning. Concurrently, EVT (Eccles & Wigfield, 2002) offered a theoretical lens to interpret attitudinal and motivational changes by addressing students' expectancy for success and the subjective value they placed on STEM learning (Wang & Degol, 2013; Wigfield et al., 2017).

Following the quantitative analysis, a qualitative case study was conducted with students in the STEM+MM group to explain the statistical results in greater depth. In this phase, students' modeling competencies were initially analyzed per the modeling cycle phases (Borromeo Ferri, 2006). These observed competencies were then evaluated within the broader context of critical mathematical modeling, systems thinking, and adaptive thinking processes (English, 2023), using semi-structured interviews to capture students' detailed reflections (Creswell, 2014).

Participants

The sample comprised eighth-grade students from a public middle school in XXX, Türkiye, during the second semester of the 2020–2021 academic year. Criterion sampling was used to include only students who had not previously received STEM or MM instruction (Mertkan, 2015). Within the school's administrative structure, three intact classes were selected and randomly assigned to the experimental and control conditions by drawing lots. This resulted in three groups: Experimental Group 1 (STEM + MM, 10 females and 9 males, n = 19), Experimental Group 2 (STEM, 12 females and 11 males, n = 23), and the Control group (11 females and 11 males, n = 22). Groups were balanced for gender and prior academic performance to maintain baseline equivalence (Fraenkel et al., 2012; Creswell & Creswell, 2017). The gender distribution was nearly equal across groups, and the mean school achievement scores (out of 100) were closely matched, with intergroup differences within ±3 points. Informed consent was obtained from all students and their parents prior to participation. The middle school level was selected due to its critical role in developing the future STEM workforce (Knezek et al., 2013; Wang et al., 2020).

Data Collection Instruments

STEM Attitude Scale

Students' attitudes toward STEM were measured using the Attitudes Toward STEM Scale, originally developed by The Friday Institute for Educational Innovation (2012) and adapted into Turkish by Özcan and Koca (2019). This 37-item scale uses a 5-point Likert format and includes four subdimensions: mathematics, science, engineering and technology, and 21st-century skills. The reported Cronbach's alpha reliability coefficients were .91 for the overall scale, with subscale reliabilities of .86 (mathematics), .87 (science), .86 (engineering and technology), and .88 (21st-century skills) (Özcan & Koca, 2019). In the present study, the Cronbach's alpha for the scale was .77, indicating acceptable internal consistency.

STEM Motivation Scale

To assess students' motivation toward STEM, the STEM Motivation Scale developed by Luo et al. (2019) and adapted into Turkish by Dönmez (2020) was used. This 25-item instrument employs a 4-point Likert scale and includes four subdimensions: science, technology, engineering, and mathematics. In the adaptation study by Dönmez (2020), the Cronbach's alpha reliability coefficient was reported as .84 for the total scale, with subscale reliabilities of .69 (science), .72 (technology), .72 (engineering), and .80 (mathematics). In this study, the Cronbach's alpha for the total scale was .70.

Interview Form

Qualitative data were collected using a semi-structured interview form developed by the researchers. To ensure content validity, the draft form was reviewed by two experts with PhDs in mathematics education. A pilot study was then conducted over two weeks with two eighth-grade students (one female, one male) who were not part of the main sample. Based on the pilot results, the questions were deemed clear and understandable, so the form was finalized without modifications. Example questions included: What are the distinctive features of MM? Did you encounter any difficulties during the modeling activities, and at which stages? Did your views on the usefulness of mathematics in other subjects change after the implementation? The interviews provided in-depth insights into students' responses to modeling-based STEM education

(Bakker & Wagner, 2020; Moore et al., 2014).

Intervention Design, Implementation, and Data Collection

The intervention and data collection were conducted face-to-face during out-of-class hours, following parental consent. A two-week (16-hour) pilot study was conducted to refine procedures and instruments. Based on observations during this phase, one of the originally planned STEM activities was excluded due to persistent difficulties in student comprehension and implementation. Consequently, the main study proceeded with the finalized set of activities listed in Table 1. Both STEM and the interdisciplinary modeling-oriented environment (IMOE) were structured using the 5E instructional cycle, facilitating engagement and conceptual integration. In the modeling group, the 5E phases were embedded within the modeling cycle, ensuring continuity between inquiry-based exploration and model formulation (Çavuş-Erdem, 2018; Gürbüz & Doğan, 2019). This structure balanced cognitive demand with motivational support, consistent with EVT (Eccles & Wigfield, 2002; Wang et al., 2020).

All groups completed the STEM attitude and motivation scales as pretests. Experimental Group 1 engaged in IMOE integrated with STEM tasks; Experimental Group 2 participated in STEM activities only; and the Control Group received traditional instruction aligned with the national mathematics curriculum. Posttests were administered after the interventions. The total implementation lasted 44 hours over 11 weeks, with activities distributed as shown in Table 1.

Table 1. *Implemented Activities and Duration*

IMOE Activities	Duration	STEM Activities	Duration
Modeling introductory training	6h (1 week)	STEM introductory training	6 h (1 week)
Global Warming Problem (Gürbüz & Doğan, 2019)	4h (1 week)	Building a Water Bridge for Tomorrow (Muğla İl MEM, 2020)	7 h (2 weeks)
Recycling Problem (Gürbüz & Doğan, 2019)	4h (1 week)	Slope (Muğla İl MEM, 2020)	6 h (2 weeks)
Recycling Adventure Problem (Çavuş-Erdem, 2018)	3h (1 week)	Photosynthesis (Muğla İl MEM, 2020)	5 h (1 week)
Energy Saving Problem (Güder & Gürbüz, 2017)	3h (1 week)	–	–
Total	**20h (5 weeks)**	**Total**	**24 h (6 weeks)**

Qualitative Data Collection

In the qualitative phase, data were collected exclusively from Experimental Group 1 to gain deeper insights into students' modeling processes. All modeling sessions were video- and audio-recorded to capture students' actions and interactions in real time. Their engagement across the five phases of the modeling cycle was systematically evaluated using an observation form developed in alignment with the rubric adapted from Turner et al. (2014) and Borromeo Ferri (2006), ensuring consistency and reliability in coding. Observation sessions were synchronized with the activities presented in Table 1, and the observation form used for data collection is provided in Appendix A.

Following the quantitative analysis, semi-structured interviews were conducted with fifteen students who had completed all IMOE activities. These interviews provided an in-depth exploration of students' perceptions of modeling, their engagement in real-world problem solving, and the challenges they encountered (Creswell, 2014). To uphold ethical standards and promote equity, a crossover intervention was implemented after data collection: the Control Group subsequently participated in STEM activities, while Experimental Group 2 engaged in IMOE tasks. This design ensured that all participants had equitable access to similar educational opportunities.

Data Analysis

Quantitative data were analyzed using both parametric and non-parametric tests. Normality was assessed with the Shapiro–Wilk test, appropriate for small samples (Kalaycı, 2008). A significance threshold of 0.05 was applied, and the results are presented in Table 2. All analyses were conducted using SPSS version

26, and effect sizes were calculated whenever statistically significant differences were identified.

Table 2. *Shapiro-Wilk Normality Test Results for Pretest and Posttest Scores*

Scale	Group	Test	Statistic	df	p
STEM Attitude	Experimental 1	Pre	0.904	19	0.057
		Post	0.999	19	0.999
	Experimental 2	Pre	0.954	23	0.359
		Post	0.942	23	0.203
	Control	Pre	0.978	22	0.888
		Post	0.987	22	0.986
STEM Motivation	Experimental 1	Pre	0.964	19	0.649
		Post	0.959	19	0.559
	Experimental 2	Pre	0.959	23	0.446
		Post	0.964	23	0.544
	Control	Pre	0.956	22	0.413
		Post	0.914	22	0.057

Non-parametric tests were used when the data deviated from normality. Effect sizes were reported for statistically significant results.

Students' modeling performances were evaluated using a rubric adapted from Turner et al. (2014) and aligned with Borromeo Ferri's (2006) modeling cycle. The rubric consisted of six stages: (1) understanding the task, (2) simplifying/structuring the task, (3) mathematizing, (4) working mathematically, (5) interpreting, and (6) validating. Each stage was rated on a three-point scale (0 = insufficient, 1 = partially sufficient, 2 = sufficient). The criteria focused on students' ability to make and justify assumptions, interpret and simplify real-world situations, construct and apply mathematical models, and explain or validate their solutions in context. This structure allowed for a systematic and comparable evaluation of modeling competencies across the stages of the IMOE activities.

Content Analysis and Reliability

Direct quotations from participants were included, coded as K1–K19. Qualitative data from interviews were analyzed by two experts using content analysis (Miles & Huberman, 1994; Saldaña, 2011). Coding discrepancies were resolved through discussion until consensus was reached, yielding an inter-coder reliability coefficient of 0.92, exceeding the accepted threshold for qualitative research.

Ethical Approval

This study received ethical clearance from the Van Yuzuncu Yil University Social and Human Sciences Ethics Committee (17.02.2021; Decision No: 2021/02-05), and appropriate permissions were obtained from the relevant Provincial Directorate of National Education. Prior to data collection, the purpose and scope of the study were explained to both the students and their legal guardians. Written informed consent was obtained from all parents, and verbal assent was secured from the students, with the understanding that participation was entirely voluntary and that they could withdraw at any time without consequence. To ensure confidentiality and anonymity, participants' personal identifying information was replaced with codes (e.g., K1, K2) during data analysis and reporting. All collected data were stored in secure, password-protected files accessible only to the research team and were used solely for scientific purposes.

Results

The results of the data analyses are presented under subheadings corresponding to the research questions.

Findings Related to Attitudes Toward STEM

Total scores from the Attitudes Toward STEM Scale were normally distributed across all groups in both the pretest and posttest. Therefore, one-way ANOVA and post-hoc tests (Tukey and Tamhane's T2) were conducted to compare group differences. Table 3 presents the ANOVA results.

Table 3. *One-way ANOVA Results for Attitudes toward STEM Scale*

Measure	Source	Sum of Squares	df	Mean Square	F	p
Pretest	Between Groups	1684.645	2	842.322	1.130	.330
	Within Groups	45480.090	61	745.575		
	Total	47164.734	63			
Posttest	Between Groups	5735.086	2	2867.543	5.380	.007
	Within Groups	32510.774	61	532.964		
	Total	38245.859	63			

Pretest total scores on the Attitudes Toward STEM Scale did not differ across the Control, STEM, and MM+STEM groups, confirming baseline equivalence, $F(2,61) = 1.13$, $p = .33$ (Table 3). At posttest, a significant omnibus difference emerged, $F(2,61) = 5.38$, $p = .007$. Levene's test results for homogeneity of variance are presented in Table 4.

Table 4. *Levene's Test for Homogeneity of Variance*

Measure	Levene Statistic (F)	df1	df2	p
Pretest	4.093	2	61	.021
Posttest	2.811	2	61	.068

Since the pretest scores violated the assumption of homogeneity ($p = .021$), Tamhane's T2 test was used for pretest comparisons. For posttest scores, the assumption was met ($p = .068$), so Tukey's test was applied. Table 5 summarizes the post-hoc test results.

Table 5. *Post-hoc Test Results for Attitudes toward STEM Scale*

Measure	Group 1	Group 2	Mean Difference	Std. Error	p	95% CI Lower	95% CI Upper
Pretest	Exp. 1	Exp. 2	-12.03	9.58	.520	-35.94	11.88
	Exp. 1	Control	-10.11	8.07	.526	-30.58	10.36
	Exp. 2	Control	1.92	7.59	.992	-17.10	20.93
Posttest	Exp. 1	Exp. 2	10.73	7.16	.299	-6.47	27.92
	Exp. 1	Control	23.60*	7.23	.005	6.23	40.97
	Exp. 2	Control	12.88	6.88	.156	-3.66	29.42

**Statistically significant at $p < .05$.*

Tukey's test indicated that MM+STEM outperformed the Control group (mean difference = 23.60, $p = .005$); no other pairwise comparisons were significant (Table 5). Further analyses were conducted for each subscale of the Attitudes Toward STEM Scale to identify the dimensions contributing to the observed differences. Since some subscales did not meet the assumption of normality, Kruskal–Wallis tests were performed (Table 6).

Table 6. *Kruskal–Wallis Test Results for STEM Attitude Subscales*

Measure	Subscale	Group	N	Mean Rank	Chi-square	df	p
Pretest	Mathematics	Exp. 1	19	26.34	3.522	2	.172
		Exp. 2	23	37.11			
		Control	22	33.00			
	Science	Exp. 1	19	27.76	2.503	2	.286
		Exp. 2	23	36.85			
		Control	22	32.05			
	Engineering & Technology	Exp. 1	19	30.16	0.731	2	.694
		Exp. 2	23	32.00			
		Control	22	35.05			
	21st Century Skills	Exp. 1	19	29.21	0.846	2	.655
		Exp. 2	23	33.96			
		Control	22	33.82			

Posttest	Mathematics	Exp. 1	19	45.13	17.531	2	.000
		Exp. 2	23	33.24			
		Control	22	20.82			
	Science	Exp. 1	19	36.76	5.636	2	.060
		Exp. 2	23	36.26			
		Control	22	24.89			
	Engineering & Technology	Exp. 1	19	36.42	1.900	2	.387
		Exp. 2	23	33.11			
		Control	22	28.48			
	21st Century Skills	Exp. 1	19	39.63	4.725	2	.094
		Exp. 2	23	31.80			
		Control	22	27.07			

To identify which dimensions drove the effect, Kruskal–Wallis tests were conducted for subscales that violated normality. Only the Mathematics subscale differed significantly among groups, $\chi^2(2) = 17.53$, $p < .001$: MM+STEM showed the highest attitudes (mean rank = 45.13), followed by STEM (33.24) and Control (20.82) (Table 6). The effect of MM+STEM versus Control on Mathematics was large ($\eta^2 = .45$). No significant group differences were found for Science, Engineering & Technology, or 21st-Century Skills.

Findings Related to STEM Motivation

The results addressing students' motivation toward STEM are presented in line with the second research question. One-way ANOVA results for the total scores on the STEM Motivation Scale are shown in Table 7.

Table 7. *One-way ANOVA Results for STEM Motivation Scale Total Scores*

Measure	Source of Variance	Sum of Squares	df	Mean Square	F	p
Pretest	Between Groups	130.500	2	65.250	0.541	.585
	Within Groups	7357.437	61	120.614		
	Total	7487.938	63			
Posttest	Between Groups	4244.252	2	2122.126	25.170	.000*
	Within Groups	5142.982	61	84.311		
	Total	9387.234	63			

Pretest analyses revealed no statistically significant differences among the groups ($p = .585$), indicating initial equivalence in STEM motivation. In contrast, posttest results demonstrated a statistically significant difference in overall STEM motivation across the three groups ($p = .000$).

Table 8. *Levene's Test for Homogeneity of Variance (STEM Motivation Scale)*

Measure	Levene Statistic (F)	df_1	df_2	p
Pretest	0.280	2	61	.756
Posttest	0.309	2	61	.736

Note. Homogeneity assumptions were met for both pre- and posttest scores ($p > .05$).

Levene's tests confirmed homogeneity at both time points (Table 8). Post-hoc comparisons (Table 9) indicated that Experimental Group 1 (STEM + MM) scored higher than Experimental Group 2 (STEM only; $p < .001$) and the Control Group ($p < .001$); Experimental Group 2 also outperformed the Control Group ($p = .025$).

Table 9. *Post-hoc (Tukey and Tamhane's T2) Results for STEM Motivation Scale Total Scores*

Measure	Group 1	Group 2	Mean Difference	Std. Error	p	95% CI Lower	95% CI Upper
Pretest	Exp. 1	Exp. 2	3.48	3.40	.567	−4.70	11.65
	Exp. 1	Control	1.33	3.44	.921	−6.93	9.59
	Exp. 2	Control	−2.15	3.28	.790	−10.02	5.72
Posttest	Exp. 1	Exp. 2	12.91*	2.85	.000	6.07	19.74
	Exp. 1	Control	20.26*	2.88	.000	13.35	27.16
	Exp. 2	Control	7.35*	2.74	.025	0.77	13.93

*Note. * p < .05.*

Subscale analyses using Kruskal–Wallis tests (Table 10) found no pretest differences. Posttest differences emerged in Science, $\chi^2(2) = 25.52$, $p < .001$; Engineering, $\chi^2(2) = 22.91$, $p < .001$; and Mathematics, $\chi^2(2) = 23.56$, $p < .001$; Technology was not significant ($p = .141$).

Table 10. *Kruskal–Wallis Test Results for STEM Motivation Subscales*

Measure	Subscale	Group	n	Mean Rank	χ²	df	p
Pretest	Science	Exp. 1	19	30.05	0.58	2	.748
		Exp. 2	23	34.41			
		Control	22	32.61			
	Technology	Exp. 1	19	32.21	3.33	2	.189
		Exp. 2	23	27.70			
		Control	22	37.77			
	Engineering	Exp. 1	19	40.03	5.16	2	.076
		Exp. 2	23	27.09			
		Control	22	31.66			
	Mathematics	Exp. 1	19	35.05	0.86	2	.650
		Exp. 2	23	33.02			
		Control	22	29.75			
Posttest	Science	Exp. 1	19	47.82	25.52	2	.000
		Exp. 2	23	33.20			
		Control	22	18.55			
	Technology	Exp. 1	19	39.11	3.92	2	.141
		Exp. 2	23	31.57			
		Control	22	27.77			
	Engineering	Exp. 1	19	47.92	22.91	2	.000
		Exp. 2	23	31.57			
		Control	22	20.16			
	Mathematics	Exp. 1	19	48.55	23.56	2	.000
		Exp. 2	23	30.70			
		Control	22	20.52			

Note. Significant posttest differences were observed in Science, Engineering, and Mathematics subscales ($p < .05$).

Mann–Whitney pairwise tests (Table 11) showed that Experimental Group 1 exceeded Experimental Group 2 in Science ($p = .007$, $\eta^2 = .176$), Engineering ($p = .002$, $\eta^2 = .321$), and Mathematics ($p = .002$, $\eta^2 = .230$), and outperformed the Control Group in Science ($p < .001$, $\eta^2 = .600$), Engineering ($p < .001$, $\eta^2 = .507$), and Mathematics ($p < .001$, $\eta^2 = .581$). Experimental Group 2 also scored higher than the Control Group in Science ($p = .006$, $\eta^2 = .174$) and Engineering ($p = .022$, $\eta^2 = .118$); Technology showed no significant pairwise differences, and Mathematics did not differ between Experimental Group 2 and Control ($p = .070$).

Table 11. *Mann–Whitney U Pairwise Comparisons for STEM Motivation Subscales (Posttest)*

Subscale	Comparison	n_1	n_2	Median 1	Median 2	U	Z	p	η²
Science	Exp. 1 vs Exp. 2	19	23	23	19	113.50	−2.68	.007 *	.176
	Exp. 1 vs Control	19	22	23	16	23.00	−4.90	.000 *	.600
	Exp. 2 vs Control	23	22	19	16	132.00	−2.77	.006 *	.174
Technology	Exp. 1 vs Exp. 2	19	23	22	21	163.00	−1.41	.158	–
	Exp. 1 vs Control	19	22	22	20	139.00	−1.85	.065	–
	Exp. 2 vs Control	23	22	21	20	219.00	−0.78	.436	–
Engineering	Exp. 1 vs Exp. 2	19	23	17	13	97.00	−3.08	.002 *	.321
	Exp. 1 vs Control	19	22	17	10	37.50	−4.50	.000 *	.507
	Exp. 2 vs Control	23	22	13	10	153.00	−2.28	.022 *	.118
Mathematics	Exp. 1 vs Exp. 2	19	23	26	20	97.50	−3.07	.002 *	.230
	Exp. 1 vs Control	19	22	26	17.5	25.00	−4.82	.000 *	.581
	Exp. 2 vs Control	23	22	20	17.5	173.50	−1.81	.070	–

Note. * $p < .05$. Effect sizes (η^2) indicate large effects for significant results.

Overall, both experimental conditions improved STEM motivation relative to the Control Group, with MM-integrated STEM yielding the largest and most consistent gains—particularly in Science, Engineering, and Mathematics—consistent with expectancy–value theory (Eccles & Wigfield, 2002).

Findings Related to Students' Experiences and Views

During the IMOE implementation in Experimental Group 1, student groups were reorganized after each session to promote diverse collaboration. Student engagement with MM was analyzed through their performance on four authentic problems, evaluated using the modeling cycle framework (Borromeo Ferri, 2006). The groups' competencies for each problem—coded as T1 (Global Warming), T2 (Recycling), T3 (Recycling Adventure), and T4 (Energy Saving)—are presented in Table 12.

Table 12. *Groups' Competencies in MM Tasks*

Task	Groups	Understanding	Simplifying	Mathematizing	Working mathematically	Interpreting	Validating
T1	G1-4	1,1,1,2	1,1,1,2	1,1,1,1	0,1,1,1	0,0,1,1	0-0-0-0
T2	G1-3	2,2,1	2,2,1	1,2,1	1,2,1	0,2,0	0-0-0-0
T3	G1-3	2,2,2	2,2,1	2,1,1	2,1,1	2,2,2	0-0-0-0
T4	G1-3	2,2,2	2,2,2	2,2,2	2,2,2	2,2,2	0-0-0-0

Note. 0 = Insufficient, 1 = Partially sufficient, 2 = Sufficient. G1-4: G1, G2, G3, G4 respectively.

The analysis revealed that students progressed notably across the earlier stages of the modeling cycle—from *understanding* to *interpreting*—showing increasing sufficiency through repeated practice (T1–T4). However, none of the groups demonstrated competency in the validation stage, with all scores remaining at zero. This pattern aligns with Borromeo Ferri's (2006) distinction between intuitive and *knowledge-based validation*, suggesting that students relied primarily on internal or "inner-mathematical" checks rather than evaluating the correspondence of their models with real-world situations. In other words, validation was largely limited to recalculating results instead of assessing their realism or contextual plausibility. The absence of explicit real-world validation highlights a persistent gap between mathematical reasoning and situational interpretation, emphasizing the need for instructional scaffolds that promote conscious, knowledge-based validation.

Representative student responses were analyzed across each stage of the modeling process to illustrate varying levels of understanding and competence. During the understanding-the-task stage, some students demonstrated a clear grasp of the problem requirements. For instance, one student stated, "*What is asked from us is to find how many trees are needed to offset the carbon dioxide produced by a family in one year*" (T1–Group 4). Others displayed only partial understanding, such as, "*We are asked to calculate the carbon footprint of the items we use*" (T1–Group 3).

At the simplifying-the-task stage, students attempted to make reasonable assumptions to narrow down the problem. A sufficient response was, "*First, we should determine the average number of people in a family... and use proportional reasoning to find the yearly amounts*" (T1–Group 4). Subsequently, a partially sufficient explanation reflected limited justification: "*We assumed there are six people in a family and estimated usage time for the items accordingly*" (T1–Group 2).

During mathematizing, students transitioned from qualitative reasoning to quantitative representation. One group reported, "*We checked online for dimensions... sketched the structure and calculated measurements based on bottle sizes*" (T2–Group 2), demonstrating strong mathematization skills. Another group struggled with abstraction: "*We decided on a cylindrical shape but couldn't decide how to make the roof*" (T2–Group 1).

In the working-mathematically phase, competence varied. A sufficient response reflected procedural accuracy: "*Calculated surface area and fabric size precisely for the structure*" (T3–Group 1), while others relied on estimations: "*Estimated emissions, divided by absorption rate, found an approximate answe*r" (T1–Group 3) or "*Couldn't calculate exactly; tried to estimate*" (T1–Group 1).

During interpreting, students evaluated the plausibility of their results to varying extents. One group verified their solution systematically: "*Verified bottle counts matched calculated dimensions for the playhouse; confirmed solution's plausibility*" (T2–Group 2). Others expressed uncertainty: "*Our result included some factors, but others might affect the outcome*" (T1–Group 3), or minimal evaluation, as in "*Checked calculations; assumed correctness*" (T1–Group 2).

Students who engaged more deeply in problem interpretation and iterative refinement generally achieved higher modeling competency. Partial sufficiency often reflected incomplete data use or limited critical review. The most persistent difficulties emerged during the transition to model explanation, revealing challenges in linking mathematical outcomes to real-world contexts.

Students' reflections on their modeling experiences were also analyzed thematically. Twenty-three codes were identified under three overarching themes: nature and challenges of the task, supportive factors related to learning and teaching, and limitations and constraints (Table 13).

Table 13. *Thematic Analysis of Students' Views on Modeling Experience*

Theme	Subthemes (Frequency)
Nature and Challenges of the task	Long questions (11); Group work (11); Extended duration (10); Difficult problems (4); Multiple stages (4); Calculations (3); Interpretation (6); Model construction (1); Scientific conclusion (1); Presentation (1)
Supportive Factors	LGS exam relevance (4); Problem solving (4); Mathematical knowledge (6); Peer learning (3); Enjoyment (3); Estimation (3); Real-life connections (10); Importance of mathematics (7); Interdisciplinary relations (6); Checking–verification (8); Multiple solutions (9)
Limitations and Constraints	Lack of help/hints (1); Assumptions (1)

Students identified three principal facets of their experience corresponding to the themes presented in Table 13, illustrating the cognitive and affective depth fostered by the intervention. Regarding the "Nature and Challenges of the Task," the complexity of the problems was frequently cited. Codes such as "Long Questions" (f = 11) and "Extended Duration" (f = 10) initially appeared as hurdles; however, students reframed these challenges as opportunities for growth. As one student noted, "The questions being very long was somewhat negative... but it helped me not to be afraid of long questions anymore" (K15). This resilience reflects the emergence of *adaptive thinking* (English, 2023), where learners adjust their cognitive strategies to manage complex, non-routine tasks.

Under the theme of "Supportive Factors," the code "Group Work" (f = 11) emerged as a critical driver for collaborative problem-solving. While some students noted difficulties in reaching consensus—"Sometimes we couldn't agree on a single idea" (K3)—others emphasized, "Working in a group allowed us to see different perspectives" (K6). This negotiation of meaning is central to *systems thinking* (English, 2023), as students learned to integrate diverse viewpoints to understand the problem as a whole. Furthermore, the high frequency of "Real-life Connections" (f = 10) and "Interdisciplinary Relations" (f = 6) indicates that students began to view mathematics not as an isolated discipline but as a tool for interpreting complex systems. As K7 remarked, "I understood much better how mathematics is related to daily life," reflecting a shift from procedural calculations to contextualized systems reasoning.

Finally, the analysis revealed significant shifts in students' epistemic beliefs, aligning with critical and adaptive ways of thinking (English, 2023). The codes "Multiple Solutions" (f = 9) and "Checking–Verification" (f = 8) highlight this transformation. Students moved away from seeking a single correct answer toward valuing flexibility and validation. One student stated, "Before, there was only one correct answer; now I see that a question can have several" (K5), demonstrating adaptive thinking in handling open-endedness. Similarly, the realization that "Normally, we didn't check our answers, but I realized how important it is" (K9) points to the development of critical thinking, where students actively evaluate the validity of their models against real-world constraints. Despite limitations, such as a "Lack of Help/Hints," the findings suggest that the modeling environment, structured by the 5E model, successfully cultivated the multifaceted ways of thinking essential for STEM literacy.

Discussion

This study demonstrates that MM serves as the cognitive core of STEM integration, the 5E instructional model provides essential scaffolding for inquiry and reflection, and EVT clarifies the psychological mechanisms that sustain student engagement.

The Role of Mathematical Modeling in STEM Integration

MM allows students to represent real-world phenomena through formal mathematical constructs, thereby enhancing both conceptual understanding and applied reasoning. This dual role of modeling—as both a cognitive process and a learning environment—aligns with the frameworks proposed by Blum and Niss (1989) and elaborated by Blum (1991). In this study, students initially faced difficulties in constructing and validating models, reflecting challenges identified in the qualitative analysis, such as "Long Questions" and "Difficult Problems" (Table 13). However, their progressive improvement throughout the intervention highlights the capacity of authentic modeling tasks to foster sustained engagement and the gradual internalization of mathematical reasoning. Similar trends have been documented internationally; for example, Corrêa (2021) and Çavuş-Erdem et al. (2021) found that students' mathematical competencies improved even when their models were incomplete, underscoring the intrinsic value of the modeling process. Additionally, Tasarib et al. (2025) emphasized in their systematic review that, while modeling promotes higher-order thinking, the validation phase remains particularly challenging—a finding consistent with students' experiences in this study.

Modeling-based STEM instruction also appears to strengthen interdisciplinary awareness and collaborative practices. Armutcu and Bal (2023) reported that MM within STEM enhanced middle-school students' modeling competencies, interest in engineering and technology, thinking skills, and adaptation to group work. This aligns with the present study's qualitative finding that "Group Work" supported meaning-making and perspective taking. Likewise, Gamboa et al. (2021) showed that integrating modeling into science topics, such as population growth, engaged learners in authentic scientific–mathematical practices and deepened extra-mathematical connections. Collectively, these results suggest that MM functions as a unifying cognitive mechanism in STEM, enabling students to experience mathematics as dynamic and applicable. Supporting this applicability, modeling activities designed in university-based out-of-school learning environments strengthen the theory–practice bridge and authentic STEM connections by allowing students to transform discipline-specific experiences gained in research facilities and laboratories into technology-supported mathematical models (Gök & Yılmaz, 2025).

Beyond skill development, modeling-rich environments also influence motivation and affect. Manunure and Leung (2024) reported improvements in both conceptual understanding and STEM attitudes, while Bayanova et al. (2023) highlighted motivation as central to sustained participation. In higher education, Czocher et al. (2020) observed increases in mathematics self-efficacy following MM interventions, likely driven by authentic engagement and collaborative work. Consistent with these findings, the present study suggests that motivational gains may precede or exceed attitudinal shifts, indicating that extended exposure may be necessary for lasting attitudinal change—a trajectory commonly noted in affective research.

Creativity represents another salient dimension. MM fosters creative reasoning by supporting problem formulation and flexible thinking—skills closely tied to modeling competence and motivation. Okamoto et al. (2023) demonstrated that engagement with Fermi-type estimation problems—simplified modeling tasks—is strongly associated with mathematical creativity. From this perspective, creativity is integral to modeling rather than ancillary; open-ended, authentic modeling can simultaneously enhance competence, creative reasoning, and motivational engagement.

Structured Learning Through the 5E Model

The results further indicate that integrating modeling with structured STEM practices produces stronger motivational outcomes than STEM-only interventions. This aligns with research on 5E-based STEM instruction (Ha et al., 2023), which shows that students benefit most when inquiry-based learning is scaffolded across the stages of engagement, exploration, explanation, elaboration, and evaluation. Similarly, recent studies in mathematics education have demonstrated that the 5E model, when combined with pedagogical tools such as concept cartoons, effectively enhances both academic achievement and retention (Yılmaz & Usta, 2024), supporting the model's efficacy in structuring mathematical learning. Although the current intervention did not explicitly follow the 5E sequence, students' progressive mastery of the modeling phases reflected the advantages of such structured scaffolding, facilitating both active exploration and reflective synthesis. A more explicit implementation of the 5E framework—incorporating systematic feedback and argumentation—could plausibly further improve both affective and cognitive outcomes, particularly regarding STEM-related attitudes. This view is reinforced by national reports emphasizing that elements like systematic feedback and peer interaction within structured STEM practices are critical for holistic student development (Akgündüz et al., 2015).

Motivational Mechanisms Explained by Expectancy-Value Theory

EVT (Eccles & Wigfield, 2002) offers a compelling explanation for the observed motivational gains, particularly in mathematics. Students in the MM+STEM group developed stronger beliefs in their ability to succeed (expectancy) and perceived mathematics as more meaningful and useful (value). Integrating modeling, which situates mathematics within authentic, real-world contexts, enhances perceived utility value—a key motivational factor (Lopes, 2022). This theoretical perspective is strongly supported by students' qualitative feedback, especially the high frequency of the codes "Real-life Connections" and "Importance of Mathematics" (Table 13). These reflections indicate that students began to see mathematics not merely as an abstract school subject, but as a critical tool for understanding the world. Similarly, Fong et al. (2020) found that expectancy–value profiles mediate students' engagement in STEM. Thus, the observed increase in mathematical motivation in this study likely results from a dual mechanism: enhanced self-efficacy through successful problem-solving experiences and elevated task value through meaningful, contextualized application.

Conclusion

This study provides empirical evidence that integrating MM within STEM instruction substantially enhances middle school students' motivation, attitudes, and modeling competence, particularly in the mathematics dimension of STEM learning. The experimental findings showed that, while all students benefited from STEM-based instruction, those in the IMOE (MM+STEM) group achieved the greatest cognitive and affective gains. Statistically significant improvements were observed in attitudes toward mathematics and in motivation across the Science, Engineering, and Mathematics subdomains, with large effect sizes. These results indicate that MM serves as a catalyst for deeper engagement by linking abstract concepts to authentic, real-world contexts.

Students' progressive development across the modeling cycle—from problem interpretation to model construction and explanation—demonstrates the potential of modeling-based learning to cultivate problem-solving and reasoning skills. Qualitative findings further revealed that modeling activities promoted autonomy, collaboration, and metacognitive reflection, consistent with inquiry-oriented frameworks such as the 5E instructional model. Through iterative engagement, students began to perceive mathematics as meaningful, applicable, and interconnected with other STEM fields, reflecting the internalization of both expectancy (belief in success) and value (perceived usefulness) as described by EVT (Eccles & Wigfield, 2002).

Overall, these findings highlight that the integration of MM and STEM not only enhances conceptual understanding but also strengthens the affective foundations essential for sustained participation in STEM education. By providing authentic, interdisciplinary problem contexts supported by structured inquiry, educators can bridge the gap between mathematics learning and real-world applicability, fostering both competence and motivation among students during the critical middle school years.

Limitations and Future Research

In this study, the limited duration of the intervention constrained the observation of long-term effects, particularly for affective variables such as attitudes. Additionally, the research involved only eighth-grade students from a specific region, limiting the generalizability of the findings across different age groups and educational contexts.

Future research could investigate the long-term retention effects of modeling-based STEM instruction through extended interventions spanning multiple grade levels. The impact of MM interventions explicitly structured using the 5E instructional model could also be experimentally examined to evaluate how guided inquiry stages contribute to the development of motivation and self-efficacy. Quantitative analyses grounded in EVT (e.g., mediation models) may help clarify the indirect effects of students' expectancy beliefs and value perceptions on motivation. Finally, exploring factors such as teacher competencies, classroom interaction patterns, and the integration of technological tools could provide valuable insights into how these elements influence students' engagement and achievement in modeling-based STEM learning.

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References

Adler, R. M., Rittle-Johnson, B., Hickendorff, M., & Durkin, K. (2024). A longitudinal examination of the relations between motivation, math achievement, and STEM career aspirations among Black students. *Contemporary Educational Psychology*, *76*, 102240. https://doi.org/10.1016/j.cedpsych.2023.102240

Akarsu, M., Akçay, N. O., & Elmas, R. (2020). STEM eğitimi yaklaşımının özellikleri ve değerlendirilmesi [Characteristics and evaluation of STEM education approach]. *Boğaziçi University Journal of Education*, *37*, 155-175.

Akgündüz, D., Aydeniz, M., Çakmakçı, G., Çavaş, B., Çorlu, M., Öner, T., & Özdemir, S. (2015). *STEM eğitimi Türkiye raporu: Günümüz modası mı yoksa gereksinim mi?* [STEM education Turkey report: A temporary fad or a necessity?]. Istanbul Aydin University STEM Center.

Andersen, L., & Ward, T. J. (2013). An expectancy-value model for the STEM persistence of ninth-grade, underrepresented minority students. In R. T. Palmer & J. L. Wood (Eds.), *Community colleges and STEM: Examining student success* (pp. 79–94). Routledge.

Anhalt, C. O., Cortez, R., & Bennett, A. B. (2018). The emergence of mathematical modeling competencies: An investigation of prospective secondary mathematics teachers. *Mathematical Thinking and Learning*, *20*(3), 202-221. https://doi.org/10.1080/10986065.2018.1474532

Ärlebäck, J. B., & Albarracín, L. (2019). The use and potential of Fermi problems in the STEM disciplines to support the development of twenty-first century competencies. *ZDM*, *51*(6), 979-990. https://doi.org/10.1007/s11858-019-01075-3

Ärlebäck, J. B., & Albarracín, L. (2024). Lessons learned from research on Fermi problems and mathematical modelling: Theoretical and practical implications for school STEM education. In T. Barkatsas (Ed.), *The contribution of mathematics to school STEM education: Current understandings* (pp. 201-219). Springer.

Armutcu, Y., & Bal, A. P. (2023). The effect of mathematical modeling activities on students' mathematical modeling skills in the context of STEM education. *International Journal of Contemporary Educational Research*, *10*(1), 42-55. https://doi.org/10.33200/ijcer.1131928

Arslan, T., & İnan Sonakalan, E. (2022). STEM eğitimi almış sınıf öğretmenlerinin derslerde STEM uygulamalarına yer verememelerinin gerekçeleri [The reasons of classroom teachers who can not reflect the STEM education received in classroom practices]. *Journal of Social and Humanities Sciences Research*, *9*(82), 667-679. http://dx.doi.org/10.26450/jshsr.3047

Bakker, A., & Wagner, D. (2020). Pandemic: lessons for today and tomorrow? *Educational Studies in Mathematics*, *104*(1), 1–4. https://doi.org/10.1007/s10649-020-09946-3

Bayanova, A. R., Orekhovskaya, N. A., Sokolova, N. L., Shaleeva, E. F., Knyazeva, S. A., & Budkevich, R. L. (2023). Exploring the role of motivation in STEM education: A systematic review. *EURASIA Journal of Mathematics, Science and Technology Education*, *19*(4), em2250. https://doi.org/10.29333/ejmste/13086

Blum, W. (1991). Applications and modelling in mathematics teaching – A review of arguments and instructional aspects. In M. Niss, W. Blum, & I. Huntley (Eds.), *Modelling applications* (pp. 10–29). Ellis Horwood.

Blum, W., & Leiss, D. (2007). How do students and teachers deal with modelling problems? In C. Haines, P. Galbraith, W. Blum, & S. Khan (Eds.), *Mathematical modelling: Education, engineering and economics—ICTMA 12* (pp. 222–231). Horwood.

Blum, W., & Niss, M. (1989). Mathematical problem solving, modelling, application, and links to other subjects – State, trends and issues in mathematics instruction. In M. Niss, W. Blum, & I. Huntley (Eds.), *Modelling applications and applied problem solving* (pp. 1–19). Halsted Press.

Bolat, Y. İ., & Gülcü, A. (2022). *STEM temelli matematik uygulamaları*. Efe Akademi Yayınları.

Borromeo Ferri, R. (2006). Theoretical and empirical differentiations of phases in the modelling process. *Zentralblatt für Didaktik der Mathematik*, *38*(2), 86–95. https://doi.org/10.1007/bf02655883

Borromeo Ferri, R. (2018). *Learning how to teach mathematical modeling in school and teacher education*. Springer. https://doi.org/10.1007/978-3-319-68072-9

Bybee, R. W. (1997). *Achieving scientific literacy: From purposes to practices*. Heinemann.

Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities*. NSTA Press.

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). *The BSCS 5E instructional model: Origins, effectiveness, and applications* (Full report). BSCS. https://bscs.org/wp-content/uploads/2022/01/bscs_5e_full_report-1.pdf

Cevikbas, M., Mießeler, D., & Kaiser, G. (2025). Pre-service mathematics teachers' experiences and insights into the benefits and challenges of using explanatory videos in flipped modelling education. *ZDM – Mathematics Education*, 1–14. https://doi.org/10.1007/s11858-025-01650-x

Christensen, R., Knezek, G., & Tyler-Wood, T. (2015). Alignment of hands-on STEM engagement activities with positive STEM dispositions in secondary school students. *Journal of Science Education and Technology*, *24*(6), 898–909. https://doi.org/10.1007/s10956-015-9572-6

Corrêa, P. D. (2021). The mathematical proficiency promoted by mathematical modelling. *Journal of Research in Science, Mathematics and Technology Education*, *4*(2), 107–131. https://doi.org/10.31756/jrsmte.424

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches* (4th ed.). Sage.

Creswell, J. W., & Clark, V. L. P. (2017). *Designing and conducting mixed methods research* (3rd ed.). Sage.

Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). Sage.

Czocher, J. A., Melhuish, K., & Kandasamy, S. S. (2020). Building mathematics self-efficacy of STEM undergraduates through mathematical modelling. *International Journal of Mathematical Education in Science and Technology*, *51*(6), 807–834. https://doi.org/10.1080/0020739X.2019.1634223

Çavuş-Erdem, Z. (2018). *Matematiksel modelleme etkinliklerine dayalı öğrenim sürecinin alan ölçme konusu bağlamında incelenmesi* (Investigation of the learning process based on mathematical modeling activities in the context of area measurement) [Doctoral dissertation]. Adıyaman University.

Çavuş-Erdem, Z., Doğan, M. F., & Gürbüz, R. (2021). Ortaokul öğrencilerinin disiplinler arası matematiksel modelleme becerilerinin incelenmesi [Investigation of middle school students' interdisciplinary mathematical modeling skills]. *Cumhuriyet International Journal of Education*, *10*(4), 1763–1788. https://doi.org/10.30703/cije.927243

Deng, W., Chen, G., & Feng, R. (2025). The STEM curriculum integration through big ideas and learning progression frameworks: Attitudes and insights from teacher and student. *Research in Science & Technological Education*, 1–17. https://doi.org/10.1080/02635143.2025.2555184

Deniz, Ş., & Kurt, G. (2022). Investigation of mathematical modeling processes of middle school students in model-eliciting activities (MEAs): A STEM approach. *Participatory Educational Research*, *9*(2), 150–177. https://doi.org/10.17275/per.22.34.9.2

Doğan, M. F., Gürbüz, R., Çavuş-Erdem, Z., & Şahin, S. (2019). Using mathematical modeling for integrating STEM disciplines: A theoretical framework. *Turkish Journal of Computer and Mathematics Education*, *10*(3), 628–653. https://doi.org/10.16949/turkbilmat.502007

Dönmez, İ. (2020). STEM motivasyon ölçeğinin Türkçe'ye uyarlanması: Geçerlik ve güvenirlik çalışması [Adaptation of STEM motivation scale into Turkish: Validity and reliability study]. *YYU Journal of Education Faculty*, *17*(1), 486–510. https://doi.org/10.33711/yyuefd.693825

Eccles, J. S., & Wigfield, A. (2002). Motivational beliefs, values, and goals. *Annual Review of Psychology*, *53*, 109–132.

https://doi.org/10.1146/annurev.psych.53.100901.135153

English, L. D. (2016). STEM education K-12: Perspectives on integration. *International Journal of STEM Education*, *3*, Article 3. https://doi.org/10.1186/s40594-016-0036-1

English, L. D. (2023). Ways of thinking in STEM-based problem solving. *ZDM – Mathematics Education*, *55*(6), 1219–1230. https://doi.org/10.1007/s11858-023-01474-7

English, L. D., & Gainsburg, J. (2016). Problem solving in a 21st-century mathematics curriculum. In L. D. English & D. Kirshner (Eds.), *Handbook of international research in mathematics education* (3rd ed., pp. 313–335). Routledge.

English, L. D., & King, D. (2019). STEM integration in sixth grade: Designing and constructing paper bridges. *International Journal of Science and Mathematics Education*, *17*(5), 863–884. https://doi.org/10.1007/s10763-018-9912-0

Fong, C. J., & Kremer, K. P. (2020). An expectancy-value approach to math underachievement: Examining high school achievement, college attendance, and STEM interest. *Gifted Child Quarterly*, *64*(2), 67–84. https://doi.org/10.1177/0016986219890599

Fraenkel, J. R., Wallen, N. E., & Hyun, H. H. (2012). *How to design and evaluate research in education* (8th ed.). McGraw-Hill.

Friday Institute for Educational Innovation. (2012). *Middle and high school STEM-student survey*. North Carolina State University.

Gamboa, G. D., Badillo, E., Couso, D., & Márquez, C. (2021). Connecting mathematics and science in primary school STEM education: Modeling the population growth of species. *Mathematics*, *9*(19), 2496. https://doi.org/10.3390/math9192496

Genç, M., & Karataş, İ. (2017). Problem çözme süreçlerinde öğrencilerin modelleme seviyelerinin belirlenmesi [Determination of students' modeling levels in problem solving processes]. *Ahi Evran Üniversitesi Kırşehir Eğitim Fakültesi Dergisi*, *18*(3), 608–632.

Gök, M., & Demir, N. (2021). The Opinions of Mathematics Teachers about Using Mathematical Modeling in the Solution of Daily Life Problems and an Application of the Chinese Remainder Theorem. *Education Quarterly Reviews*, *4*(3), 100-116. https://doi.org/10.31014/aior.1993.04.03.322

Gök, M., & Yılmaz, T. Y. (2025). Mathematical modeling in the context of out-of-school learning: Exploring the potential of universities. In S. Alkan, G. Karaali, & M. Taştepe (Eds.), *Mathematics beyond the classroom* (pp. 215–236). Springer. https://doi.org/10.1007/978-3-032-05318-3_10

Gürbüz, R., & Doğan, M. F. (2019). Giriş: Matematiksel modellemeye disiplinler arası bakış: Bir STEM yaklaşımı. In R. Gürbüz & M. F. Doğan (Eds.), *Matematiksel modellemeye disiplinler arası bakış: Bir STEM yaklaşımı* (2nd ed., pp. 1–5). Pegem Akademi.

Ha, V. T., Chung, L. H., Hanh, N. V., & Hai, B. M. (2023). Teaching science using argumentation-supported 5E-STEM, 5E-STEM, and conventional didactic methods: Differences in the learning outcomes of middle school students. *Education Sciences*, *13*(3), 247. https://doi.org/10.3390/educsci13030247

Hallström, J., & Schönborn, K. J. (2019). Models and modelling for authentic STEM education: Reinforcing the argument. *International Journal of STEM Education*, *6*(1), 22. https://doi.org/10.1186/s40594-019-0178-z

Imaduddin, M., Praptaningrum, D. N. W., & Safitri, D. A. (2020). Students' attitude toward STEM project-based learning in the fun cooking activity to learn about the colloid system. *International Journal of Contemporary Educational Research*, *8*(1), 14–26. https://doi.org/10.33200/ijcer.820898

Johnson, C. C., Peters-Burton, E. E., & Moore, T. J. (Eds.). (2015). *STEM road map: A framework for integrated STEM education*. Routledge.

Kalaycı, Ş. (2008). *SPSS uygulamalı çok değişkenli istatistik teknikleri*. Asil Yayın Dağıtım.

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, *3*(1), 11. https://doi.org/10.1186/s40594-016-0046-z

Kertil, M., & Gurel, C. (2016). Mathematical modeling: A bridge to STEM education. *International Journal of Education in Mathematics, Science and Technology*, *4*(1), 44–55.

Knezek, G., Christensen, R., Tyler-Wood, T., & Periathiruvadi, S. (2013). Impact of environmental power monitoring activities on middle school student perceptions of STEM. *Science Education International*, *24*(1), 98–123.

Ling, L. S., Pang, V., & Lajium, D. (2019). Evaluation of the implementation of a science project through the application of integrated STEM education as an approach. *International Journal of Education*, *4*(33), 263–283.

Lopes, A. P. C. (2022). Aspects of attitudes towards mathematics in modeling activities: Usefulness, interest, and social roles of mathematics. *International Electronic Journal of Mathematics Education*, *17*(4), em0711. https://doi.org/10.29333/iejme/12394

Luo, T., Wang, J., Liu, X., & Zhou, J. (2019). Development and application of a scale to measure students' STEM continuing motivation. *International Journal of Science Education*, *41*(14), 1885–1904. https://doi.org/10.1080/09500693.2019.1647472

Maass, K., Geiger, V., Ariza, M. R., & Goos, M. (2019). The role of mathematics in interdisciplinary STEM education. *ZDM – Mathematics Education*, *51*(6), 869–884. https://doi.org/10.1007/s11858-019-01100-5

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. https://doi.org/10.1002/sce.20441

Manunure, K., & Leung, A. (2024). Integrating inquiry and mathematical modeling when teaching a common topic in lower secondary school: An iSTEM approach. *Frontiers in Education*, *9*, Article 1376951. https://doi.org/10.3389/feduc.2024.1376951

Mayerhofer, M., Lüftenegger, M., & Eichmair, M. (2024). The development of mathematics expectancy-value profiles during the secondary–tertiary transition into STEM fields. *International Journal of STEM Education*, *11*(1), Article 31. https://doi.org/10.1186/s40594-024-00491-6

Mertkan, Ş. (2015). *Karma araştırma tasarımı*. Pegem.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook* (2nd ed.). Sage.

Moore, T. J., & Smith, K. A. (2014). Advancing the state of the art of STEM integration. *Journal of STEM Education: Innovations and Research*, *15*(1), 5–10.

Moore, T. J., Stohlmann, M. S., Wang, H. H., Tank, K. M., Glancy, A. W., & Roehrig, G. H. (2014). Implementation and integration of engineering in K-12 STEM education. In Ş. Purzer, J. Strobel, & M. E. Cardella (Eds.), *Engineering in pre-college settings: Synthesizing research, policy, and practices* (pp. 35–60). Purdue University Press.

National Research Council. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. The National Academies Press. https://doi.org/10.17226/18612

Okamoto, H., Hartmann, M., & Kawasaki, T. (2023). Analysis of the relationship between creativity in Fermi problems measured by applying information theory, creativity in psychology, and mathematical creativity. *Education Sciences*, *13*(3), 315. https://doi.org/10.3390/educsci13030315

Ozturk, D. Z., & Cinar, S. (2022). The effect of engineering design based STEM education on the problem-solving skills of pre-school students. *Trakya Journal of Education*, *12*(1), 34–56. https://doi.org/10.24315/tred.868414

Özcan, H., & Koca, E. (2019). Turkish adaptation of the attitude towards STEM scale: A validity and reliability study. *Hacettepe University Journal of Education*, *34*(2), 387–401. https://doi.org/10.16986/HUJE.2018045061

Perez, T., Wormington, S. V., Barger, M. M., Schwartz-Bloom, R. D., Lee, Y. K., & Linnenbrink-Garcia, L. (2019). Science expectancy, value, and cost profiles and their proximal and distal relations to undergraduate science, technology, engineering, and math persistence. *Science Education*, *103*(2), 264–286. https://doi.org/10.1002/sce.21490

Rhodes, T., & Lancaster, K. (2020). Mathematical models as public troubles in COVID-19 infection control: Following the numbers. *Health Sociology Review*, *29*(2), 177–194. https://doi.org/10.1080/14461242.2020.1764376

Roberts, T., Maiorca, C., Jackson, C., & Mohr-Schroeder, M. (2022). Integrated STEM as problem-solving practices. *Investigations in Mathematics Learning*, *14*(1), 1–13. https://doi.org/10.1080/19477503.2021.2024721

Saldaña, J. (2011). *The coding manual for qualitative researchers*. Sage.

Schuchardt, A., & Roehrig, G. (2024). Critical thinking in mathematics and mathematical modeling related to STEM. In L. D. English (Ed.), *Ways of thinking in STEM-based problem solving* (pp. 205–217). Routledge.

Shankar, S., Lee, S. Y., Johnson, C. D., & Robinson, K. A. (2025). Make or break STEM course experiences: Profiles of situated expectancy, value, cost, and major intentions. *Contemporary Educational Psychology*, *82*, 102404. https://doi.org/10.1016/j.cedpsych.2025.102404

Slavit, D., Grace, E., & Lesseig, K. (2021). Student ways of thinking in STEM contexts: A focus on claim making and reasoning. *School Science and Mathematics*, *121*(8), 466–480. https://doi.org/10.1111/ssm.12501

Stillman, G. A., Blum, W., & Kaiser, G. (2017). Crossing boundaries in mathematical modelling and applications educational research and practice. In G. A. Stillman, W. Blum, & G. Kaiser (Eds.), *Mathematical modelling and applications: Crossing and researching boundaries in mathematics education* (pp. 1–32). Springer. https://doi.org/10.1007/978-3-319-62968-1_1

Stillman, G., Kaiser, G., & Lampen, C. (2020). Sense-making in mathematical modelling and applications educational research and practice. In G. A. Stillman, G. Kaiser, & C. E. Lampen (Eds.), *Mathematical modelling education and sense-making* (pp. 15–29). Springer.

Tasarib, A., Rosli, R., & Rambely, A. S. (2025). Impacts and challenges of mathematical modelling activities on students' learning development: A systematic literature review. *Eurasia Journal of Mathematics, Science and Technology Education*, *21*(5), em2641. https://doi.org/10.29333/ejmste/16398

Turner, E. E., Roth McDuffie, A., Bennett, A. B., Aguirre, J., Chen, M. K., Foote, M. Q., & Smith, J. E. (2022). Mathematical modeling in the elementary grades: Developing and testing an assessment. *International Journal of Science and Mathematics Education*, *20*(7), 1387–1409. https://doi.org/10.1007/s10763-021-10195-w

Turner, R., Blum, W., & Niss, M. (2014). Using competencies to explain mathematical item demand: A work in progress. In K. Stacey & R. Turner (Eds.), *Assessing mathematical literacy: The PISA experience* (pp. 85–115). Springer.

Tytler, R. (2020). STEM education for the twenty-first century. In J. Anderson & Y. Li (Eds.), *Integrated approaches to STEM education* (pp. 21–43). Springer. https://doi.org/10.1007/978-3-030-52229-2_3

Wang, H.-H., Charoenmuang, M., Knobloch, N. A., & Tormoehlen, R. L. (2020). Defining interdisciplinary collaboration based on high school teachers' beliefs and practices of STEM integration using a complex designed system. *International Journal of STEM Education*, *7*, Article 4. https://doi.org/10.1186/s40594-019-0201-4

Wang, M. T., & 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), 304–340. https://doi.org/10.1016/j.dr.2013.08.001

Wang, T., Zhang, L., Xie, Z., & Liu, J. (2023). How does mathematical modeling competency affect the creativity of middle school students? The roles of curiosity and guided inquiry teaching. *Frontiers in Psychology*, *13*, Article 1044580. https://doi.org/10.3389/fpsyg.2022.1044580

Wigfield, A., Muenks, K., & Eccles, J. S. (2021). Achievement motivation: What we know and where we are going. *Annual Review of Developmental Psychology*, *3*(1), 87–111. https://doi.org/10.1146/annurev-devpsych-050720-103500

Yanar, A. N., & Ergene, Ö. (2024). Farklı eğitim seviyelerindeki katılımcıların sosyo-kritik matematiksel modelleme etkinliği çözüm süreçlerinin incelenmesi [Investigation of the solution processes of socio-critical mathematical modeling activity of participants at different educational levels]. *Uludağ Üniversitesi Eğitim Fakültesi Dergisi*, *37*(3), 830–865. https://doi.org/10.19171/uefad.1495955

Yılmaz, A., & Usta, N. (2024). Kavram karikatürleri destekli 5E modeli uygulamasının ortaokul öğrencilerinin matematik başarılarına ve öğrenilenlerin kalıcılığına etkisi [The effect of concept cartoons supported 5E model application on middle school students' mathematics achievements and retention of learning]. *Journal of Social, Humanities and Administrative Sciences (JOSHAS)*, *9*(68), 3435–3447. https://doi.org/10.29228/JOSHAS.71970