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The Effect of Mathematical Modeling Activities on Seventh Grade Students' Mathematical Literacy and Affective Outcomes *

Matematiksel Modelleme Etkinliklerinin Yedinci Sınıf Öğrencilerinin Matematik Okuryazarlığı ve Duyuşsal Özellikleri Üzerindeki Etkisi

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Abstract: This study examines the effect of mathematical modeling activities on seventh-grade students' mathematical literacy levels and some affective outcomes. A quasi-experimental framework was created; in this framework, students were assigned to experimental and control groups, and their pre-test and post-test results were compared. The sample consisted of 52 seventh grade students attending a public middle school. MANCOVA was used to analyze the data, followed by ANCOVA as follow up analyses. The results revealed that mathematical modeling activities had a statistically significant effect on students' mathematical literacy posttest scores. However, no significant differences were found between the groups in terms of mathematical literacy self efficacy, engagement, and attitudes toward mathematics. Student opinions indicated that the modeling interventions successfully promoted mathematical thinking and clarified the relevance of mathematics to real-life contexts and that mathematical modeling activities were perceived positively. Overall, the findings suggest that mathematical modeling activities constitute an effective instructional approach for improving students' cognitive learning outcomes in mathematics.

Keywords: *Mathematical modelling, mathematical literacy, middle school students, seventh grade*

Özet: Bu çalışma, yedinci sınıf öğrencilerine uygulanan matematiksel modelleme etkinliklerinin öğrencilerin matematik okuryazarlık düzeyleri ve bazı duyuşsal özellikleri üzerindeki etkisini incelemektedir. Yarı deneysel bir çerçeve oluşturuldu; bu çerçevede öğrenciler deney ve kontrol gruplarına atanarak ön test ve son test sonuçları karşılaştırıldı.Araştırmanın örneklemini bir ortaokulda öğrenim gören 52 yedinci sınıf öğrencisi oluşturmuştur. Verilerin analizinde MANCOVA ve takip analizleri olarak ANCOVA kullanılmıştır. Elde edilen bulgular, matematiksel modelleme etkinliklerinin öğrencilerin matematik okuryazarlık düzeyleri üzerinde anlamlı bir etkiye sahip olduğunu, buna karşın matematik okuryazarlık öz yeterliği, matematik dersine katılım ve matematiğe yönelik tutum değişkenleri açısından anlamlı bir farklılık oluşturmadığını göstermiştir. Öğrenci görüşleri, modelleme müdahalelerinin matematiksel düşünmeyi başarıyla teşvik ettiğini, matematiğin günlük yaşamla olan ilişkisini netleştirdiğini ve matematiksel modelleme etkinliklerinin olumlu algılandığını göstermiştir. Bu sonuçlar, matematiksel modelleme etkinliklerinin bilişsel öğrenme çıktıları üzerinde etkili bir öğretim yaklaşımı olduğunu göstermektedir.

Anahtar Kelimeler: *Matematiksel modelleme, matematik okuryazarlık, ortaokul öğrencileri, yedinci sınıf*

1. Introduction

Mathematics, due to its reliance on abstract concepts and symbolic expressions, is often perceived by middle school students as a challenging discipline. A lot of students think that mathematics is not related to their life. Furthermore, this perception is cited as one of the primary reasons for student underachievement (Çiltaş & Işık, 2012). Teacher-centered learning processes and the passive roles assumed by students limit both the deep understanding of mathematical knowledge and the transfer of such knowledge to real-life situations. Conversely, core objectives in

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mathematics curricula include enabling students to develop mathematical meaning through concrete experiences, establish connections between concepts, and integrate mathematics within daily life contexts (Ministry of National Education [MoNE], 2018; 2024). Accordingly, to enhance the usefulness and meaning of mathematics instruction, it is essential to adopt methods that place learners at the heart of the educational experience and utilize problems rooted in the real world (NCTM, 2000). Mathematical modeling provides a holistic learning process that allows students to represent real-life problems through mathematical structures, reason within these structures, and interpret the results in a contextually appropriate manner (Kaiser & Stender, 2013; Lesh & Doerr, 2003). The seventh-grade level of middle school represents a critical period during which students begin to engage with mathematical concepts at a more abstract level and their mathematical literacy skills are being developed. Therefore, examining the effects of mathematical modeling activities (MMAs) implemented at this level on students' cognitive and affective characteristics is of considerable importance.

1.1. Mathematical Modeling

According to Lesh and Doerr (2003), the mathematical modeling process serves as a transformative framework that helps students interpret real-life challenges through mathematical lenses and tools, thus establishing a consistent link between theory and practice. In this process, problem situations drawn from real life are represented and analyzed using mathematical concepts and methods, and the resulting mathematical outcomes are then interpreted within the original real-life context (Blum & Leiss, 2007; Niss, Blum, & Galbraith, 2007). Modeling activities allow students to apply their mathematical knowledge within meaningful contexts rather than merely at the level of symbolic operations; they activate higher-order cognitive processes such as understanding the problem situation, selecting appropriate mathematical representations, formulating assumptions, and developing solution strategies (Bukova Güzel et al., 2016). Throughout this process, students test the mathematical models they construct, interpret the results, and, when necessary, revise their models to produce more valid solutions (Lesh & Doerr, 2003). Accordingly, mathematical modeling is regarded not only as a problem-solving process but also as a productive learning process that supports students in recognizing the functionality of mathematics and enhancing their mathematical thinking skills (Kaiser & Stender, 2013).

Mathematical modeling involves a set of interrelated steps. This process has been conceptualized by various researchers through different modeling cycles grounded in a similar theoretical framework (Blomhøj & Jensen, 2007; Borromeo Ferri, 2006; Doerr, 1997; Kaiser & Stender, 2013). In the modeling process, students analyze problem situations derived from real life, transform these situations into mathematical representations, and re-evaluate the resulting mathematical findings within the real-world context. In this regard, the modeling process offers a dynamic structure that includes validation and refinement stages, allowing for flexible transitions between the problem situation and mathematical representations (Blomhøj & Jensen, 2003; Kaiser & Stender, 2013). Therefore, mathematical modeling is considered an iterative learning process that involves not only reaching a solution but also the holistic evaluation of the entire process.

The modeling process can also be addressed within a structure that centralizes individuals' mental representations and cognitive processes (Borromeo Ferri, 2006). Students' processes of making sense of problem situations, selecting appropriate mathematical representations, developing strategies, and interpreting results become visible through modeling activities. Within this framework, when definitions of mathematical modeling are evaluated together, it is evident that modeling is a multidimensional learning process that centralizes real-life problems, requires active student participation, activates higher-order cognitive processes, and supports the functional use of mathematical knowledge.

1.2. Mathematical Literacy

Numerous problems, whether mathematical or non-mathematical, are an integral part of daily life, and individuals utilize mathematics directly or indirectly while solving these problems. Mathematical literacy encompasses the ability of individuals to efficiently apply the mathematical expertise and skills they need to solve a variety of problem scenarios they encounter (Adams, 2020; Altun, 2018; Kabael, 2019). In this regard, mathematical literacy encompasses not only the ability to perform mathematical operations but also the proficiency to make sense of, interpret, and apply mathematical knowledge within daily life contexts. Mathematical literacy is addressed within the framework of individuals' abilities to formulate, employ, and interpret mathematics in real-life problem situations (OECD, 2019a). The evaluation of mathematical literacy as a core competency area within PISA emphasizes its importance in revealing the extent to which individuals can associate mathematics with daily life and utilize mathematical thinking in a functional manner (MoNE, 2019; OECD, 2019a). Mathematical literacy is not limited to mathematics courses; it can also be utilized to explain situations in different disciplines, make predictions, and support decision-making processes (Hamilton et al., 2008; Pollak, 2007). Indeed, the association of the mathematical literacy cycle in PISA 2003 with the mathematical modeling process clearly demonstrates the theoretical proximity between mathematical literacy and mathematical modeling (Stacey, 2015).

The literature emphasizes that mathematical literacy and mathematical modeling processes involve similar steps and share a strong theoretical relationship (OECD, 2019b; Stacey, 2015). Stacey (2015) states that mathematical literacy and mathematical modeling are closely interconnected and that mathematical modeling can be used fully or partially within mathematical literacy processes. Indeed, within the PISA framework, mathematical literacy is conceptualized as a cycle that encompasses individuals' processes of formulating problem situations mathematically, employing mathematical knowledge, and interpreting the results obtained; this cycle overlaps with the mathematical modeling process (OECD, 2019b). In learning environments aimed at developing mathematical literacy, it is considered important for students to encounter real-life problems beyond routine tasks and to actively participate in the solution process. Viewed through this lens, mathematical modeling functions as a procedural learning framework that facilitates the cultivation of mathematical literacy.

One of the significant affective variables influencing students' mathematical literacy levels is self-efficacy. self-efficacy represents students' perceptions of their own competence to manage tasks effectively, which in turn exerts a substantial influence on their achievement (Çavdar & Şahan, 2019; Çelik Işık, 2019). Stronger perceptions of mathematical self-efficacy often lead students to be more persistent in mathematical tasks and employ more effective strategies when coping with difficulties (Çavdar & Şahan, 2019; Çelik Işık, 2019). Among the variables affecting mathematical literacy, students' attitudes—such as their perceptions of self-efficacy toward mathematics—are reported to hold an important place (Aksu & Güzeller, 2016; OECD, 2019b). In addition, students' engagement in lessons is considered a significant variable associated with both mathematics achievement and mathematical literacy (Appleton, Christenson, & Furlong, 2008; Çelik, Örenoğlu Toraman, & Çelik, 2018; Green et al., 2012).

Extensive academic literature has investigated the influence of MMAs on students' learning outcomes. These studies indicate that modeling-based learning environments enhance students' academic achievement in mathematics and contribute to the meaningful construction of mathematical knowledge (Freeman, 2014; Işık, 2016; Krutikhina et al., 2018; Park et al., 2013). Modeling activities support the retention of learning by enabling students to engage with mathematical concepts not merely at a procedural level but within real-life contexts.

1.3. The Impact of Mathematics Modeling on Affective Variables

The mathematical modeling approach enables students to relate mathematical knowledge to real-life contexts while centering on active participation and meaningful learning. In this respect, mathematical modeling has the potential to influence not only cognitive outcomes but also students’ affective characteristics related to mathematics (Kaiser & Stender, 2013). Indeed, the literature includes numerous studies demonstrating that MMAs have increased students’ mathematics achievement, attitudes toward mathematics, and various cognitive skills (Freeman, 2014; Muşlu & Çiltaş, 2016; Pazarcı Çelenk, 2019; Park et al., 2013; Ünlü, 2023). It has been reported that students who develop positive attitudes participate more willingly in mathematics lessons and display more favorable approaches toward mathematical activities (Aiken Jr., 1970; Çavdar & Şahan, 2019; Kartowagiran & Manaf, 2021). Through the exploratory and democratic learning environments they offer, MMAs support the development of positive attitudes toward mathematics (Türker Biber & Yetkin Özdemir, 2021). Modeling tasks allow learners to apply their mathematical expertise in a multifaceted and practical way, as well as fostering more positive attitudes and encouraging strong participation in classroom activities (Ärlebäck, Doerr, & O’Neil, 2013; Çavuş Erdem & Gürbüz, 2018; Lesh & Doerr, 2003; Tutkun & Kabar, 2018). Similarly, MMAs are reported to motivate students to participate more willingly in the lessons. Within the mathematical modeling process, students are expected to actively participate in problem solving, develop their own strategies, and discuss their solutions. Studies examining students’ views on mathematical modeling problems has determined that these problems are perceived as more engaging, thought-provoking, and relevant to daily life (Deniz, 2014; Kal, 2013; Kandemir, 2011; Kocayayla, 2019). Student engagement is also closely related to mathematical achievement and literacy. Engagement refers to the levels of students' cognitive, affective, behavioral and social involvement in the learning process (Appleton, Christenson, & Furlong, 2008). Research reveals that active student engagement increases mathematical achievement (Çelik, Örenoğlu Toraman & Çelik, 2018; Green et al., 2012). The structure of MMAs —which encourages collaborative work, discussion, and the sharing of ideas—is considered a significant factor in increasing student engagement in mathematics (Ärlebäck, Doerr & O’Neil, 2013; Çavuş Erdem & Gürbüz, 2018; Lesh & Doerr, 2003).

Overall, it is noteworthy that while the relationship between MMAs and mathematical literacy is frequently emphasized, research addressing this relationship within an experimental design and a multivariate framework is quite scarce (Niss et al., 2007; Stacey, 2015). Furthermore, it is observed that in a significant portion of existing studies, pre-test differences are not sufficiently controlled, and the effects of modeling activities are not evaluated through a holistic approach. This situation highlights the need for research that more comprehensively examines the impact of the MMAs on various learning outcomes. Particularly when considering research conducted at the middle school level, experimental studies that address MMAs together with critical variables such as students’ mathematical literacy, self-efficacy perceptions, attitudes toward mathematics, and engagement remain limited. Yet, these variables are of central importance for understanding students’ mathematics learning processes and for revealing the educational effects of the mathematical modeling approach in a more in-depth manner. The seventh-grade level is considered a critical period during which students begin to engage with mathematical concepts at a more abstract level and their mathematical literacy skills are structured (MoNE, 2018). Therefore, concurrently examining the impact of MMAs implemented at this level on students' cognitive (mathematical literacy), and affective (self-efficacy, attitude and engagement), characteristics emerges as a significant necessity from both theoretical and practical perspectives.

The purpose of this study is to investigate the effects of MMAs implemented with seventh-grade students on their levels of mathematical literacy, self-efficacy perceptions related to mathematical literacy, attitudes toward mathematics, and engagement in mathematics. In this regard, by addressing the effects of the mathematical modeling approach on multiple learning outcomes through an experimental approach, this study aims to fill a significant gap in the literature and provide guiding findings for practitioners. In line with this purpose, the following hypothesis was tested in the study.

When pretest scores are controlled, the posttest scores of the students in the experimental group who participated in MMAs differ significantly from those of the control group in terms of

(a) mathematical literacy,

(b) self-efficacy related to mathematical literacy,

(c) attitudes toward mathematics, and

(d) engagement in mathematics.

2. Methodology

The research framework was structured around a quasi-experimental approach, incorporating both pre-intervention and post-intervention assessments across experimental and control conditions. The quasi-experimental design is a research design commonly preferred in educational settings, particularly in situations where a randomized distribution of participants across study groups is not feasible (Büyüköztürk, Akgün, Demirel, Karadeniz, & Çakmak, 2017). This design allows for the combined use of pretest and posttest measurements in order to more accurately evaluate the effects of the experimental intervention. In the research process, following the administration of the pretests, MMAs were implemented in the experimental group for six weeks. Meanwhile, the Control group continued training based on the existing curriculum. Upon completion of the experimental treatment, quantitative data were collected by administering post-tests to both groups. Additionally, at the end of the experimental process, the opinions of students regarding the MMAs were gathered, thereby supporting the quantitative findings with qualitative data. Information regarding the pretests, instructional process, and posttests administered in the groups is presented in Table 1.

Table 1

Implementation Process in the Experimental Design

Group	Pretest	Instructional Process	Posttest
Experimental Group	MLT, MLSES, MES, MAS	MMAs were implemented for six weeks.	MLT, MLSES, MES, MAS + Interview Questions
Control Group	MLT, MLSES, MES, MAS	Educational activities were conducted following the official guidelines of the current program	MLT, MLSES, MES, MAS

Note. MLT: Mathematical Literacy Test; MLSES: Mathematical Literacy Self-Efficacy Scale; MES: Mathematics Engagement Scale; MAS: Mathematics Attitude Scale

2.1. Participants

A total of 52 seventh-grade students were involved in this study. The seventh-grade level is regarded as a period in which students begin to address mathematical concepts at a more abstract level and during which MMAs become applicable. Due to administrative constraints, individual students could not be randomly assigned to groups; Therefore, two intact seventh-grade classes were used. To minimize selection bias, one of these classes was randomly assigned as the experimental group and the other as the control group. The experimental group consisted of 24 students (13 females and 11 males), while the control group consisted of 28 students (14 females and 14 males). The numbers of students in both groups were close to each other (n_control / n_experimental = 1.17), indicating that an acceptable numerical balance between the groups was achieved.

2.2. Measures

Mathematical Literacy Test (MLT)

In order to measure mathematical literacy, the Mathematical Literacy Test developed by Akıllı (2020) was used in the study. During the test development process, items were adapted from PISA questions and from the questions included in Altun's (2015) work titled EFEMAT 7–8: Mathematical Applications, Non-routine Problems, Mathematical Literacy Questions. A scoring rubric established by the original developers was used for the evaluation of the test. Prior to the main implementation in the current study, a pilot study was conducted. Following the reliability analysis of the pilot implementation, two questions were omitted from the original test. The final version of the test consists of 18 items. Each item is scored on a scale ranging from 0 to 5, with the minimum possible total score being 0 and the maximum being 90. The reliability coefficient calculated for the test within the scope of this study was found to be 0.74.

Self-Efficacy Scale toward Mathematical Literacy (MLSES)

To assess learners' self-efficacy beliefs regarding their mathematical literacy skills, (MLSES) the developed by Baypınar and Tarım (2019) was utilized. The scale was developed specifically for middle school seventh-grade students. This scale consists of a total of 30 items, 6 of which are reverse-coded. The minimum possible score on the scale is 30, while the maximum is 150. An analysis of the instrument's internal reliability in this research context produced a coefficient of .95

Mathematics Engagement Scale (MES)

To assess students' engagement levels in mathematics courses, the MES adapted for mathematics education by Gürel (2021), was employed. It consists of a total of 32 items, 18 of which are reverse-coded. The scores range from a minimum of 32 to a maximum of 160. In the present study, the internal consistency coefficient of the scale was found to be 0.94.

Mathematics Attitude Scale (MAS)

To determine students' attitudes, the MAS developed by Önal (2013) was used. The scale consists of 22 items. Of these items, 11 are reverse-coded. The minimum and maximum possible scores from the scale are 22 and 110, respectively. An analysis of the instrument's internal reliability in this research context produced a coefficient of .93

Interview Form

Qualitative data were collected to support the quantitative findings obtained in the research and to determine students' opinions regarding MMAs. A structured interview method was preferred to gather the views of all students in the experimental group and to enable the determination of the frequencies of the obtained data. Structured interviews enhance the comparability of data by establishing a specific standard for the responses provided. The interview questions addressed students' most engaging modeling activities, the relationship of the activities to daily life, differences from traditional problem-solving processes, skills gained during the process, changes in their feelings and thoughts toward mathematics lessons, and their views on group work.

2.3. Implementation Process

It is emphasized that group work supports the learning process and increases students' active participation in MMAs (Bukova Güzel et al., 2016; Zawojewski, Lesh & English, 2003). Accordingly, students worked in groups of two or three and carried out the modeling activities collaboratively. Initial preparations involved introducing the modeling approach to the learners, where the primary stages of the cycle and the structural organization of the activities were explicitly clarified. During the six-week experimental implementation, one mathematical modeling problem was administered each week. In this context, the following problems were presented to the students respectively: the Weather Problem (Doerr & English, 2003), the Travel Problem (Zawojewski, Lesh & English, 2003; adapted by Doruk, 2010), the Big Foot Problem (Lesh & Doerr, 2003), the Long Jump Problem (Swan et al., 2007), the School Party Problem (Henning & Keune, 2007), and the Gas Station Problem (Blum & Borromeo Ferri, 2009; adapted by Tekin Dede, 2015). The Big Foot Problem can be cited as an example of the implemented problems. In this problem, students were asked to estimate the height of the owner of a footprint based on a given track. Throughout the problem-solving phase, learners were required to employ proportional reasoning and transform the real-life context into a mathematical model.

In the course of the interventions, the researcher assumed the role of a facilitator, without intervening directly in the students' problem-solving processes. Scaffolds were provided to the students during the solution process, and they were supported in reflecting on the problems through feedback and corrections when necessary. To minimize potential researcher bias arising from this dual role, several methodological precautions were taken. First, the implementation strictly followed a predefined manual and lesson plans grounded in Borromeo Ferri’s (2006) modeling cycle to ensure consistency. Second, an independent expert in mathematics education observed a sample of the sessions to monitor the neutrality of the facilitator’s role and ensure treatment fidelity. Furthermore, all student assessment data were anonymized during the scoring process to ensure objectivity. In the problem-solving process, Borromeo Ferri’s (2006) cognitive perspective-based mathematical modeling cycle was adopted as the framework; students were encouraged through guiding questions aligned with the stages of the modeling cycle, namely “*understanding, simplifying, mathematizing, working, interpreting, and validating*”. The questions directed to the students during this process were structured to correspond to each stage and aimed to make the students' thinking processes visible.

2.4. Data Analysis

Statistical processing of the quantitative outcomes was facilitated by a comprehensive data analysis application and to understand participants' perspectives on the experimental process and MMAs, the collected qualitative data underwent a systematic descriptive evaluation. Prior to the quantitative data analysis, it was examined whether the assumptions for parametric analyses were met. In this context, skewness and kurtosis coefficients were evaluated alongside normality tests. Although the normality tests yielded significant results for some variables, it was decided that the use of parametric analyses was appropriate, as the distribution values remained within acceptable limits and the sample size was sufficient.

In accordance with the research objective, multivariate analysis of covariance (MANCOVA) was employed to examine the impact of MMAs on students' MLT, self-efficacy toward mathematical literacy, engagement in mathematics, and attitudes toward mathematics. MANCOVA was preferred as it allows for the simultaneous analysis of multiple dependent variables and enables the control of initial differences between groups through pre-test scores. To identify suitable covariates for MANCOVA, the relationships between baseline and final assessments were rigorously examined using Pearson correlation analyses. It was determined that all pre-test scores were significantly correlated with their corresponding post-test scores ($p < .05$). Accordingly, it was concluded that using pre-test scores as covariates was appropriate. Prior to the analyses, the fundamental assumptions of MANCOVA were tested; no significant violations were detected regarding the assumptions of normality, homogeneity of variances, homogeneity of regression slopes, multicollinearity, and equality of covariance matrices. Levene’s test results indicated that the equality of error variances was met, except for the student engagement variable; however, for this variable, it was determined that the analysis results could be interpreted reliably due to the balanced group sizes.

3. Results

3.1. Descriptive Statistics

To facilitate a comprehensive understanding of the intervention's impact, descriptive statistics are first reported to highlight group-level trends and to justify the assumptions of the subsequent multivariate analyses. An overview of the descriptive statistics for both groups' initial and final performances across the measures of MLT, MLSES, MAS, and MES is detailed in Table 2.

Tablo 2

Descriptive Statistics of MLT, MLSES, MAS and MES Scores for Both Groups

		Experimental Group		Control Group	
Variable	Statistic	Pre-test	Post-test	Pre-test	Post-test
MLT	Mean	21.67	30.71	21.23	28.11
	SD	10.91	15.73	10.15	10.59
	Range	47.00	60.00	40.00	36.00
	Skewness	0.72	0.46	0.24	0.23
	Kurtosis	0.57	-0.04	-0.34	-0.87
	Shapiro-Wilk	0.50	0.55	0.34	0.25
MLSES	Mean	100.17	108.67	111.68	115.00
	SD	21.91	18.94	18.08	19.73
	Range	74.00	65.00	63.00	62.00
	Skewness	-0.23	0.19	0.84	0.42
	Kurtosis	-0.58	-0.51	-0.20	-1.14
	Shapiro-Wilk	0.43	0.41	0.02	0.45
MES	Mean	115.88	122.38	125.61	126.79
	SD	19.71	22.60	18.23	19.53
	Range	67.00	71.00	76.00	75.00
	Skewness	0.06	-0.38	-0.42	-0.72
	Kurtosis	-0.96	-1.40	0.03	-0.08
	Shapiro-Wilk	0.51	0.02	0.66	0.18
MAS	Mean	72.54	78.96	85.00	88.18
	SD	18.45	16.47	16.60	16.06
	Range	56.00	58.00	56.00	48.00
	Skewness	0.17	-0.23	-0.16	-0.18
	Kurtosis	-1.41	-0.90	-1.05	-1.33
	Shapiro-Wilk	0.73	0.58	0.25	0.05

Prior to the intervention, pre-MLT averages were recorded at 21.67 for the treatment group, compared to 21.23 for the control subjects. This finding indicates that the groups were at very similar levels with respect to this variable before the intervention. Once the intervention was finalized, the experimental participants' final mean rose to 30.71, whereas the comparison group achieved an average of 28.11. These results indicate that the increase observed in the experimental group was greater than that observed in the control group.

The pre-MLSES scores were calculated as 100.17 for the experimental group and 111.68 for their counterparts in the control group. The mean post-MLSES scores were 108.67 for the experimental group and 115.00 for the comparison group. At the final stage of the intervention, the participants in the modeling group showed an 8.50-point improvement, whereas the corresponding increase for the comparison group was 3.32 points.

The mean scores for student pre-MES were calculated as 115.88 for the experimental group and 125.61 for the control group. This finding indicates that, prior to the experimental treatment, the engagement levels of students in the control group were higher than those in the experimental group. Following the experimental treatment, the MES post-test mean score of the experimental group increased to 122.38, while the post-test mean score of the control group was determined to be 126.79. At the end of the implementation process, an increase of 6.50 points was observed in the experimental group, whereas the increase in the control group was 1.18 points.

The mean for pre-MAS scores were calculated as 72.54 for the experimental group and 85.00 for the comparison group. This result indicates that, prior to the experimental treatment, the attitudes of students in the control group toward mathematics were more positive than those in the experimental group. Following the experimental procedure, the mean post-MAS score of the experimental group increased to 78.96, while the control group was 88.18. An increase of 6.42 points occurred in the experimental group, whereas the increase in the control group was determined to be 3.18 points.

3.2. Inferential statistics

The collective effect of MMAs on students' MLT, MLSES, MES, MAS when controlling for the respective pre-test scores was tested using MANCOVA. The findings regarding the MANCOVA results are presented in Table 3.

Table 3

Analysis Results of the MANCOVA

Effect	Wilks' Λ	F	df (Hyp., Error)	p	Partial η^2
Group (Exp. vs Cont.)	.800	2.68	(4, 43)	.044	.20

Note. pre-MLT, pre-MLSES, pre-MES, and pre-MAS were controlled as covariates in the analyses. The significance level is α = .05

The MANCOVA results demonstrate a statistically significant difference at the multivariate level between the groups when the dependent variables are considered together (Wilks' Λ = .80, F(4, 43) = 2.68, p = .044, partial η^2 = .20). This result reveals that MMAs have a moderate to large effect on students' cognitive and affective variables related to mathematics. To examine the significant multivariate effect obtained from the MANCOVA in detail, a follow-up univariate analysis of covariance (ANCOVA) was performed for each dependent variable. In all analyses, the significance level was set at .05.

Table 4

Results of ANCOVA for the Impact of Mathematical Modeling on Dependent Variables

Dependent Variable	F(1, 46)	*p*	partial η^2
MLT	5.24	.027	.10
MLSES	0.49	.487	.01
MES	0.80	.375	.02
MAS	0.18	.672	.00

Note. pre-MLT, pre-MLSES, pre-MES, and pre-MAS were entered as covariates. *p* < .05 indicates statistical significance.

The analysis of the MANCOVA results indicated that the experimental group attained substantially higher scores than the control group in the final mathematical literacy evaluations F(1, 46) = 5.24, p = .027, partial η^2 = .10). This finding suggests that MMAs have a medium-level effect on students' MLT levels. In contrast, no statistically significant difference was found between the groups for post-MLSES scores F(1, 46) = 0.49, p = .487, partial η^2 = .01). Similarly, no significant differences were detected between the experimental and comparison groups in terms of MES F(1, 46) = 0.80,

$p = .375$, partial $\eta^2 = .02$) and MAS $F(1, 46) = 0.18$, $p = .672$, partial $\eta^2 = .00$). These results demonstrate that, MMAs significantly enhanced students' MLT levels, while failing to influence their self-efficacy, engagement, or attitudes when baseline differences were accounted for

3.3. Student Opinions on MMAs

The student opinions presented in this section were utilized to provide a profound understanding and explanation of the findings obtained from the quantitative analyses. Quantitative results indicated that MMAs had a significant impact on students' mathematical literacy levels. When students were asked which of the problems implemented during the study they found most interesting, ten students identified the "Big Foot" problem. The "Travel" and "Long Jump" problems were preferred by three students each, while the "Gas Station" and "Weather" problems were found engaging by one student each. Moreover, three students stated that they liked all of the problems, whereas three students reported that they did not like any of the problems. An analysis of the responses from students who preferred the "Big Foot" problem revealed that their preferences were rooted in measuring their own feet and height with rulers, as well as the requirement for proportional and logical reasoning. Students also noted their surprise that a person's height could be determined from their footprints. Regarding other preferences, students who selected the "Travel" problem found it step-by-step and enjoyable, while those who chose the "Long Jump" or "Gas Station" problems expressed that the outcomes of these problems were more satisfying. Students who liked all activities described them as fun, while those who liked none categorized them as boring.

It was observed that students perceived the implemented mathematical modeling problems as situations they might encounter in daily life. The reasons provided included calculating vehicle fuel, managing money during shopping, and estimating costs for a destination. Only one student responded negatively, attributing this to a lack of prior exposure to such problems. Analysis of student opinions suggested that MMAs were evaluated positively, particularly regarding mathematical thinking, problem-solving, and relating mathematics to daily life. A significant proportion of the students expressed that the modeling activities included real-world problems and that they gained a better grasp of how mathematics is utilized in real life. One student articulated this by saying: "Thanks to mathematical modeling activities, I learned what mathematics is for and how it is used in daily life."

When asked about the differences between mathematical modeling problems and those they had previously solvedin regular lessons, three students highlighted the need for planning, eight noted they were more challenging, four found them more enjoyable, and four emphasized their connection to daily life. Additionally, students mentioned that these were being skill-based problems requiring reading comprehension, estimation, and thinking skills. They also noted the use of materials like tape measures and rulers, the necessity of mental visualization, the lack of a single correct answer, and the inclusion of prior knowledge. To reach solutions in these problems, students identified essential factors such as accurate comprehension (n=5), logical reasoning (n=3), performing correct operations (n=10), measurement (n=2), and focused attention. They also noted that modeling activities prepared them for new generation (skill-based problems) questions and enhanced their skills in data processing, reading tables, viewing events from a mathematical perspective, and rapid problem-solving. These views, which highlight the use of skills associated with mathematical literacy—such as measuring, estimating, and proportional reasoning—align with and support the quantitative findings regarding the mathematical literacy variable.

Conversely, student opinions indicated that the impact of MMAs on attitudes toward the course and other affective variables remained more limited compared to cognitive variables. Sixteen students expressed a desire to continue learning through mathematical modeling because the problems were fun, useful, and memorable. However, seven students responded negatively, citing that the problems were too difficult, demanding, or simply not to their liking. One student remained undecided, noting that while the problems were fun, they required an adjustment period.

Regarding the change in feelings and thoughts toward mathematics, 14 students reported a change, nine reported no change, and one remained undecided. Students who reported a positive change stated that they learned the utility of mathematics, found the lessons more enjoyable, and felt less intimidated by long, complex questions. Among those whose opinions did not change, some noted they already loved mathematics, while others maintained their existing dislike for the subject. This finding is consistent with the lack of statistically significant differences in attitude and engagement variables in the quantitative analysis.

Finally, regarding group work, ten students found it more productive due to the exchange of ideas, while eight found it more enjoyable. They stated that working in groups allowed them to support each other, learn more through discussion, and collaborate as "a single brain."

4. Discussion and Conclusion

4.1. The Effect of MMAs on Mathematical Literacy

In this study, the impact of MMAs on the mathematical literacy levels of seventh-grade students was examined. The findings demonstrated that the mathematical literacy levels of the students in the experimental group increased significantly, with a statistically significant difference found between the experimental and control groups in favor of the former. This result reveals that mathematical modeling is an promising instructional approach for developing mathematical literacy. This finding is consistent with previous studies that have highlighted the positive impact of mathematical modeling on mathematical literacy (Erol, 2015; Demirci, 2018; Armutcu & Bal, 2023). The fact that the mathematical modeling process and the mathematical literacy cycle share similar cognitive stages—such as understanding the problem, mathematizing, generating solutions, and interpreting—can be considered one of the primary reasons for this significant difference. The significant increase in literacy levels observed in 12–13-year-old seventh graders suggests that MMAs can be effective in younger age groups as well. In this regard, the study provides a substantial contribution to the feasibility of the mathematical modeling approach at the middle school level. The literature contains varying results regarding the effects of MMAs on mathematics achievement. Some studies report that such activities do not significantly affect achievement (Büyükadıgüzel, 2019; Dışbudak, 2014). Conversely, it has been reported that mathematical modeling positively affects achievement in specific topics such as operations with natural numbers (Muşlu & Çiltaş, 2016), percentages (Kurtuluş Kayan, 2019), and multiplication and division of fractions (Kaya, 2019). In this context, the findings of this research support the positive outcomes documented in the literature.

4.2. The Effect of MMAs on Self-Efficacy, Attitude, and Engagement

Although increases were observed in the experimental group regarding self-efficacy toward mathematical literacy, attitude toward mathematics, and engagement in mathematics, No significant statistical divergence was identified between the two groups. This finding suggests that while MMAs can be effective on cognitive variables in the short term, they may have more limited effects on affective variables. While some studies show that mathematical modeling positively influences self-efficacy (Ata Baran, 2019), current results reflect the patterns observed in earlier studies indicating no significant effect on mathematical literacy self-efficacy (Özdemir, 2021). Armutcu and Bal (2023) noted that modeling activities implemented within a STEM context significantly increased self-efficacy. Thus, the absence of a STEM-based approach in this study might be a reason for the differing results.

Similarly, while the experimental group showed increases in engagement and attitude, these did not reach statistical significance compared to the control group. The literature presents mixed results regarding the effects of various instructional approaches, such as gamification or flipped learning, on these variables (Fidan, 2016; Demir Öztürk & Eren, 2020). The primary reason for the lack of a significant difference in self-efficacy and attitude scores in this research is the limited six-week duration of the intervention. The literature emphasizes that affective traits are more resistant to change than cognitive skills. According to Bloom (1976), affective characteristics function as stable 'entry behaviors' that require prolonged and consistent intervention to undergo meaningful change. Similarly, Bandura (1997) argues that self-efficacy beliefs are constructed through a longitudinal synthesis of mastery experiences; thus, a six-week period remains below the critical threshold required to restructure a student's deeply rooted self-perception. Furthermore, as emphasized by Pintrich and Schunk (2002), affective shifts necessitate the internalization of new values and emotional responses, a process that typically requires at least a full academic semester—approximately 14 weeks—to manifest as a permanent and statistically significant change. The qualitative data in this study further supports this theoretical stance; the fact that some students still perceived modeling activities as "difficult" or "demanding" indicates that the affective "adjustment period" was still ongoing at the time of the post-test. Therefore, the cognitive-affective discrepancy observed here suggests that while MMAs effectively activate cognitive processes in the short term, meaningful affective development requires a more sustained and longitudinal pedagogical commitment.

Qualitative findings indicate that MMAs effectively activated students' cognitive processes. Students reported utilizing processes such as accurate comprehension, planning, logical reasoning, measurement, and mathematical interpretation. These processes overlap with the stages of Borromeo Ferri's (2006) cognitive mathematical modeling cycle. Student opinions further suggest that while modeling activities are effective in the cognitive dimension of mathematical literacy, their impact on affective variables remains limited. This is consistent with the quantitative findings and supports the holistic perspective provided by the mixed-methods approach.

The literature recommends conducting modeling activities through group work (Bukova Güzel et al., 2016; Zawojewski, Lesh & English, 2003) and notes that students develop positive attitudes toward collaborative work (Büyükadıgüzel, 2019; Karakaş, 2020). In the current study, students' positive views on group work are attributable to the facilitation of the process for tasks perceived as challenging and the reinforcement of their communication skills. Previous research has indicated that modeling activities positively impact communication skills and students' ability to use mathematical language (Ata Baran, 2019; Doruk, 2011).

Overall, this research demonstrates that MMAs are an promising instructional approach for increasing the mathematical literacy levels of seventh-grade middle school students. However, for such activities to create significant impacts on affective variables—such as self-efficacy, attitude, and engagement—it is recommended that they be implemented over longer periods, supported by different contexts (e.g., STEM), and structured according to students' readiness levels.

A primary limitation of this research is the relatively small sample size (N=52), which may limit the statistical power of the multivariate analysis (MANCOVA). While the sample was sufficient to detect a significant multivariate effect and a medium-level effect on mathematical literacy, it may have been less sensitive to smaller effects in the affective variables. Future studies with larger and more diverse samples are recommended to validate these findings across different contexts.

5. Recommendations

Based on the results of this research, MMAs significantly increased students' mathematical literacy levels, yet did not lead to a significant improvement in their self-efficacy toward mathematical literacy. This situation may stem from students' lack of awareness regarding their performance during the modeling process or their underdeveloped perceptions of their own mathematical competencies. Accordingly, it is recommended to increase the frequency of constructive feedback provided to students, explicitly highlight their progress during the learning process, and actively support their self-beliefs regarding their capabilities.The finding that the experimental process did not yield statistically significant differences in self-efficacy, engagement, and attitude is further corroborated by qualitative student opinions. Alongside positive evaluations, a non-negligible number of students characterized the problems as "difficult" or "boring," providing a critical clue regarding the limited impact on affective variables. Therefore, it is recommended to design more accessible, scaffolded, and engaging MMAs that ensure students undergo positive affective experiences while simultaneously achieving cognitive gains.Another limitation of this study is the six-week duration of the experimental process. It is recommended that future studies implement MMAs over a longer duration (e.g., a full academic semester) to examine their effects across a more extended timeframe. The literature emphasizes that students should assume an active, interactive, and productive role in the learning process, while the teacher should act as a facilitator (Korkmaz, 2006). Furthermore, group work in mathematical modeling is stated to support the learning process and is generally welcomed by students (Bukova Güzel et al., 2016; Zawojewski et al., 2003). The positive feedback regarding group work in this study underscores the importance of supporting modeling activities with collaborative learning environments. Consequently, it is recommended to conduct MMAs through group work and to expand learning environments where the teacher assumes a guiding role. Finally, this research was conducted in a single school with a limited number of students. Future studies involving different school types, student groups from diverse socio-economic backgrounds, and various grade levels would contribute to a more comprehensive evaluation of the effects of mathematical modeling.

Declaration of Conflicts of Interest

The authors declare that there are no conflicts of interest in relation to this study.

Declaration of Generative AI Use

Generative artificial intelligence (AI) was used in a limited capacity during the writing process. Specifically, Gemini and ChatGPT were utilized for translating the manuscript into English, as well as for grammar checking and enhancing sentence clarity. All scientific content, analyses, and conclusions were independently developed by the authors. The authors assume full responsibility for any ethical or academic implications arising from the use of generative AI tools.

Ethical Statement

This research involves data collection from human participants through surveys. The study received ethical approval from the Burdur Mehmet Akif Ersoy University Non-Interventional Clinical Research Ethics Committee (GOKA) (Decision No: GO 2021/361, dated 03.11.2021).

Author Contributions

This study is derived from the master's thesis prepared by the first author under the supervision of the second author. Abdullah TOPCU planned the data collection process, conducted the data collection, and carried out the experimental process. Ramazan GÜREL contributed to the data analysis and discussion. The first draft of the article was written by Abdullah TOPCU, and all versions were reviewed by all authors. All authors read and approved the final version of the article.

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