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Research Article

The effect of mathematical modeling-based instruction on seventh graders' mathematical literacy and academic performance

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This study investigates the impact of mathematical modeling-based learning environments on 7th grade students' mathematical literacy and academic performance. A quasi-experimental design with pre-test and post-test control groups was employed in the study, which involved 60 middle school students enrolled in a public school. A mathematical modeling-based learning process was undertaken by the experimental group, while a mathematics instruction without modeling applications was delivered to the control group. Skills-based mathematics tests were used to evaluate students' academic performance, and a literacy scale was used to evaluate their mathematical literacy. The students in the experimental group demonstrated a statistically significant improvement in their mathematical literacy scores between the pre-test and post-test. In contrast, the students in the control group did not show a statistically significant difference between their pre-test and post-test scores. Notably, students in the experimental group advanced to the fifth and sixth levels of mathematical literacy, whereas the control group exhibited minimal change, with no students reaching these higher levels. The experimental group performed better on all skill tests in terms of academic performance. Findings suggest that seventh-grade students' mathematical literacy and academic performance are positively impacted by mathematical modeling-based learning environments. The effect of modeling-based learning environments on students' affective dimensions and process skills could be explored in future research, employing diverse research designs to provide comprehensive insights.

Keywords: Academic performance, mathematical modeling, mathematical literacy, middle school

1. Introduction

Mathematics teaching must be aligned with current trends and orientations for each level, including kindergarten, primary school, secondary school, and high school, and must be updated accordingly. Efforts are being made to develop effective and efficient methods of teaching mathematics. One of the solutions to this may lie in trying new approaches in learning environments to encourage meaningful and permanent mathematical learning, especially by attempting to apply what is learned to real-world situations. Mathematical skills are an important goal of curricula at all levels of education (Ministry of National Education [MoNE], 2013, 2018; National Council of Teachers of Mathematics [NCTM], 2000). The traditional methods of teaching mathematics do not provide students with the opportunity to directly apply the mathematical concepts and processes they have learned to the real world problems they encounter or to reflect their life experiences and knowledge in the classroom. It is therefore essential that mathematics courses include practices that facilitate the use of mathematics in real life, or, in other words, supporting the use of mathematical concepts and processes to solve real world problems (Erbaş et al., 2016; Özaltun et al., 2013; Özaltun Çelik & Bukova Güzel, 2019; Özer & Bukova Güzel, 2022). Mathematics education literature emphasizes mathematical modelling and mathematical literacy as two important concepts that enable mathematics to be integrated into daily life. Mathematics models and mathematical literacy are important components of Turkish mathematics curricula and educational goals (MoNE, 2018).

Modeling in mathematics is defined as the representation of real-life problems mathematically through continuous transitions between the mathematical and physical worlds (Bukova Güzel et al., 2016). According to Galbraith and Clatworthy (1990), mathematical modelling is the application of mathematics to solve unstructured problems. A mathematical representation of a real-life situation is created through modelling, a structured process (Blum & Niss, 1991) that involves expressing real-life situations in a mathematical language, processing them mathematically, and interpreting the results in relation to reality. According to Lesh and Doerr (2003), while analyzing modelling activities that require model construction, mental actions such as determining relationships, performing mathematical analyses, reinterpreting the model are carried out. Described by Borromeo Ferri (2006) as a process in which learners' multifaceted mental actions are integrated, mathematical modelling consists of six basic steps: understanding, simplifying, mathematising, mathematising, working mathematically, interpreting and verifying the results. Mathematical modelling begins by understanding the real world problem, simplifying it, and associating it with mathematical concepts and knowledge. It is necessary to solve a mathematical problem using mathematical methods and knowledge, then interpret the mathematical results obtained with the solution, and verify the results, which must be verified to ensure that these results are valid in the context of real life and that the operations and results performed are accurate. The mathematical modelling process is a cyclical process that enables multidirectional transitions between all these steps. Upon examination of studies in the field of modelling, it is evident that studies are conducted with various participants at different levels, ranging from primary school to university, and studies can be classified as determining modeling competencies or developing modelling competencies (e.g. Akgün et al, 2013; Canbazoğlu & Tarım, 2021a; Çavuş Erdem et al., 2021; Hıdıroğlu et al., 2014; Hıdıroğlu et al., 2018; Kertil et al., 2017; Özgen & Şeker, 2021; Uzun et al., 2023).

Mathematical literacy emphasizes the concept of real life context, which is frequently emphasized in modelling definitions and modelling processes. Initially introduced in the Programme for International Student Assessment [PISA] framework, which assesses how well students use the knowledge and skills they acquire at school, the concept of mathematical literacy was later expanded with ongoing PISA assessments (Organisation for Economic Cooperation and Development [OECD], 2000). Individuals who are mathematically literate are able to apply mathematical reasoning effectively, solve real-life problems, and make informed decisions in situations. OECD (2019, 2022) describes mathematical literacy as the ability to comprehend mathematical concepts as well as apply, interpret, and reason about mathematical processes. In order to understand, interpret, and apply mathematical concepts in a real-life setting, students need to have a combination of knowledge of mathematical operations and reasoning skills as well as the ability to make informed decisions based on quantitative and spatial information (Blum & Niss, 1991). According to McCrone and Dossey (2007), mathematical literacy involves comprehending the role mathematics plays in real life and using mathematical reasoning and skills to solve real-life problems. Throughout the Turkish mathematics curriculum, the development of students' mathematical literacy skills and their effective use of this skill is stressed both as part of the objectives and as part of the learning outcomes (MoNE, 2018, 2024). Erdoğan and Arslan (2023) define mathematical literacy as finding solutions to issues they face in everyday life based on rational and critical thinking, thinking flexibly, and understanding the role of mathematics. Using high-level thinking skills and associating mathematics with their social lives, Karakaş and Ezentaş (2021) define mathematical literacy as the ability to solve everyday problems through mathematics.

Almost every profession today requires mathematics and mathematical thinking, and raising mathematically literate individuals can address this need (Taşkın et al., 2018). According to Karakaş and Ezentaş (2021), individuals can be equipped with mathematical literacy skills through school activities that involve daily life situations involving critical thinking. It has been suggested by Leibowitz (2016) that in order to increase students' mathematical literacy, learning environments should not rely solely on memorisation or procedural skills, but rather should enable students to comprehend mathematical concepts deeply and conceptually, and that abstract concepts should be explained in the context of real-life situations. Developing mathematical literacy requires relating mathematics to daily life, demonstrating how useful mathematics is beyond the classroom, incorporating teaching methods that encourage analytical thinking and problem-solving, providing metacognitive guidance to encourage thinking about problem-solving processes, and enabling students to interpret the world around them using mathematics as a tool (Höfer & Beckmann, 2009; Kabael & Barak, 2016; Kramarski & Mizrachi, 2004).

A review of the national literature on mathematical literacy indicates that several studies examined the levels of mathematical literacy among students, the factors that influence these levels, and how mathematical literacy affects students' achievement (e.g. Gürsakal, 2012; Taşkın et al., 2018; Uysal & Yenilmez, 2011). The related studies aimed at determining the factors affecting mathematical literacy are frequently conducted. Among the literature, the use of real-life applications to improve mathematical literacy stands out. The context of this study makes it important to discuss the reasons for including mathematical literacy and modelling together. The relationship between these two concepts is particularly important to explain why mathematical modeling applications will improve students' mathematical literacy in learning environments. Canbazoğlu and Tarım (2023) assert that mathematical modelling should be used in the primary school years and that children's mathematical literacy can be improved by confronting them with mathematical modelling problems and activities related to daily life.

Specifically, Öztürk and Masal (2020) state that mathematics curriculum is geared toward developing individuals able to employ mathematical literacy skills effectively, apply mathematical concepts in daily life, and understand the relationship between people and objects in a mathematical way. This is the kind of skill possessed by individuals who score high on the PISA mathematics proficiency scale, which is at the fourth level and higher. Canbazoğlu and Tarım (2023) point out that mathematical modelling is prominent in applications such as TIMSS and PISA. According to PISA 2018, the proportion of students with the fifth and sixth proficiency levels, which determine a student's mathematical modelling skills, is 3.9% and 0.9%, respectively, based on the results. Turkey's mathematical literacy performance is below the majority of participating countries and students are at the basic level in terms of mathematical skills (Canbazoğlu & Tarım, 2021b). Considering students' levels and performances, these results illustrate the importance of gaining modelling competencies and the need to involve students in mathematical modelling environments to improve their competency.

1.1. Relating Mathematical Modelling and Mathematical Literacy

Blum and Niss (1991), who conducted the most comprehensive study on the relationship between mathematical modelling and mathematical literacy, argue that the two skills should overlap in order to develop practical mathematical knowledge. The authors argue that mathematical modelling can promote mathematical literacy by providing structured solutions to complicated and realistic problems, making abstract mathematical concepts more accessible and relevant. A student's ability to deal with real-life problems through the use of mathematics in a systematic manner is a benefit of mathematical literacy, which can be applied to a wide range of settings. Furthermore, they assert that students will be able to solve mathematical problems as well as develop mathematical reasoning skills in a variety of everyday situations by combining both approaches.

In a recent study, Frejd, Ärlebäck, and Vos (2024) highlight the conceptual distinctions and overlaps between mathematical literacy and modeling. They argue that the term "literacy" pertains to human competence, while "modeling" relates to "human activities." Accordingly, they suggest that the concept most closely aligned with literacy is "modeling competence." Although both concepts connect mathematics to practices beyond its disciplinary boundaries and emphasize its service role in various contexts, they underscore their fundamental differences. The study defines mathematical literacy as the set of mathematical abilities individuals require to actively participate in and contribute to society, bridging societal and individual perspectives. A mathematically literate individual, for instance, can interpret graphs in a news article, predict the weather, or identify trends such as a rise in COVID-19 cases. However, the authors clarify that interpreting graphs alone does not constitute modeling; rather, it is a component of a broader modeling activity that addresses real-world questions such as "What clothes should I wear today?" or "Is it safe to gather socially?". The authors further differentiate the two by noting that mathematical modeling can be undertaken by students, citizens, or professional modelers. Professional modeling, which often involves advanced mathematical techniques, is typically excluded from the scope of mathematical literacy since such activities are beyond the capacity of ordinary citizens aiming to contribute to society. They emphasize that problem-solving at this advanced level is rarely performed by the general population. Despite these differences, the authors identify a shared objective between the two perspectives: the design, implementation, and evaluation of learning activities based on modeling tasks can effectively support students in developing mathematical literacy. This alignment highlights the potential of modeling tasks to foster essential skills for societal participation.

Mathematical literacy emphasizes interpreting and understanding the world through a mathematical lens, focusing on cultivating higher-order thinking and general problem-solving abilities rather than solely advancing the use of basic mathematical skills (Kozaklı Ülger et al., 2020). Mathematical literacy requires teaching practices that facilitate higher-order thinking, and mathematical modelling is an activity that requires higher-order thinking. Using this study, it will be possible to determine whether integrating modeling activities as activities that require higher-order thinking into teaching affects students' mathematics performance and mathematical literacy, thus establishing a model for mathematics educators to follow.

Among the studies conducted in Türkiye, three stand out as combining modelling with mathematical literacy. The first of these studies examined the effect of mathematical modeling education on mathematical literacy in 10th grade students in a one-group experimental study, and determined that the students' mathematical literacy levels increased to the fourth level at most. Demirci (2018) found that most of the students at the second level went on to the next level, but none of them were at the 5th and 6th levels and none were able to answer high-level mathematical literacy questions. Based on his experimental study of the effects of mathematical modeling activities on 9th grade students' mathematical literacy and beliefs, Erol (2015) found that students who were in the experimental group had higher mathematical literacy than those who were in the control group, and there was a statistically significant difference between pre-test and post-test math literacy. Using a mathematical modeling approach, Ata Baran (2019) found that fifteen 8th grade students improved their mathematical literacy performance.

This study examines the effects of a design that includes mathematical modeling-supported learning environments in 7th grade mathematics courses on students' academic performance and mathematical literacy. Through the experimental design, teachers will be able to find out how modeling activities can be incorporated into their mathematics lessons every week without disrupting the curriculum, how they can easily implement them, and what their role will be in this process. By examining the impact of mathematical modelling-supported educational environments on the development of students' mathematical literacy levels and how their academic performance is affected by all subjects within the 7th grade curriculum, this study is expected to contribute to the literature. Taking into account the similarities and distinctions between mathematical literacy and mathematical modelling, the aim of this study is to examine how mathematical modelling-based learning environments influence students' mathematical literacy and academic performance in 7th grade. In relation to this aim, two sub-problems were sought to be answered:

RQ 1) Is there a statistically significant difference between the mathematical literacy pre-test and post-test levels of the experimental and control group students in the 7th grade mathematics course?

RQ 2) Is there a statistically significant difference between the pre-test and post-test scores of the experimental and control group students' academic performance in the 7th grade mathematics course?

2. Method

This study used an experimental design with a pretest-posttest control group as a quantitative research method to examine the effect of mathematical modelling-based learning environments on the mathematical literacy and academic performance of 7th grade students. This study employed a quasi-experimental design since two existing classrooms in a public secondary school. As part of the quasi-experimental study, pre-tests were conducted to determine the current situation of the two groups before the study began, and the analysis of the data indicated that at the beginning of the study, both groups had similar characteristics. The experimental and control group were taught by one of the researchers during the thirteen-week study conducted in the 2020-2021 academic year. Mathematical modeling activities were incorporated during the implementation process for the experimental group, while no modelling activities were incorporated for the control group.

2.1. Study Group

The study involved 60 students in the 7th grade attending to a public secondary school in İzmir in the 2021-2022 academic year. Each group included 30 students from two different classes with an equal number of students and similar mathematics performances. Prior to application, a statistical test was performed to determine whether there was a difference in the pre-test scores between the experimental and control groups of students. Statistically, there was no significant difference between the experimental and control groups in terms of the study variables (see Table 1).

Table 1
Pre-post test comparison results of experimental and control groups

Mathematical Literacy	*n*	*Mean*	*SD*	*t*	*p*
Experimental group pre-test scores	30	10.87	6.06	0.713	.479
Control group pre-test scores	30	9.87	4.73		

2.2. Data Collection

2.2.1. Mathematical literacy scale

This study utilized a nine-question *mathematical literacy scale* (Altun et al., 2018) which were selected from 53 questions used in the PISA 2003 and 2006 to determine students' mathematical literacy levels. There are two or three sub-questions for some of these questions based on the roots of the items. The mathematical literacy scale contains 16 questions when each is considered separately. Three of these 16 questions were multiple choice, one was True/False, and the other 12 were open-ended. As part of the mathematical literacy assessment framework, the researchers selected questions based on their mathematical content, context, item types, and mathematical processes, and classified them according to their productive, associative, and reflective skill dimensions. Figure 1 shows an example of a question within this scale.

Figure 1
A sample question from the mathematical literacy scale

It is important to limit your activities when playing sports, for example, so as not to exceed a certain heart rate. For many years, the relationship between a person's recommended maximum heart rate and the person's age has been defined by the following formula: *Recommended maximum heart rate = 220 – age*. Recent studies have shown that this formula has been slightly modified. The new formula is as follows: *Maximum recommended heart rate = 208 – (0.7xage)* This formula can also be used to determine the most efficient time for physical activity. Studies have shown that physical activity is most productive when the heart rate is 80 percent of the maximum rate recommended. Formulate a formula for calculating the best time to do physical work, expressed in terms of age.

2.2.2. Skill-based tests

In order to ensure validity and reliability, the "7th Grade Skill-Based Tests" published on the website of the Ministry of National Education were used as pre-test and post-test. In light of the fact that these questions do not directly assess knowledge, instead require students to relate concepts to their everyday life, make associations between concepts and use their mathematical skills, they were deemed a better way to assess students' academic performance. Kertil et al. (2021) state that the questions used in PISA serve as good examples of skill-based questions. In addition to using images and figures, skill-based questions have informative functions and are associated with the daily life (Kedikli & Katrancı, 2022). Also, these questions are designed to improve students' cognitive abilities, analytical thinking skills, and problem-solving abilities, and they require students not just to memorize information, but rather to apply and analyze it (Dilekçi, 2022). In addition to measuring high-level skills, skill-based questions also require students to analyze, interpret, and infer data, solve problems in real-life contexts, and apply scientific processes. Therefore, students' academic performance was assessed using these tests in order to improve their process skills. A list of the contents of the 7th grade skills-based tests is provided in Table 2.

Table 2
Contents of skill-based tests

Learning Area	*Number of questions*
Operations with Whole Numbers	20
Rational Numbers and Operations with Rational Numbers	20
Algebraic Expressions and Equations	20
Ratio-Proportion, Percentages	23
Lines and Angles, Polygons	22
Data Analysis, Views of Objects from Different Perspectives	19

Question 19 in the 'Rational Numbers and Operations with Rational Numbers' test is presented in Figure 2 as an example of the questions in the 7th grade skill-based tests.

Figure 2
A sample question from skill-based tests

An olive oil's acidity can be determined by the amount of oleic acid it contains in 100 grams. The term 'extra virgin' describes olive oils with acidity between 0.2 and 0.8, whereas the term 'natural first' describes olive oils with acidity between 0.8 and 2. Below is a table containing the amounts of oleic acid found in samples taken from olive oils from brands A, B, and C.

Oleic acid amounts in the samples

Brand	Amount of sample (g)	Amount of oleic acid (g)
A	250	3
B	200	2
C	500	3

In light of this, what labels will be assigned to olive oils of the A, B, and C brands?

A	B	C
A) Extra virgin	Extra virgin	Natural first
B) Natural first	Natural first	Extra virgin
C) Extra virgin	Natural first	Extra virgin
D) Natural first	Extra virgin	Natural first

2.3. Implementation

This quasi-experimental design study was conducted during the autumn term of 2021-2022. This study involved both teaching practices using mathematical modelling activities and the use of data collection tools for both experimental and control groups. One of the researchers taught mathematics to both experimental and control groups. A summary of the measurements taking place before the experimental study, the procedures performed during the experimental process, and the measurements taken after the experimental study is preseted in Table 3.

Table 3
Embodiment of the pretest-posttest quasi-experimental design

Procedures	*Control group*	*Experimental group*
Measurements before the implementation	-Grade 7 Skill-Based Tests -Mathematical Literacy Scale	-Grade 7 Skill-Based Tests -Mathematical Literacy Scale
Implementation Process	-Traditional instruction	-Instruction in mathematical modelling supported learning environments
Measurements after the implementation	-Grade 7 Skill-Based Tests -Mathematical Literacy Scale	- Grade 7 Skill-Based Tests - Mathematical Literacy Scale

In order to conduct the experimental study, we obtained all the necessary permissions for the research, implementation, and the collection of data. Research was explained to students and their families, and volunteering and ethical principles were explained to participants. The implementation of the study was carried out with the experimental group and the process was completed two hours a week from the second week until the 13th week as indicated in Table 4.

Table 4
Implementation plan

Weeks	*Tasks*	*Learning area*
Week 1	Pre-tests: Implementation of Mathematical Literacy Scale and Skill-based Tests	-
Week 2	Introduction: Informing about Mathematical Modelling	-
Week 3	Problem: Ataturk Relief (Tekin Dede, 2015)	Ratio and Proportion - Percentages
Week 4	Problem: Step (Tekin Dede, 2015)	Algebraic Expressions – Equations Ratio and Proportion - Percentages
Week 5	Problem: Time at School (Maaß & Mischo, 2011)	Data Analysis - Ratio and Proportion
Week 6	Problem: Tooth Brushing (Tekin Dede, 2017)	Data Analysis - Ratio and Proportion
Week 7	Problem: Apple Pie (Tekin Dede, 2015)	Rational Numbers and Operations with Rational Numbers
Week 8	Problem: Lighthouse (Borromeo Ferri, 2010)	Lines and Angles - Ratio and Proportion
Week 9	Problem: Karşıyaka Ferry Pier (Karluk & Bukova Güzel, 2014)	Data Analysis - Ratio and Proportion
Week 10	Problem: Izmir Clock Tower (Bukova Güzel, 2014 cited in Bukova Güzel et. al)	Ratio and Proportion
Week 11	Problem: Talk Time in Mobile Phone (Tekin Dede, 2017)	Algebraic Expressions – Equations
Week 12	Problem: Distance between Izmir and Aydın (Tekin Dede, 2017)	Operations with Whole Numbers
Week 13	Post-tests: Implementation of Mathematical Literacy Scale and Skill-based Tests	

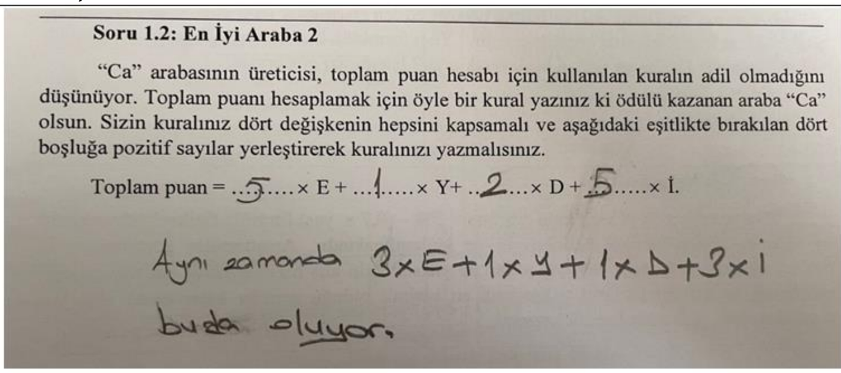
The pretests and posttests were administered face-to-face during one lesson in the first and last weeks. Since distance education was involved, both experimental and control group mathematics lessons were conducted online. Experimental group members were informed about mathematical modelling and modelling activities in the second week. A mathematical modelling activity was carried out each week for the next ten weeks by the experimental group. Students in these online lessons were sent the first modelling activity one day before the lesson, instructed to solve the problems individually, and then instructed to send their solutions to the researcher before the lesson. Afterwards, all modelling activities presented in Table 4 were solved by students in the presence of a researcher for two hours. A discussion followed the presentation of each student's individual solution. The modeling activities were selected in accordance with the 7th grade mathematics curriculum's order of topics, and were appropriate for the students' level and included different learning areas. Additionally, two mathematics educators working in the field of modelling provided expert opinions.

2.4. Data Analysis

The data were analyzed according to the rubric developed by Altun et al. (2018) for scoring the Mathematical Literacy Scale. In this context, complete solutions received 2 points, partial solutions 1 point, and no solutions received 0 point. Below is an example of a student's scoring for the "Best Car 2" question, where he received 2 full points by giving two different correct solutions. Students' mathematical literacy achievement test responses were individually coded by one of the researchers and a mathematics educator expert, and the final scores for each student were determined by comparing them.

Figure 3

Sample response to the question Best Car 2



Soru 1.2: En İyi Araba 2

"Ca" arabasının üreticisi, toplam puan hesabı için kullanılan kuralın adil olmadığını düşünüyor. Toplam puanı hesaplamak için öyle bir kural yazınız ki ödülü kazanan araba "Ca" olsun. Sizin kuralınız dört değişkenin hepsini kapsamalı ve aşağıdaki eşitlikte bırakılan dört boşluğa pozitif sayılar yerleştirerek kuralınızı yazmalısınız.

Toplam puan = ..5.... × E + ...1..... × Y+ ..2...× D + .5.....× İ.

Aynı zamanda 3×E+1×Y+1×D+3×İ buda oluyor.

The manufacturer of car 'X' thinks that the rule used to calculate the total points is unfair. Write a rule to calculate the total score such that the car that wins the prize is 'Ca'. Your rule must cover all 4 variables. You should write your rule by placing positive numbers in the four spaces left in the equation below.

Furthermore, in the study, the number of proficiency levels was calculated by dividing the difference between the total score (32%) and the lowest score (0) from the test's scoring system by the number of proficiency levels. Table 5 shows the mathematical literacy proficiency levels, PISA 2012 scores and the score ranges determined in the study.

Table 5

Mathematical Literacy Proficiency Levels

Proficiency Levels	*PISA 2012 Scores*	*Current study scores*
Level 1	357.77-420.07	0-5.5
Level 2	420.07-482.38	5.6-11.1
Level 3	482.38-544.68	11.2-16.7
Level 4	544.68-606.99	16.8-22.3
Level 5	606.99-669.30	22.4-27.9
Level 6	669.30+	28-32

Using the MoNE's answer key, the 7th Grade Skill-Based Tests were scored as '1' for the correct answer and '0' for the incorrect or blank answer. One of the researchers scored each of these tests fort he participants. Statistical package program SPSS 20 was used to analyze the data collected in the study. Statistical methods such as mean, standard deviation, frequency and percentage distributions were used to analyse the quantitative data obtained. For the purpose of determining which tests should be used to compare and associate the data, it was checked whether the data were normally distributed (see Table 6).

Table 6

Normality Test Results

Tests	*Skewness*	*Kurtosis*
Mathematical Literacy Scale -Pretest	0.461	−0.771
Mathematical Literacy Scale -Posttest	0.876	0.334
Operations with Whole Numbers -Pretest	−0.394	−0.861
Operations with Whole Numbers - Posttest	−0.309	−1.191
Rational Numbers and Operations with Rational Numbers - Pretest	−0.142	−0.619
Rational Numbers and Operations with Rational Numbers - Posttest	0.170	−1.160
Algebraic Expressions/Equations - Pretest	0.415	−1.135
Algebraic Expressions/Equations - Posttest	0.284	−1.106
Ratio and Proportion/Percentages - Pretest	0.972	−0.088
Ratio and Proportion/Percentages - Posttest	0.534	−0.772
Lines and Angles - Pretest	0.929	0.248
Lines and Angles - Posttest	0.688	−0.380
Data Analysis/ Views of Objects from Different Perspectives Pretest	0.849	−0.278
Data Analysis/ Views of Objects from Different Perspectives - Posttest	0.859	−0.108

It is evident from Table 6 that all tests have skewness and kurtosis values within −1.50 and +1.50, which shows their distributions are normal (Tabachnik & Fidell, 2015). Therefore, parametric tests were applied to analyse the data.

3. Findings

3.1. Comparison of the Mathematical Literacy

It was evaluated whether there was a statistical difference between the pre and post test scores of the experimental group after incorporating mathematical modeling support into the learning environment. Table 7 presents the comparison results related to the in-group difference of the experimental group for this purpose.

Table 7

Comparison of pretest and posttest scores for mathematical literacy in the experimental group

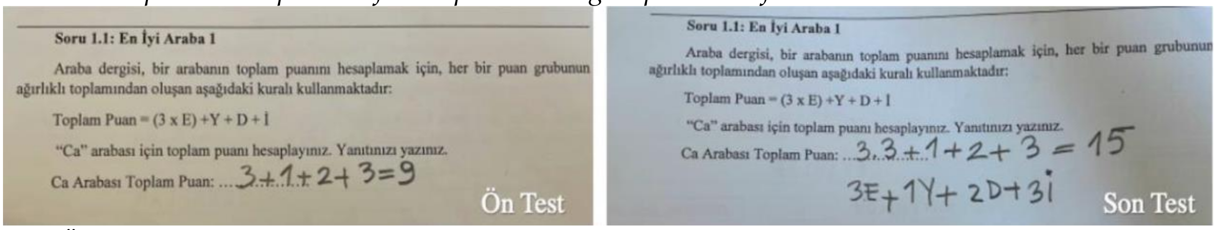
Mathematical Literacy Scale	*n*	*Mean*	*SD*	*t*	*p*
Pre-test	30	10.87	6.06	−7.16	.001*
Post-test	30	14.57	7.61		

Note. **p* < .05.

The results of the analysis of Table 7 demonstrate that there was a statistically significant difference between the pre-test and post-test levels of the *mathematical literacy scale* in the experimental group ($p < .05$). Post-test results of the mathematical literacy scale showed a significant increase. Mathematical modelling-based learning environment was found to positively affect the students' mathematical literacy achievement levels. Figure 4 shows a student's responses to the 'Best Car 1' task in the mathematical literacy scale pretest and posttest.

Figure 4

Pretest and posttest responses of an experimental group student for the "Best Car 1"


Soru 1.1: En İyi Araba 1

Araba dergisi, bir arabanın toplam puanını hesaplamak için, her bir puan grubunun ağırlıklı toplamından oluşan aşağıdaki kuralı kullanmaktadır:

Toplam Puan = (3 x E) +Y + D + İ

"Ca" arabası için toplam puanı hesaplayınız. Yanıtınızı yazınız.

Ca Arabası Toplam Puan: ...3+1+2+3=9

Ön Test

Soru 1.1: En İyi Araba 1

Araba dergisi, bir arabanın toplam puanını hesaplamak için, her bir puan grubunun ağırlıklı toplamından oluşan aşağıdaki kuralı kullanmaktadır:

Toplam Puan = (3 x E) +Y + D + İ

"Ca" arabası için toplam puanı hesaplayınız. Yanıtınızı yazınız.

Ca Arabası Toplam Puan: ...3.3+1+2+3 = 15

3E+1Y+2D+3İ

Son Test

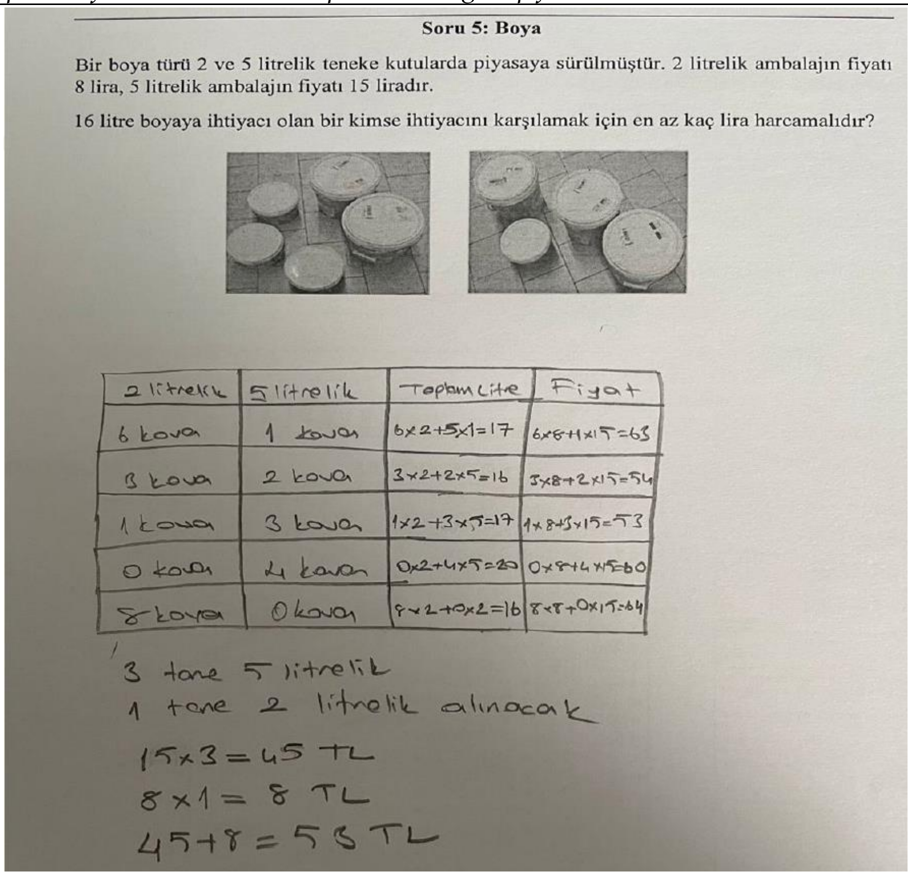
Note. Ön test: Pretest; Son Test; Posttest.

Regarding this question, it is seen that the student in the experimental group paid attention to the use of variables in the post-test. At the same time, it was determined that the student could not find the correct answer in the pre-test and wrote only the coefficients, but in the post-test, he reached the correct answer as well as the use of variables.

Another example from the solutions of the experimental group students is the post-test answer given by a student for the question 'Paint' in Figure 5.

Figure 5

The post-test response of a student in the experimental group for 'Paint' task


Soru 5: Boya

Bir boya türü 2 ve 5 litrelik teneke kutularda piyasaya sürülmüştür. 2 litrelik ambalajın fiyatı 8 lira, 5 litrelik ambalajın fiyatı 15 liradır.

16 litre boyaya ihtiyacı olan bir kimse ihtiyacını karşılamak için en az kaç lira harcamalıdır?

2 litrelik	5 litrelik	Toplam Litre	Fiyat
6 kova	1 kova	6x2+5x1=17	6x8+1x15=63
3 kova	2 kova	3x2+2x5=16	3x8+2x15=54
1 kova	3 kova	1x2+3x5=17	1x8+3x15=53
0 kova	4 kova	0x2+4x5=20	0x8+4x15=60
8 kova	0 kova	8x2+0x2=16	8x8+0x15=64

3 tane 5 litrelik
1 tane 2 litrelik alınacak
15x3=45 TL
8x1= 8 TL
45+8=53 TL

A type of paint is marketed in 2 and 5 litre cans. The price of a 2-litre package is 8 liras and the price of a 5-litre package is 15 liras.

How much should a person who needs 16 liters of paint spend at least?

While the student did not answer the question in the pre-test, in the post-test, in addition to solving the question correctly, he analysed the question in his solution and created a table compiling the information he obtained. The answer requires sixteen litres of paint but it is the minimum cost required mainly in the question. For this reason, the remainder of 1 litre in the answer does not cause a problem, it is even vital. It is the desired situation that both the need for 16 litres of paint is met and it is the cheapest cost. In the post-test solution, the student concretised the situation in the table he created and reached the correct solution of this problem that he adapted to daily life.

In order to evaluate the effect of mathematical modelling supported learning environment on the development of students' mathematical literacy levels, it was investigated whether there was a statistical difference between the pretest and posttest scores of the control group. For this purpose, the comparison results related to the in-group difference of the control group are presented in Table 8.

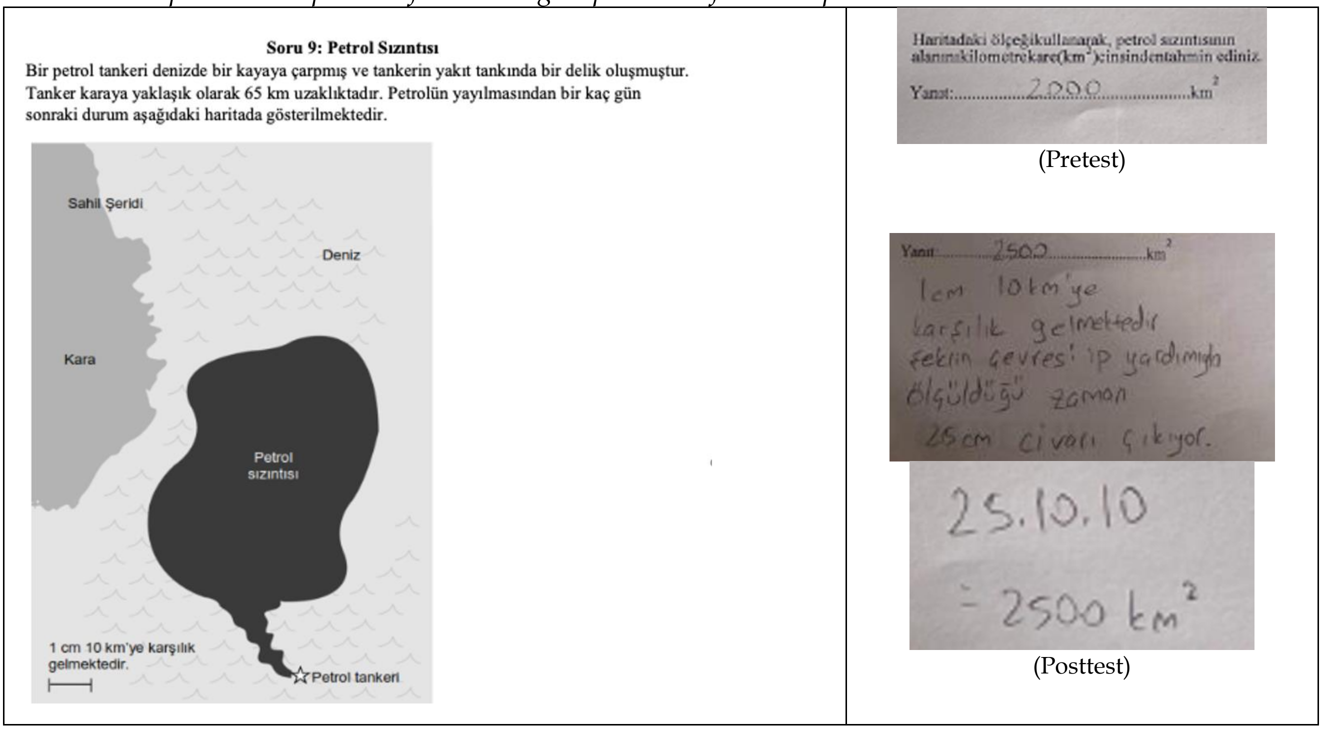
Table 8
Comparison of pretest and posttest scores for mathematical literacy in the experimental group

Mathematical Literacy Scale	*n*	*Mean*	*SD*	*t*	*p*
Pre-test	30	9.87	4.73	−1.424	.165
Post-test	30	10.33	4.51		

Table 8 presents that there was not a statistically significant difference between the pre-test and post-test levels of the Mathematical Literacy Scale in the control group (p>.05). Although a difference was observed between the pre-test and post-test average scores, this difference was not statistically significant and was not as pronounced as the difference observed in the experimental group.

Figure 6 presents the pre-test and post-test responses of a control group student to the "Oil Spill" question from the Mathematical Literacy Scale. Although the pre-test answer of the student in the control group was correct, as were all values between 2000-3300 depending on the size and scale of the given figure, the student did not make any explanation for this result. The student also tried to use scale in the post-test answer, but in this process, he calculated the perimeter, which led to the conclusion that the student could not understand the problem.

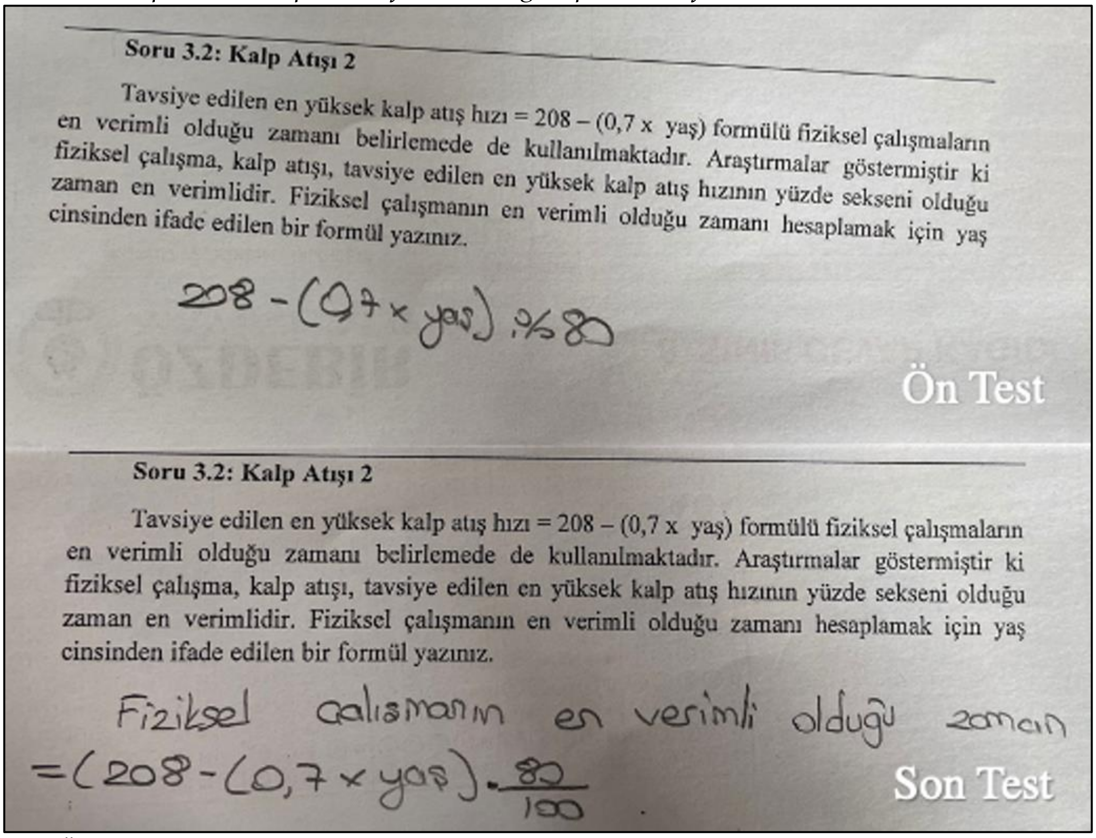
Figure 6
Pre-test and post-test responses of a control group student for 'Oil Spill' task



(Pretest)
(Posttest)

Figure 7 shows the pre-test and post-test responses of a student in the control group for the question 'Heartbeat 2'.

Figure 7
Pre-test and post-test responses of a control group student for 'Heartbeat 2' task



Soru 3.2: Kalp Atışı 2

Tavsiye edilen en yüksek kalp atış hızı = 208 – (0,7 x yaş) formülü fiziksel çalışmaların en verimli olduğu zamanı belirlemede de kullanılmaktadır. Araştırmalar göstermiştir ki fiziksel çalışma, kalp atışı, tavsiye edilen en yüksek kalp atış hızının yüzde sekseni olduğu zaman en verimlidir. Fiziksel çalışmanın en verimli olduğu zamanı hesaplamak için yaş cinsinden ifade edilen bir formül yazınız.

208 - (0,7 x yaş) %80

Ön Test

Soru 3.2: Kalp Atışı 2

Tavsiye edilen en yüksek kalp atış hızı = 208 – (0,7 x yaş) formülü fiziksel çalışmaların en verimli olduğu zamanı belirlemede de kullanılmaktadır. Araştırmalar göstermiştir ki fiziksel çalışma, kalp atışı, tavsiye edilen en yüksek kalp atış hızının yüzde sekseni olduğu zaman en verimlidir. Fiziksel çalışmanın en verimli olduğu zamanı hesaplamak için yaş cinsinden ifade edilen bir formül yazınız.

Fiziksel çalışmanın en verimli olduğu zaman $= (208 - (0,7 \times yaş)) \cdot \frac{80}{100}$

Son Test

Note. Ön test: Pretest; Son Test; Posttest.

Figure 7 shows that the pre-test and post-test answers were the same and the student made mistakes in both solutions. However, the student was able to write the given expression mathematically in the post-test solution. This situation is thought to be due to the fact that the solution of the problem was asked after the teaching of the topic of percentages, in other words, the student's current knowledge.

The frequency distributions of the students in the experimental and control groups in the pre-test and post-tests in terms of the levels (see Table 5) determined for mathematical literacy were presented in Table 9.

Table 9
Frequency Distribution of Mathematical Literacy Levels

Levels	*Experimental group*		*Control group*	
	Pre-test	*Post-test*	*Pre-test*	*Post-test*
Level 1	7	3	5	4
Level 2	10	8	14	13
Level 3	6	7	8	9
Level 4	5	7	3	4
Level 5	2	1	0	0
Level 6	0	4	0	0

Analysis of Table 9 reveals that no control group student is in the fifth or sixth level. Even though two students in the experimental group scored at the fifth level in the pre-tests, the number of students scoring at the fifth and sixth levels in the experimental group increased. Though the experimental group had a higher percentage of first-level students in the pre-test, more than half of these students developed toward higher levels in the post-test. In both groups, the majority of students scored between the first and second level on the pre-tests; however, more than half of experimental group students scored above the second level on the post-tests. As a result of the mathematical modelling supporting instruction practices, the mean mathematical literacy scores of the experimental group students increased from the bottom of the second level to the top of the third level. There were no students in the control group who advanced beyond the fourth level. Despite changes in the average scores of the experimental group, the control group did not experience similar improvements in mathematical literacy. Moreover, the pre-test mean (10.87) and post-test mean (14.57) values of the Mathematical Literacy Scale in the experimental group showed the impact of mathematical modelling compared to the control group (see Tables 7 and 8).

3.2. Comparison of the Academic Performance

An analysis of pre- and post-test scores of the experimental and control groups was conducted to determine whether mathematical modeling supported learning environment increased students' academic performance. Table 10 shows the comparison results of the in-group difference of the experimental group.

Table 10

Comparison of pretest and posttest scores of the experimental group on academic performance

Academic performance tests	*N*	*Mean*	*SD*	*t*	*p*
Operations with Whole Numbers –Pretest	30	11.77	4.52	−4.563	.001*
Operations with Whole Numbers – Posttest	30	14.20	4.40		
Rational Numbers and Operations with Rational Numbers –Pretest	30	11.37	3.93	−6.046	.001*
Rational Numbers and Operations with Rational Numbers – Posttest	30	14.47	4.31		
Algebraic Expressions/Equations - Pretest	30	9.00	4.70	−5.286	.001*
Algebraic Expressions/Equations - Posttest	30	12.87	3.71		
Ratio and Proportion/Percentages - Pretest	30	7.93	4.89	−7.037	.001*
Ratio and Proportion/Percentages - Posttest	30	12.30	4.36		
Lines and Angles - Pretest	30	6.77	4.78	−7.459	.001*
Lines and Angles - Posttest	30	11.20	4.51		
Data Analysis/ Views of Objects from Different Perspectives Pretest	30	7.60	5.30	−6.894	.001*
Data Analysis/ Views of Objects from Different Perspectives - Posttest	30	10.83	4.76		

Note. *$p < .05$

Table 10 shows a statistically significant difference between the pre- and post-test levels of all the tests ($p < .05$). It was determined that the post-test mean scores for all tests were significantly higher. Moreover, the effect sizes of the differences are high since the effect sizes are above 0.50 (Field, 2009). Analysis of the results indicated a high rate of academic improvement for students who participated in modelling-supported education.

A statistical analysis of the pre- and post-test scores of the control group was also conducted. Table 11 presents the comparison results of the control group regarding the within-group difference. Table 11 shows that there is a statistically significant difference in the pre/post-tests of Ratio and Proportion/Percentages in the control group ($p < .05$). A significant increase was found in the test scores after the post-test. While the control group scored higher on the other tests that measured academic performance, there was no statistically significant difference between the pre- and post-test scores of the control group.

Table 11

Comparison of pretest and posttest scores of the control group on academic performance

Academic performance tests	*n*	*Mean*	*SD*	*t*	*p*
Operations with Whole Numbers -Pretest	30	12.10	5.25	−1.596	.121
Operations with Whole Numbers - Posttest	30	12.73	5.26		
Rational Numbers and Operations with Rational Numbers –Pretest	30	8.60	4.77	−1.12	.272
Rational Numbers and Operations with Rational Numbers – Posttest	30	9.10	4.09		
Algebraic Expressions/Equations - Pretest	30	7.77	5.08	−1.27	.214
Algebraic Expressions/Equations – Posttest	30	8.30	4.24		
Ratio and Proportion/Percentages – Pretest	30	6.90	4.88	−2.395	.023*
Ratio and Proportion/Percentages – Posttest	30	7.60	4.19		
Lines and Angles – Pretest	30	6.30	4.84	−2.032	.051
Lines and Angles – Posttest	30	7.10	4.18		
Data Analysis/ Views of Objects from Different Perspectives Pretest	30	6.83	4.96	−0.424	.674
Data Analysis/ Views of Objects from Different Perspectives - Posttest	30	7.00	3.77		

Note. $^{*}p < .05$

4. Discussion and Conclusion

This study examines the effects of mathematical modelling supported learning environments on students' mathematical literacy and academic performance. According to the results, the mathematical modeling-supported learning environment improved the mathematical literacy and academic performance of 7th grade students. Both their scores and their mathematical literacy levels changed as a result of the mathematical modelling supported learning environment. In our study, we found that experimental group students demonstrated a significant increase in mathematical literacy; in other words, there was a statistically significant difference between pre- and post-test mathematical literacy scores. The results here are consistent with those shown by Demirci (2018), Erol (2015), and Ata Baran (2019). A one-group experimental design study conducted by Demirci (2018) found that mathematical modeling-oriented teaching activities positively contributed to students' mathematical literacy, enabling them to reach a maximum of the fourth level, although they were unable to progress to the fifth or sixth levels. As stated in Erol (2015), students in the experimental group became more mathematically literate as a result of the education with modeling activities, whereas students in the control group did not acquire any new skills in this area.

The experimental students' mathematical literacy scores increased within the scope of the study, but another important finding was the difference between their levels of mathematical literacy. Students in the experimental group were at the fifth and sixth levels in terms of mathematical literacy, whereas students in the control group reached only the fourth level at most. It is particularly noteworthy in light of Türkiye's success in PISA. In the study conducted by Canbazoğlu and Tarım (2023), the proportion of students at the fifth and sixth proficiency levels prior to the experiment was significantly different than the proportion at the fifth and sixth level after the experiment (5 out of 30 students). Clearly, this situation illustrates the benefits of modeling-based learning environments. A key contributing factor to this result was that real-life problems encountered in the teaching process were analyzed in detail in terms of their mathematical meanings and understood holistically. Based on this thirteen-week study, we conclude that mathematical modelling should be integrated into all teaching processes starting from the primary level. Future research should examine the changes in students' mathematical literacy through longitudinal and developmental studies that incorporate modelling activities at different levels. Mathematical modelling is viewed as part of mathematical literacy, which is why it has a positive impact on students' mathematical literacy.

A statistically significant difference was found between the pre- and post-test scores for each skill-based test in the experimental group, as assessed by academic performance evaluations. Using skill-based questions, students and teachers have difficulty solving them because they require multiple skills to be used at the same time. Mathematics teachers are able to improve students' higher-order thinking skills by including mathematical modelling activities in in-class activities, making it easier for them to comprehend and solve skill-based questions (Duran & Bahadır, 2022). A mathematical modeling-supported learning environment we achieved within the scope of the study increased the students' academic performance, proving the statement. Control group scores increased statistically significantly only in one skill-based test, and other differences between pre-test and post-test scores were not statistically significant.

As a result of the mathematical model-based learning environment, students' academic performances improved, they became more mathematically literate, they felt more self-confident and participated more in the lessons. Using real life examples in the teaching process makes the applications more engaging. It was not possible to conduct a systematic examination in this regard in our study, and we recommend that further research be conducted on variables such as mathematics self-efficacy, mathematics anxiety, attitude, and motivation. In addition, results of modeling-supported instruction carried out online should also be tested face-to-face. Furthermore, this study can serve as an exemplary design for mathematics teachers when it comes to integrating mathematics modelling activities into the teaching process, selecting and sequencing the activities appropriately, and implementing them. The literature can be contributed to by sharing the design with secondary school teachers and reporting on its usability both online and face-to-face.

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Data availability: The dataset of the study is available from the corresponding author on reasonable request.

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