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The impact of Socratic method on middle school students' achievement in non-routine problem solving and their attitudes toward mathematical problem solving

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Abstract
Non-routine problems play a significant role in mathematics learning due to their potential to foster students' reasoning, inquiry, and critical thinking skills. Students, however, often experience difficulties in solving these problems and may experience negative attitudes toward them. In this context, the Socratic method, which is a dialectical dialogue organized through questions and answers, may serve as an effective tool for solving non-routine problems. This study investigates the effect of problem-solving activities supported by the Socratic method on students' achievement in non-routine problems and their mathematics problem-solving attitudes. A quasi-experimental pre-test-post-test control group design was adopted. The sample consisted of a total of 33 seventh-grade students, including 16 in the experimental group and 17 in the control group. Data was collected through a non-routine problem-solving achievement test and a mathematics problem-solving attitude scale, which consists of teaching and enjoyment dimensions, administered before and after the implementation. The findings indicate that the Socratic method led to a significant improvement in students' achievement in non-routine problems. However, mathematics problem-solving attitudes scores declined in both groups. This decline was particularly evident in the teaching dimension of scale and may be associated with the cognitive demands of non-routine problems and the abstract nature of algebra. In conclusion, while the Socratic method appears to be effective in improving achievement in non-routine problems, its implementation should be supported by strategies that address students' affective needs.

Keywords: Achievement; Attitude; Middle school mathematics; Non-routine problems, Problem-solving, Socratic method

1. Introduction

Mathematics education seeks to develop students' problem-solving, inquiry, critical thinking, and reasoning skills. Accordingly, mathematics instruction should enable students to discover pathways to knowledge, construct new learning based on their prior knowledge and experiences, establish connections with real-life situations, and enhance their mathematical literacy, going beyond mere knowledge transmission (Ministry of National Education [MoNE], 2024; Steen, 1999). Such instruction facilitates students' transition from a passive role to that of an active learner (Wagner, 2008). In contrast, traditional teaching methods often direct students toward formula- and procedure-based, repetitious exercises that lack inquiry. Therefore, providing students open-ended, real-life, non-routine problem situations that encourage them to express their own thinking and actively engage in inquiry-based and critical reasoning processes is essential. However, studies have shown that students struggle with non-routine problems (Elia et al., 2009; Gavaz et al., 2021; Yeo, 2009). Instructional approaches that promote questioning, dialogue, and justification can support these learning processes. The Socratic method, which is based on a structured form of dialogic inquiry, may serve as an alternative pedagogical approach to engage students with critical reasoning process in non-routine problem-solving activities.

Research indicates that the Socratic method positively influences students' academic achievement in social studies courses and their attitudes toward the course (Hüner, 2021). Zaimoğlu (2022) and Özsaraç (2019) concluded that the Socratic method contributes to students' critical thinking, problem-solving, and higher-order thinking skills. Berg (2024) found that the use of the Socratic method on the logarithm topic positively influenced high school students' mathematical motivation, participation, and interaction levels with the subject. Similarly, Taylor (2023) showed that the Socratic method increases middle school students' participation, academic achievement, and reasoning skills. Previous studies have demonstrated the effectiveness of the Socratic method in teaching specific mathematical topics such as calculus and algebra and in a variety of other disciplines by promoting students' participation, reasoning, academic achievement, and attitudes (Hüner, 2021; Taylor, 2023; Yakar, 2017; Yıldız & Dadı, 2019). Based on the literature review, we found limited evidence of research explicitly focusing on the use of the Socratic method in mathematics problem-solving activities. Given its potential to support active and student-centered learning, conducting problem-solving stages drawing on the Socratic method could enable students to gain a deeper and more critical perspective, particularly regarding non-routine problems. The comprehensive integration of the Socratic method with the problem-solving process is thought to be essential to improve students' achievement and mathematics problem-solving attitudes. Thus, the primary contribution of the present study lies in integrating Socratic questioning into non-routine mathematical problem-solving activities structured around Polya's (1957) problem-solving stages. In this context, the purpose of the study is to examine the effect of non-routine problem-solving activities supported by the Socratic method on seventh-grade students' academic achievement in non-routine problems and mathematics problem-solving attitudes. The research questions of the study are as follows:

RQ 1) Is there a significant difference between the academic achievement scores on the non-routine problems of 7th-grade students exposed to Socratic questioning–based problem-solving activities and those receiving traditional instruction based on paper-and-pencil problem-solving activities?

RQ 2) Is there a significant difference between the mathematics problem-solving attitudes of 7th-grade students exposed to Socratic questioning–based problem-solving activities and those receiving traditional instruction based on paper-and-pencil problem-solving activities?

2. Background

This section presents the theoretical background of the study. It first discusses the characteristics of non-routine problems and Polya's (1957) problem-solving framework, followed by an overview of the Socratic method and its pedagogical principles to provide a conceptual basis for integrating Socratic questioning into non-routine mathematical problem-solving activities.

2.1. Non-Routine Problems

A non-routine problem is a problem for which the solution method is not immediately obvious and cannot be solved by directly applying a memorized formula, algorithm, or procedure, and requires a sustained effort (Polya, 1957; Zhu & Fan, 2006). Students often tend to reach a solution directly by relying on familiar formulas without engaging in deep thinking on the problem situation (Arslan & Altun, 2007). However, the problem-solving process is beyond obtaining merely a mathematical result; it is a dynamic process consisting of understanding the problem, planning a strategy for the solution, implementing the plan, and evaluating the solution (Polya, 1957). In this regard, Polya's (1957) problem-solving framework emphasizes that these four steps are intertwined and should be considered as a holistic process. In the stage of understanding the problem, the student interprets the problem situation and clearly identifies the given information along with the required outcomes. During the planning stage, appropriate strategies (e.g., tables, diagrams, graphs, and formulas) are selected. The implementation stage involves systematically applying the decided strategy. Finally, in the evaluation stage, the results are reviewed; potential errors are analyzed, and if necessary, the process is revisited and adjusted accordingly. This process requires students not only to perform calculations but also to engage in questioning, justify their reasoning, and discuss alternative solutions. In this context, the Socratic method can be considered an effective pedagogical approach that aligns with problem-solving steps and has the potential to deepen students' engagement in the problem-solving process (Rhee, 2007).

2.2. The Socratic Method

The Socratic method was developed by Socrates based on dialectical dialogue organized through questions and answers. This method is based on engaging in dialogue through probing questions that stimulate critical thinking, rather than providing direct answers to the student's initial question (Benson, 2011). An important component of the Socratic method is the use of maieutic questions, which guide learners to construct understanding through a sequence of probing questions that encourage reflection and self-discovery rather than providing direct answers (Dowie, 2023). It is firmly rooted in active learning, promoting student-centered, collaborative, and dialogic interactions that have been demonstrated to improve learning outcomes (Michael, 2006). Drawing on the Socratic tradition, knowledge is developed through dialogue and reflective questioning, allowing learners to actively construct understanding rather than passively receive information (Nuraeni et al., 2026). This method has a long historical background and has been used from Socrates to the present day as a means of encouraging students to think, and of supporting their inquiry and self-expression skills (Rhee, 2007; Taylor, 2023). Furthermore, the Socratic method is related to critical thinking (Paul & Elder, 2008). Its emphasis on dialogue involving the articulation, critique, and refinement of arguments contributes to students' problem-solving skills and conceptual understanding (Dekker & Elshout-Mohr, 1998; Pijls & Dekker, 2011). These characteristics position the Socratic method as an effective student-centered pedagogical approach. Thus, it encourages students to be active participants rather than passive recipients of information by questioning, justifying their thoughts, and evaluating different perspectives.

3. Method

3.1. Study Design

The study adopted a pre-test-post-test control group design, a type of quasi-experimental design. In this design, one group is assigned as the experimental group and the other as the control group (Creswell, 2012). In the experimental group, non-routine problem-solving tasks supported by the Socratic method were implemented, whereas the control group engaged in traditional instruction based on paper-and-pencil problem-solving activities. A pre-test and a post-test were administered before and after the intervention to determine the groups' levels, and comparisons were conducted between and within the groups following the intervention.

3.2. Population and Sample

The target population of the study consisted of 7th-grade students (aged 13–14) enrolled in public schools in Istanbul. A convenience sampling method was employed, which is a non-random sampling technique involving participants who are readily accessible to the researcher (McMillan & Schumacher, 2014). The sample comprised 33 students attending a public school in Istanbul who voluntarily participated in the study. While 16 students (11 female, 5 male) were assigned to the experimental group, 17 students (8 female, 9 male) formed the control group. One of the existing classes was randomly assigned to the experimental group, and the other served as the control group. Kim and Steiner (2016) argue that quasi-experimental designs are appropriate when random assignment is infeasible, because they allow researchers to estimate causal effects in real-world settings by using naturally occurring groups and design features that reduce threats to internal validity. Accordingly, the sample consisted of the accessible population (two intact seventh-grade classrooms) available in the participating school. No statistically significant pre-intervention differences were observed between the experimental and control groups in non-routine problem-solving achievement or mathematics problem-solving attitudes (see Tables 1 and 2).

3.3. Data Collection Tools

Two data collection instruments were used for the study regarding achievement and attitude. The "Non-Routine Problem-Solving Achievement Test", developed by Öztürk et al. (2020), was used as the achievement test. The test consists of a total of six open-ended problems, with a maximum possible score of 36. Students's responses were evaluated using a scoring rubric developed by Akkuş and Duatepe-Paksu (2006), as presented in Table 3. Figure 1 presents examples of scoring

Table 1

Mann–Whitney U Test Results for Pre-Test Non-Routine Problem-Solving Achievement

	N	*Mean*	*SD*	*U*	*p*
Experimental (pre-test)	16	9.563	6.044	.939	.062
Control (pre-test)	17	9.647	7.881		

Table 2

Independent-Samples t-Test Results for Pre-Test Mathematics Problem-Solving Attitudes

	N	*Mean*	*SD*	*t*	*p*
Teaching dimension					
Pre-test (Experimental)	16	34.563	4.871	.513	.612
Pre-test (Control)	17	33.529	6.520		
Enjoyment dimension					
Pre-test (Experimental)	16	36.375	5.548	−.865	.394
Pre-test (Control)	17	38.059	5.629		
Total					
Pre-test (Experimental)	16	70.938	9.504	−.180	.858
Pre-test (Control)	17	71.588	11.097		

for student responses. To ensure scoring reliability, two independent raters evaluated the student responses. Inter-rater reliability was calculated as 91.76% using the agreement formula proposed by Miles and Huberman (1994). Discrepancies between raters were subsequently discussed to reach a consensus.

Figure 1

Example of Solutions in the Non-Routine Problem-Solving Achievement Test

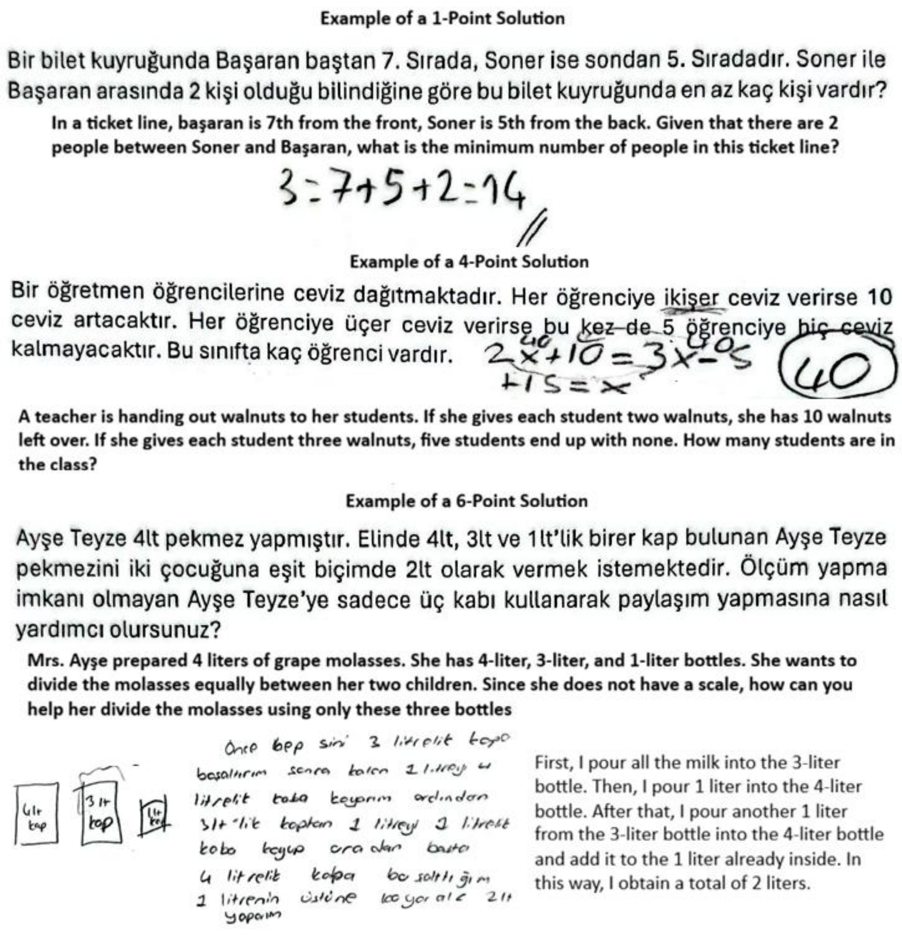

Table 3
Scoring Rubric of the "Non-Routine Problem-Solving Achievement Test

Point	*Evaluation criteria*
0	Leaving the problem blank or providing a completely irrelevant response
1	Writing only part of the problem statement or using the given information with arbitrary values
2	Applying only a limited part of the expected solution strategy but not being able to continue the process, or making incorrect calculations using arbitrary numbers
3	Applying the expected solution strategy but making computational errors, or establishing some correct relationships without reaching the final solution
4	Largely applying the expected solution strategy but not obtaining the correct result
5	Following a mostly correct solution process and progressing to the final stage but not completing the last step, or establishing correct reasoning without expressing it appropriately
6	Solving the problem completely and correctly, clearly demonstrating the underlying reasoning, applying procedures without error, and supporting the solution with appropriate explanations

The "Mathematics Problem-Solving Attitude Scale", developed by Çanakçı and Özdemir (2011), was used to measure students' mathematics problem-solving attitudes. The scale consists of 19 items with reverse-scored items, structured under two dimensions: enjoyment and teaching. The enjoyment dimension includes 10 items, while the teaching dimension comprises 9 items. The maximum possible score on the scale is 85. In the present study, the Cronbach's alpha reliability coefficient for the overall scale was calculated as .82. The reliability coefficient was found to be .78 for the enjoyment dimension and .71 for teaching dimension.

3.4. Implementation Process

Before the implementation of non-routine problem-solving activities supported by the Socratic method, pre-tests (both Non-Routine Problem-Solving Achievement Test and Mathematics Problem-Solving Attitude Scale) were administered to both the experimental and control groups. Following the intervention, post-tests (both Non-Routine Problem-Solving Achievement Test and Mathematics Problem-Solving Attitude Scale) were administered to both groups. The intervention in the experimental group lasted five weeks, with two hours of instruction per week. Students voluntarily participated in problem-solving activities in groups of four, and these groups remained the same throughout the intervention. In the control group, traditional instruction based on paper-and-pencil problem-solving activities were conducted, without the use of the Socratic method.

In the experimental group, each week a non-routine problem activity was conducted, supported by the Socratic method in line with Polya's (1957) problem-solving stages. Guiding questions aligned with each problem-solving stage were designed to facilitate the discussions based on the Socratic method during the implementation (See App. A). The activities in both the experimental and control groups were conducted by the second author in collaboration with the classroom teachers who were responsible for the mathematics lessons. To enhance implementation fidelity, all instructional sessions were conducted following a predefined lesson plan and implementation procedure. The same instructional sequence and duration were maintained across all intervention sessions. The problems were adapted from Stephenson's (2001) study, evaluated by domain experts, and a final set of five problems was selected. Although each problem is presented with a primary problem-solving strategy, the problems were intentionally selected to allow multiple solution strategies in accordance with Polya's (1957) problem-solving approach. During the implementation, the instructor did not provide direct guidance regarding specific solution strategies; instead, students were encouraged to explore and justify alternative solution strategies. Table 4 presents the non- routine problems used during the implementation.

[Insert Table 4 Here]

3.5. Data Analysis

The normality of the score distributions for the Non-Routine Problem-Solving Achievement Test and the Mathematics Problem-Solving Attitude Scale was examined using the Shapiro–Wilk test, while homogeneity of variances was assessed using the Levene test. For between-group comparisons, an independent samples *t*-test was applied when parametric assumptions were satisfied; otherwise, the Mann–Whitney *U* test was used. For within-group comparisons, a paired samples *t*-test was conducted when parametric assumptions were met, whereas the Wilcoxon signed-rank test was employed when parametric assumptions were violated. In addition, Cohen's *d* and rank-biserial correlation (*r*rb) were reported to estimate the effect sizes, aligning with the comparison tests.

The distributional properties of the non-routine problem-solving achievement test scores were analyzed through the Shapiro–Wilk normality test. Table 5 presents the findings regarding the normality analysis. The Shapiro–Wilk test results indicated that the pre-test scores of the experimental group were normally distributed ($p = .561 > .05$), whereas those of the control group were not ($p = .030 < .05$). For the post-test scores, the experimental group did not demonstrate a normal distribution ($p = .034 < .05$), while the control group met the assumption of normality ($p = .318 > .05$). Based on these findings, the Mann–Whitney U test was employed to compare the pre-test and post-test scores between the experimental and control groups. In addition, the Wilcoxon signed-rank test was used to examine within-group differences between pre-test and post-test scores.

Table 5
Normality Test Results for Non-Routine Problem-Solving Achievement

	N	*Mean*	*SD*	*p*	*Skewness*	*Kurtosis*
Experimental (pre-test)	16	9.563	6.044	.561	.124	−1.052
Control (pre-test)	17	9.647	7.881	.030	1.303	1.435
Experimental (post-test)	16	13.13	5.315	.034	1.351	1.818
Control (post-test)	17	8.000	4.987	.318	.473	−.691

The Shapiro-Wilk test was administered to both total scores and dimensions of Mathematics Problem-Solving Attitude Scale scores. The results of the Shapiro-Wilk test are presented in Table 6. The results indicate that the p-values for both the total scores and the dimension scores of the mathematics problem-solving attitude scale were above the .05 significance level in both the groups. Accordingly, the pre-test and post-test scores were normally distributed.

Table 6
Shapiro–Wilk Test Results for Mathematics Problem-Solving Attitudes

	N	*Mean*	*SD*	*p*
Experimental (pre-test total)	16	70.94	9.504	.568
Control (pre-test total)	17	71.59	11.097	.053
Experimental (pre-test teaching dimension)	16	34.56	4.871	.234
Control (pre-test teaching dimension)	17	33.53	6.520	.053
Experimental (pre-test enjoyment dimension)	16	36.38	5.548	.544
Control (pre-test enjoyment dimension)	17	38.06	5.629	.408
Experimental (post-test total)	16	64.69	10.307	.610
Control (post-test total)	17	66.71	11.607	.166
Experimental (post-test teaching dimension)	16	30.50	5.645	.079
Control (post-test teaching dimension)	17	30.65	6.882	.172
Experimental (post-test enjoyment dimension)	16	34.19	5.659	.618
Control (post-test enjoyment dimension)	17	36.06	6.280	.619

Furthermore, the results of the Levene's test for homogeneity of variances are presented in Table 7. According to the results of the Levene's test, the p-values for both the total scores and the dimension scores of the mathematics problem-solving attitude scale exceed the .05 significance level for both the experimental and control groups, indicating homogeneity of variances. Based on these findings, the independent samples t-test was used to compare the pre-test and post-test scores between the experimental and control groups, whereas the paired samples *t*-test was employed to examine within-group differences between pre-test and post-test scores.

Table 7
Levene's Test Results for Mathematics Problem-Solving Attitudes

	F	*df1*	*df2*	*p*
Post-test total	0.000	1	31	.976
Pre-test total	0.029	1	31	.866
Post-test enjoyment dimension	0.138	1	31	.712
Pre-test enjoyment dimension	0.000	1	31	.976
Post-test teaching dimension	1.197	1	31	.282
Pre-test teaching dimension	1.373	1	31	.250

4. Findings

This section presents the findings of the study in accordance with the research questions. The results are organized by first reporting the within-group comparisons of the pre-test and post-test scores for the experimental and control groups, followed by the between-group comparisons.

4.1. Findings related to Non-Routine Problem-Solving Achievement

Comparison of the pre-test scores on the Non-Routine Problem-Solving Achievement Test revealed that no statistically significant difference was found between the experimental and control groups (p = .062 > .05). The mean pre-test score of the experimental group (M = 9.563) was found to be very close to that of the control group (M = 9.647). These findings indicate that the experimental and control groups were equivalent in terms of non-routine problem-solving performance prior to the intervention.

Table 8 summarizes the within-group comparison of the experimental group's pre-test and post-test scores on the non-routine problem-solving achievement test. There is a statistically significant difference in favor of the post-test between the pre-test and post-test scores on the non-routine problem-solving achievement test for the experimental group (p = .007 < .05), with a large effect size (*r*rb = -.792). The mean post-test scores (M = 13.13) are higher than the mean pre-test scores (M = 9.563). Based on these results, the problem-solving activities supported by the Socratic method contributed positively to the students' achievement in non-routine problems in the experimental group.

Table 8
Wilcoxon Signed-Rank Test Results for Non-Routine Problem-Solving Achievement

	N	*M*	*SD*	*W*	*p*	*r*rb
Experimental (pre-test)	16	9.563	6.044	12.50	.007	−.792
Experimental (post-test)	16	13.13	5.315			

Although the mean post-test score (M = 8.000) was lower than the mean pre-test score (M = 9.647), this difference was not statistically significant (p = .308 > .05). Even though the effect size was in the moderate range (*r*rb = .330), this observed effect should be interpreted with caution because the difference was not statistically significant. Accordingly, the effect size should be regarded as a descriptive indicator of the magnitude of the observed difference rather than as evidence of a statistically reliable change. These findings suggest that the instructional practices implemented in the control group did not make a significant change in students' non-routine problem-solving achievements.

Table 9

Wilcoxon Signed-Rank Test Results for Non-Routine Problem-Solving Achievement in the Control Group

	N	*M*	*SD*	*W*	*p*	*r*rb
Control (pre-test)	17	9.647	7.881	60.50	.308	.330
Control (post-test)	17	8.000	4.987			

Analysis of the post-test results revealed a statistically significant difference between the experimental and control groups (p = .038 < .05). This difference was in favor of the experimental group. These findings demonstrate that problem-solving activities supported by the Socratic method had a positive influence on students' achievement in non-routine problem solving compared to the control group. Furthermore, the effect size (d = .555) suggests that the intervention had a moderate effect.

Table 10

Mann–Whitney U Test Results for Post-Test Non-Routine Problem-Solving Achievement

	N	*M*	*SD*	*U*	*p*	*Cohen's d*
Experimental (post-test)	16	13.13	5.315	.931	.038	.555
Control (post-test)	17	8.000	4.987			

4.2. Findings related to Mathematics Problem-Solving Attitude

There was no statistically significant differences between the experimental and control groups' pre-test scores on the mathematics problem-solving attitude scale in terms of either total or dimension scores (p = .858 > .05; p = .612 > .05; p = .394 > .05), with a small effect size. The mean scores of the groups were similar. These findings indicate that the experimental and control groups were at the same level in terms of their mathematics problem-solving attitudes prior to the intervention.

The results of the pre-test and post-test scores on the mathematics problem-solving attitude scale for the experimental group demonstrated a statistically significant difference in both total and the teaching dimension scores (p = .001 < 0.05; p = .005 < .05), with a large effect size (d = 1.004; d = .819). The mean scores indicate that the difference found for both total and the teaching dimension scores favors the pre-test. However, no significant difference was found between the experimental group's pre-test and post-test scores in the enjoyment dimension (p = .096 > .05), with a small effect size (d = .444). These findings suggest that problem-solving activities supported by the Socratic method were associated with a decline in mathematics problem-solving attitudes. It is noteworthy that the significant difference emerged in the teaching dimension rather than in the enjoyment dimension.

Table 11

Paired-Samples t-Test Results for Mathematics Problem-Solving Attitudes in the Experimental Group

	N	*M*	*SD*	*t*	*p*	Cohen's *d*
Experimental (pre-test total)	16	70.938	9.504	4.017	.001	1.004
Experimental (post-test total)	16	64.688	10.307			
Experimental (pre-test teaching dimension)	16	34.563	4.871	3.277	.005	.819
Experimental (post-test teaching dimension)	16	30.500	5.645			
Experimental (pre-test enjoyment dimension)	16	36.375	5.548	1.775	.096	.444
Experimental (post-test enjoyment dimension)	16	34.188	5.659			

A statistically significant difference was found between the pre-test and post-test scores of the control group on the mathematics problem-solving attitude scale for both total and the teaching dimension scores (p = .001 < .05; p = .021 < .05). The effect size was large for the total score (d = 0.933) and moderate for the teaching dimension score (d = 0.622). The mean scores indicate that these differences favored the pre-test scores. However, the difference between the pre-test and post-test scores for the enjoyment dimension was not statistically significant (p = .052 > .05). Although the effect size was in the moderate range (d = 0.508), this observed effect should be interpreted with caution because the difference was not statistically significant. Similar to the experimental group, the findings for the control group suggest a decline in students' mathematics problem-solving attitudes, particularly in the teaching dimension rather than the enjoyment dimension.

Table 12
Paired-Samples t-Test Results for Mathematics Problem-Solving Attitudes in the Control Group

	N	*M*	*SD*	*t*	*p*	Cohen's *d*
Control (pre-test total)	17	71.59	11.097	3.849	.001	.933
Control (post-test total)	17	66.71	11.607			
Control (pre-test teaching dimension)	17	33.53	6.520	2.564	.021	.622
Control (post-test teaching dimension)	17	30.65	6.882			
Control (pre-test enjoyment dimension)	17	38.06	5.629	2.095	.052	.508
Control (post-test enjoyment dimension)	17	36.06	6.280			

The post-test scores of the mathematics problem-solving attitude scale showed that no statistically significant differences were found for either the total or dimension scores (p = .602 > .05; p = .947 > .05; p = .376 > .05), with a small effect size (d = .350; d = .348; d = .353). The mean scores were close to one another, indicating that the experimental and control groups remained comparable in terms of mathematics problem-solving attitudes even after the intervention. These findings suggest that problem-solving activities supported by the Socratic method did not result in any changes in students' mathematics problem-solving attitudes.

Table 13
Independent-Samples t-Test Results for Post-Test Mathematics Problem-Solving Attitudes

	N	*M*	*SD*	*t*	*p*	Cohen's *d*
Experimental (post-test total)	16	64.688	10.307	−.527	.602	.350
Control (post-test total)	17	66.706	11.607			
Experimental (post-test teaching dimension)	16	30.500	5.645	−.067	.947	.348
Control (post-test teaching dimension)	17	30.647	6.882			
Experimental (post-test enjoyment dimension)	16	34.188	5.659	−.897	.376	.353
Control (post-test enjoyment dimension)	17	36.059	6.280			

5. Discussion and Conclusion

This study examined the effect of problem-solving activities supported by the Socratic method on 7th-grade students' academic achievement in non-routine problems and mathematics problem-solving attitudes. The findings revealed that the problem-solving activities supported by the Socratic method improved students' academic achievement in non-routine problems in the experimental group compared to the control group; however, no significant change was identified in students' mathematics problem-solving attitudes. In addition, academic achievement in non-routine problems increased in the experimental group, whereas no significant changes were observed in the control group. By contrast, mathematics problem-solving attitudes declined in both the experimental and control groups following the intervention.

The results showed that a significant difference emerged in favor of the experimental group following the intervention. These findings indicate that problem-solving activities supported by the Socratic method are effective in enhancing students' academic achievement in solving non-routine problems. These findings are consistent with previous studies. For instance, Bailey et al. (2012) concluded that the Socratic method encourages students to engage in problem-solving processes, while Taylor (2023) reported a positive relationship between the use of the Socratic method, inquiry-based questions, and students' participation levels as well as their performance on end-of-unit assessments. Similarly, Gavaz et al. (2021) found that non-routine problem-solving instruction has a positive effect on students' problem-solving success. It is also consistent with studies showing that problem-solving-oriented instructional designs can support students' problem-solving performance, although their effects on affective outcomes such as attitudes may be less direct or less stable (Koç & Elçi, 2022; Polat & Özkaya, 2023). Yıldız and Dadı (2019), furthermore, showed that the use of the Socratic method in chemistry class enhances achievement by guiding students to think and establish connections. Ibrahim and Badli (2025) concluded that a problem-based learning module supported by the Socratic method significantly enhances students' problem-solving skills and improves their ability to justify solutions. The Socratic method is regarded as an effective approach that facilitates student participation in discussions and strengthens students’ critical thinking skills (Copelin, 2015; Edwards, 2019; Fahim & Bagheri, 2012). The improvement in academic achievement can be attributed to the dialogic interactions during the problem-solving process. Asking students questions regarding Polya’s (1957) framework appears to have supported students in justifying their thoughts, maintaining focus on the solution process, and developing awareness regarding problem-solving steps. Such interactions likely facilitated students’ engagement with each stage of problem-solving. In this regard, the study suggests that the Socratic method is an effective pedagogical tool for fostering students’ academic achievement in non-routine problem-solving tasks.

Following the intervention, no difference emerged between the experimental and control groups’ mathematics problem-solving attitudes. These results suggest that the Socratic method has no positive influence on students’ mathematics problem-solving attitudes. This finding differs from the results of previous studies that reported the beneficial effect of the Socratic method on attitudes. Yakar (2017), for instance, concluded that the Socratic method conducted in science classes fostered positive attitudes, while Hüner (2021) noted that Socratic questioning positively influenced students’ attitudes toward life skills courses. The absence of positive influence on attitudes may be related to the nature of non-routine problems. Such problems involve exploration and analysis processes (Nancarrow, 2004) and require a substantial cognitive effort compared to routine problems, which are typically solved through procedural knowledge and have a single solution path (Mogari & Chirove, 2017). On the other hand, a comparable decline in mathematics problem-solving attitudes, along with the teaching dimension, was also observed in the control group after the implementation, similar to the experimental group. This result suggests that this situation may be related not only to the implementation of the Socratic method but also to the difficulty of the subject matter. Algebra plays a crucial role in school mathematics and is widely recognized as one of the most challenging areas for students. Research on algebra learning shows that students’ difficulties stem from multiple sources, including the abstract and symbolic nature of algebra, weak connections between arithmetic and algebraic ideas, incomplete prior knowledge, reliance on memorized procedures, and instructional practices that do not sufficiently support meaningful conceptual transition (Bozkuş et al., 2025; Elbir & Özmen, 2024; Jupri et al., 2026; Kama et al., 2023; Yıldız & Yetkin Özdemir, 2021). Similarly, Kaya et al. (2016) revealed that students’ inferencing skills regarding algebraic expressions and solving non-routine problems were at a low to moderate level. Furthermore, Şimşek and Soylu (2018) found that 7th-grade students’ knowledge regarding algebraic expressions was insufficient. These findings suggest that students’ difficulties with algebraic content may have made non-routine problem-solving tasks more cognitively demanding and may therefore be one factor underlying the decline in mathematics problem-solving attitude scores. This interpretation is also supported by recent studies showing that algebraic thinking requires students to interpret literal symbols, construct equations from verbal situations, move between representations, and connect arithmetic knowledge with algebraic meanings (Ataş Koçluk & Tanışlı, 2026; Elbir & Özmen, 2024; Yıldız & Yetkin Özdemir, 2021). In addition, unfamiliarity with the Socratic method for students may have challenged them cognitively, which in turn could have contributed to the decline in mathematics problem-solving attitude scores in the experimental group. The decline in the experimental group’s mathematics problem-solving attitude scores, particularly regarding the teaching dimension, also supports this interpretation. Similarly, Brown (2012) argued that the Socratic method may negatively affect class participation by undermining students’ confidence, particularly when they experience difficulty responding extemporaneously to questioning. In line with this, Delić and Bećirović (2016) emphasized that the Socratic method should be implemented carefully to avoid eliciting negative emotions such as humiliation, shame, or perplexity during classroom dialogue. Rather than exposing students' deficiencies, the primary purpose of the Socratic method is to help learners recognize misconceptions and reconstruct incomplete or inaccurate knowledge through guided questioning (Boghossian, 2012). Finally, the short duration of the intervention may have been insufficient to improve students' mathematics problem-solving attitudes, as attitudes generally require a longer period of time to change (Hannula, 2002; Lim & Chapman, 2015). Taken together, the attitude findings may reflect an interaction between the cognitive demands of non-routine algebraic problem solving, students' adaptation to an unfamiliar instructional approach, and the duration of the intervention, rather than an effect attributable to the Socratic method alone. The results indicate that neither the Socratic method nor traditional instruction based on paper-and-pencil problem-solving activities has a positive influence on students' mathematics problem-solving attitudes.

8. Implications and Limitations

The Socratic method appears to support students in problem-solving processes and thereby enhance their academic achievement in non-routine problems. However, it failed to produce a positive effect on students' mathematics problem-solving attitudes, which may be associated with increased cognitive load and the nature of the subject matter. This result highlights the importance of maintaining a balance between cognitive and affective outcomes in problem-solving activities. In particular, there is a potential risk that students may develop negative attitudes when they experience difficulty in problem-solving contexts that require higher-order thinking skills. Therefore, future studies should focus on how affective dimensions can be more effectively supported during the implementation of the Socratic method, which may contribute meaningfully to the literature on mathematics education and instructional design. For classroom practice, teachers may consider introducing Socratic questioning gradually by beginning with less cognitively demanding tasks before progressing to more complex non-routine problems. Finally, due to the limited sample size, the generalizability of the results beyond the context of the study should be interpreted with caution. In addition, the use of convenience sampling and the implementation of the study in a single school may further limit the external validity of the findings. Another limitation is the relatively short duration of the intervention, which may not have been sufficient to observe longer-term changes, particularly in students' mathematics problem-solving attitudes. Furthermore, some comparisons yielded moderate effect sizes despite non-significant statistical results. This pattern is not uncommon in studies with relatively small samples, where limited statistical power may have reduced the likelihood of detecting statistically significant differences. Accordingly, these effect sizes should be interpreted as descriptive indicators of the magnitude of the observed differences rather than as evidence of statistically reliable effects. Replication with larger samples is needed to determine whether these observed effects reflect true population differences.

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Data availability: The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Appendix A. Sample Maieutic Questions Aligned with Polya's (1957) Problem-Solving Framework

1. Understanding the problem
Do you think this problem makes sense or not?
Is the information provided in the problem sufficient for you to solve it? Why?
What is the problem asking you to find? What information has been given?
Can you restate the problem in your own words?
Is there any part of this problem that you find difficult to express or don't understand?
Which part or piece of information in the problem is important or unimportant?
Can you explain this problem to someone who knows nothing about it with simple phrases?
Do you think the problem is simple or complex
What makes this question difficult?

2. Planning
Do you know of a problem that is the same as or similar to this one? If so, how did you solve it? Which methods or strategies did you use?
Can you elaborate on your thoughts a bit more?
Do you think your ideas are consistent with one another?
Is there any method that comes to mind for solving this problem?
Do you think the method you've thought of will be sufficient for the solution?
Have you identified alternative methods for solving the problem?
Why do you think the method you chose is suitable for solving this problem?

3. Implementing
Where should you start to solve the problem?
Can you clearly see that the steps in the solution are correct?
Is the formula you'll use always valid, or are there situations that require a different approach or formula?
Do you think you have the necessary information and computational skills to carry out the solution?
What approach will you take when implementing the solution?
Are you confident you've reached the correct result?

4. Evaluating
Do you think the result you found is reasonable?
Can you verify the result you found?
Does the result match your initial thoughts?
Could you solve a different version of this problem?
Is there a better or more interesting version of this problem?
Is there a simpler way to solve this problem?
Could this method help solve other problems? Why?
How did you verify the accuracy of your thoughts? How can the ideas you presented be verified?
Do you think the methods you used helped you understand and solve the problem? Why or why not?