Heliyon 10 (2024) e35610

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

The impact of various teaching methods on the knowledge of students of different genders: The case of mathematics word problems abstract

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ARTICLE INFO

Keywords:
Gender
Word problems
Functional-graphical solution
Algebraic solution

ABSTRACT

Despite significant progress in recent years, there is still evidence of gender differences and underrepresentation of women in leadership positions in mathematics. To promote equal opportunities for all students, it is essential to comprehend gender differences in math learning at school and identify potential barriers to educational equality. In this regard, our study examined the gender differences in solving word problems, and whether they relate to the solution strategy the students were taught.

The study involved 100 10th-grade students divided into two groups and taught different solving approaches. One group was taught an algebraic approach using linear equations, while the other group was taught a combined approach, which incorporates the algebraic solution with a functional-graphic solution using a graph of a linear function.

The research findings reveal gender differences in various aspects: Girls who learned the algebraic approach had better attainments than boys; Boys who learned the combined approach opted to solve problems with functions and graphs, whereas girls in the same group preferred an algebraic solution; Boys who learned the combined approach achieved significantly higher than boys who learned the algebraic approach.

This study illuminates the importance of teaching word problems using diverse solution strategies because different populations of students respond differently to different strategies.

1. Introduction

Although many studies have been done on the subject, and many programs are implemented in different places to increase equality, there are still gender gaps in mathematics. International tests such as PISA [1] and TIMSS [2] have consistently shown gender differences regarding mathematics. These differences can impact an individual's confidence, ability, and aspirations in pursuing careers in STEM fields [3]. Therefore, it is crucial to understand these differences early and help and encourage both genders to pursue math-related careers.

This study explores the impact of various teaching methods on the ability to solve word problems in mathematics, a crucial topic in math curricula across all levels. Previous research has shown differences in how boys and girls solve word problems, particularly

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https://doi.org/10.1016/j.heliyon.2024.e35610
Received 13 February 2024; Received in revised form 15 July 2024; Accepted 31 July 2024
Available online 10 August 2024

among high-ability students [4] and in terms of students' problem-solving approaches [5]. However, there is limited research on whether these differences are linked to classroom teaching methods or the specific solution strategies taught (e.g., Ref. [6]). These studies did not compare specific solution strategies recommended for solving word problems and their potential differential effects on genders. Our study focused on comparing the effectiveness of teaching methods for solving a particular type of word problem. We examined the accuracy of solutions, solving strategies, and common errors made by boys and girls. Conducting such a study is important because it has practical implications for teachers' work in the classroom and for directing and adapting teaching methods at school to enhance the performance of students of different genders.

2. Literature review

2.1. Gender differences in mathematics learning

Gender differences in mathematics have been discussed among researchers and educators for several decades, but women are still underrepresented in science, mathematics, and engineering leadership positions ([3,7]). Gender differences are manifested much earlier in school, and international tests such as the TIMSS and PISA have also pointed out gender differences in mathematics performance ([2,8]). TIMSS tests have indicated that girls tend to have a lower self-concept than boys in mathematics studies, and some countries show achievement differences between genders [2]. In PISA tests, boys generally perform better than girls [1,8].

In Israel, where our study was conducted, gender differences across different age groups in national and international tests have been observed [9]. The differences are noticeable in national tests for elementary school, where boys tend to perform better than girls. Similarly, differences in the number of students who study and excel in high-level math courses have been found in school matriculation exams and the psychometric tests used as university entrance tests. The differences in the psychometric tests also indicate preferences, attitudes, perceptions regarding mathematics, and self-concept.

Many studies (e.g., Ref. [10]) have investigated gender differences in school mathematics learning. They have mainly focused on motivation and emotional aspects such as anxiety, self-efficacy, and self-concept. The studies have found that boys generally exhibit more positive attitudes toward math, whereas girls tend to experience more math anxiety than boys. For instance, it was found that boys consistently reported more positive attitudes about mathematics than girls, while girls reported more significant mathematics anxiety than boys [11,12]. According to various studies, there are significant gender differences in mathematics preferences and attitudes. One study found that boys tend to report higher levels of liking for mathematics than girls [10]. Another study revealed that girls generally have less positive attitudes towards mathematics than their male peers, experiencing lower motivation, poor perception of competence, and higher levels of anxiety [13]. Additionally, some researchers have discovered differences in learning strategies, with girls exhibiting more powerful organizational skills and better learning strategies, especially for repetitive tasks [14].

Regarding students' attainments, no consistent empirical evidence suggests that boys or girls perform better in school mathematics. Some researchers found a weak link between gender and math ability and that there are no statistically significant differences between the performance of boys and girls [15,16]. Studies examining gender differences have found that such differences are mainly observed in geometry [17] and visual-spatial tasks [18]: teachers have reported that boys tend to perform better in these tasks at younger ages. A recent study claims that gender differences exist and even deepen over the years and demonstrated that high school girls performed less than boys [19]. On the other hand, other studies claim that girls tend to excel in tasks that require verbal skills [18]. Another study reinforced these observations and showed that gifted girls outperformed gifted boys in mathematical problem-solving [4].

In this study, we focused on a central topic in mathematics learning at school, word problem solving, and examined it in high school. As far as we know, examining whether teaching high school students the topic of word problems in different ways affects different genders differently.

2.2. Word problems: solving strategies and gender differences

A word problem is a text that describes a real-life situation and poses a question related to that situation. To solve the problem, students must translate the verbal description into mathematical language and apply the tools and skills they have learned in various subjects. Solving word problems has been a central topic in mathematics in recent decades [20–22]. Students' mathematical proficiency can be determined by their ability to solve various problems using different strategies, including those from other scientific fields. Word problem solving has been identified by the National Council of Teachers of Mathematics [21] as one of the five essential mathematical learning process standards. Due to its significance, word problem solving is included in the mathematics curriculum worldwide at all levels of education. Researchers [23] state that solving word problems is an important aspect of mathematical education. This is because solving problems helps to establish mathematical connections. These connections include those between different representations of a particular mathematical concept, different concepts themselves, different meanings of the same concept, different branches of mathematics, and connections between mathematics and other subjects.

In school, students are taught various types of problems, such as buying/selling problems, problems involving percentage computations, problems involving computing the surface or the perimeter of geometric shapes, and more. This study focuses on word problems involving object movement, or "motion problems." We chose these problems because they are commonly taught in schools worldwide, relate to other scientific fields, like Newton's laws of motion in physics, and offer different solution approaches.

Many strategies can be employed to solve a problem that requires an explicit algorithm or a simple solution method. Some of the typical strategies include utilizing algebraic techniques, describing data in a table format, creating a visual or graphical representation of the problem, working backward, or breaking down the problem into smaller, more manageable parts [22]. For our research, we opted for two strategies to solve the problem. The first is the algebraic solution, in which we organize the information in a data table (speed, time, and distance), build the suitable equations, and solve them using an algebraic technique. The second one combines the algebraic solution with a functional-graphic solution, in which we use a suitable function and its graph to solve the problem. We chose the algebraic solution because it is widely used and taught in most standard textbooks. We chose the solution using a function and a graphical representation of the problem because it is highly recommended by researchers who claim that it helps students understand the movement's progress and may enable them to comprehend the connections between variables [24,25]. A graphical approach can help prevent an algorithmic solution without understanding [22]. A visual representation such as a graph is highly recommended because it may help students better understand concepts, develop mathematical thinking, and improve their skills [26,27]. Additionally, visual solutions can play a complementary and significant role in supporting the results by providing illustrations and allowing for intuitive thinking [28]. Some researchers argue that pictorial representations can be more harmful than helpful if the solver neglects the spatial relationships between the various components of the problem. They suggest using schematic diagrams to highlight spatial relationships and focus on related information within the problem [29]. The functional approach reinforces relationships between different variables and enables describing the problem data in numerical, graphic, and symbolic terms. We chose a combined approach because researchers recommend using it for flexible teaching of mathematics word problems to improve learning, understanding, and student attainments [30].

Various studies have revealed gender differences in word problem solving, either in the accuracy of the solution or the solution strategy employed. Gifted girls performed better than gifted boys in mathematical problem solving [4], and different genders tend to solve problems using diverse solution strategies [31,32]. A literature review conducted by Zhu indicates that many studies have reported gender differences in strategy use among elementary school students [33]. For instance, girls tended to use more concrete strategies, whereas boys tended to use more abstract strategies. Carr and Davis [31] also reinforced these results and indicated that girls and boys had different preferences for the strategy used to achieve the solution. Gallagher and colleagues [32] found that among secondary school students, girls preferred algorithmic strategies, while boys preferred logical estimation and insight.

A little work was done regarding the influence of the teaching strategy. A recent study examined whether the teaching method leads to gender differences. They examined a specific solving strategy and found that non-traditional methods are detrimental to girls, who are more likely to solve mathematics problems procedurally and perform better on problems that can be solved procedurally [6]. No studies (as far as we know) have investigated the impact of teaching methods comparing two particular solution strategies on gender differences in solving word problems. We examined the students' solutions regarding their accuracy, the solution strategy, and common errors they made.

2.3. Students' difficulties and errors in solving word problems

Despite the various strategies to solve them, their importance, and their place in the curriculum, word problems raise many difficulties among students. Some difficulties are related to transformation: difficulty transforming the verbal language to the appropriate mathematical representation or translating a realistic problem into symbols in the mathematical world, and vice versa [34,35]. Another study reinforces the results of linguistic difficulties and indicates that word problem solving performance is related to text comprehension but also adds errors because of a lack of arithmetic skills [36].

Researchers also note difficulties in algebraic skills and difficulty understanding the concept of variables [23,37], which means that word problem solving that depends on algebraic solutions can be difficult for students with algebraic difficulties.

Other researchers indicate that the student's knowledge gaps are a source of errors and difficulties in problem-solving. For example, Craig [38] argued that students' previous mathematical skills and knowledge are essential to their problem-solving success, so gaps in this knowledge may lead to wrong solutions. Educational or cognitive factors may cause difficulties, but emotional factors may also be involved. A study indicates that students' negative attitudes toward mathematics and lack of self-confidence led to increased difficulties in solving problems [39]. No connection was found between gender and students' difficulties [1].

Students' errors can be sorted according to different categories regarding various aspects of the errors and their place. Ashkenazi [40] classifies the common errors in mathematics into two categories. In the first category, errors are caused as a result of misconceptions. These errors contain a particular fault of logic that results from a lack of understanding of mathematical definitions or principles. In the second category, errors are caused by confusion, recklessness, speed, inattention, or laziness. Tong and Loc [41] also distinguish between serious/critical versus trivial errors in their study. They found that children can make either critical errors of misunderstanding critical aspects of concepts in their solution process or trivial errors that lead to wrong solutions. This study follows this approach and distinguishes students' errors in problem-solving into two categories.

As far as we know, no studies mapped whether there are gender differences regarding errors while solving motion problems, especially not at high school and not regarding the teaching method and the solution strategy.

3. The research aims and questions

In this study, we chose to focus on the student population that was less explored: high school students. We chose to examine their solutions for "motion problems" (MP) and their success, their solution strategy, and the errors they make. We also wanted to examine whether the solution strategy taught influences students' responses. So, the topic of MP was studied in two groups; in each group, a different solution strategy was taught, and the relationship between the teaching approach and the knowledge of students of different genders was examined.

Therefore, the research questions are:

1. Are there gender differences in solving MP regarding (a) The solution accuracy, (b) The solution strategy, and (c) The errors made?
2. Do the differences between the two teaching approaches (algebraic approach and combined algebraic-functional-graphic approach) differ?

4. Methodology

4.1. Participants

100 10th-grade students who attend one high school. About half of them are boys, and about half are girls. They were divided into two groups: Fifty students (19 boys and 31 girls) learned to solve MP using an algebraic approach. Fifty students (27 boys and 23 girls) learned to solve MP using a combined approach of functions.

In Israel, all high school students are divided into three groups according to their middle school achievements. The groups differ in contents and difficulty exercise levels, so not all students learn MP. This study examined the high-level group: half of the 10th-grade students who learned this topic.

4.2. Instruments

Pre-test: A 1-h test before the intervention, constituting items that examine previously learned content and may be required to solve problems. The test aims to verify prior knowledge and ensure no significant differences between the two groups. The test consisted of 2 sections: in the first section, algebraic techniques were tested, and the students were asked to solve equations, inequalities, and systems of linear equations; in the second section, the students were asked to draw linear functions and to answer questions regarding two linear functions graphs, like intersection points between the functions and between each function and X or Y axis. They were not asked to solve MP.

An intervention program: Eight lessons of 45 min each for teaching the subject were built for each teaching approach. In the algebraic approach, the teacher taught solving MP using a table (speed, time, and distance) and an appropriate equation. In the combined approach, the teacher taught an algebraic solution and used a linear function $y = mx + n$ and the function's graph ($m =$ slope $=$ speed, $x =$ time, $y =$ distance, and n depends on the distance starting point or the time starting point).

Post-test: A 1-h test after the intervention, constituting four MP (suggestions for solutions in both approaches for two of the four questions, see in appendix A):

Q1: Two objects moving in one direction: " One biker started riding from town A to town B at a constant speed of 10 km/h. His biker friend left 4 h later from town A to town B on the same road, at a constant speed of 20 km/h. How long after the departure of the first biker did they meet? How far from town A did they meet?"

Q2: One object moving back and forth:" A tractor traveled 100 km to the village and returned on the same road. On the way there, it traveled at a certain constant speed. On its way back, it traveled for 2 h at the same speed, rested for 20 min, and continued its journey faster, adding 5 km/h to its speed. The travel time back was equal to the travel time forth. What is the speed at which he traveled to the village?"

Q3: Two objects moving towards each other and meeting once: "The distance between A and B is 200 km. At 8:00, vehicle 1 started moving from A to B. At 8:25, vehicle 2 started moving from B to A. They met in the middle of the way and kept moving. Forty-eight minutes after they met, they were 112 km distant. What is the speed of each vehicle?"

Q4: Two objects moving towards each other, returning and meeting twice on the way: "A motorcycle and a car started moving simultaneously from two towns, A and B, 90 km apart. They met after an hour and continued on their way. The car reached town A, returned immediately, and passed the motorcycle half an hour after their first meeting. What is the speed of each vehicle?"

4.3. Validity and reliability

In the knowledge tests (pre-test and post-test) and the intervention lessons, items are used from standard and accepted sources of information in teaching mathematics in Israel, such as standard textbooks. The tests and lessons were checked and approved by four experienced teachers and three researchers from the field of mathematical education. A reliability test of internal consistency (Cronbach's alpha) was conducted for both the knowledge tests, and a high-reliability coefficient was obtained for each ($\propto > 0.7$).

4.4. Research process

First step: pre-test.

Second step: Intervention teaching the subject. One study group studied using the algebraic approach only (they were divided into two groups; in each group, boys and girls studied together), and a second study group studied using the combined approach of functional and algebraic solutions (they were divided into two groups, in each group, boys and girls studied together). In both approaches, the researchers designed the lessons and contents. The lessons for the different approaches were parallels: in each lesson, the problems solved in class in each lesson were identical but differed in the solution taught by the teacher. The researchers were present in several lessons in each group to ensure that the teachers followed the lesson program as required.

Third step: post-test.

4.5. Ethics-statement

The study was conducted to fulfill the requirements for a master's degree in the Faculty of Education at Bar-Ilan University, Israel. The study's methodology underwent review by senior faculty members and was approved. The research adhered to all ethical rules and was carried out under the supervision of the Ethics Committee of the Faculty of Education at the university. The participants' parents provided consent for their children's participation in the study, and their privacy and anonymity were preserved. The information collected was used solely for research purposes, and personal details were not disclosed. Participants were assured that any detail that might identify them or their school would be kept confidential. They were also informed that the study results had no potential to harm them in any way. Before answering the questionnaire, verbal consent was obtained from the participants.

4.6. Data analysis

1. A two-way ANOVA was conducted to compare the pre-test score according to gender and according to the pre-intervention teaching approach. The pre-test score was the dependent variable, and gender and the teaching approach were the independent variables.
2. One-way MANCOVA/ANCOVA was conducted for the knowledge test questions after the intervention to check whether gender has a significant effect, whether the teaching approach has a significant effect, and whether there is a significant interaction between gender and the teaching approach.
3. The Chi-square test was conducted to test the dependence between a group and certain variables, such as the dependence between the solution correctness and gender or the dependence between the solution method for the question and gender.

5. Results

In the pre-test, the students were tested on the topics required as prior knowledge for solving MP: algebraic techniques and knowledge about linear functions. In the post-test, the students answered four MP. Results (Table 1) show no effect for gender in the pre-test, while several differences were found after the intervention.

Regarding the pre-test, a two-way ANOVA analysis of variance concerning the pre-test score shows that no significant effect was found for gender. It means that before the intervention, no significant differences were found between the genders:

$$F(1,96)_{gender} = 0.16, \eta_p^2 = 0.02$$

Regarding the post-test, among students who learned the algebraic approach, girls had better attainments than boys. One-way MANCOVA results show a statistically significant interaction effect for gender:

$$F_{multivariate}(4,92) = 2.87, p = .027, \eta_p^2 = .111$$

Comparing the pre-test and post-test attainments, the entire sample showed no significant interaction between gender and the teaching approach. However, an examination among the boys and girls separately did indicate gender differences concerning the interaction with the teaching approach: while among the girls, no significant effect was found for the teaching approach, among the boys, a significant effect was found - the test score after intervention in the combined approach group is significantly higher than the test score after intervention in the algebraic approach group: $F(1,43) = 5.341, p = .026, \eta_p^2 = .110$.

Gender differences were also examined concerning the correctness of the solution to the post-test questions without associating it with the teaching approach. The first three questions of the questionnaire showed no significant differences. A significant difference was found in question 4, which was the most complicated problem in the questionnaire. Table 2 shows the distribution of the participants in the different genders according to the correctness of the solution. The chi-square test value indicates that in question 4, dependence was found between the solution correctness variable and gender.

Table 3 indicates that in question 4, girls solved significantly better than boys.

An examination within the different teaching approach groups with a one-way ANCOVA analysis of variance (see Table 3) showed significant differences in two questions-three and four. Also, it revealed that gender differences did not appear in both groups but only in the algebraic approach group.

Table 4 demonstrates that girls solved better in two questions, and the gender differences were significant in the algebraic approach group. It also shows differences between boys' scores in the various groups.

Chi-square tests were conducted to check whether there was a difference in the choice of the solution strategy between boys and

Table 1
Means and standard deviations of the pre-test and post-test scores.

		Boys (N = 46)		Girls (N = 54)	
		Algebraic approach (N = 19)	Combined approach (N = 27)	Algebraic approach (N = 31)	Combined approach (N = 23)
Pre-test	M	65.05	76.41	66.52	77.43
	SD	16.715	16.265	16.633	14.475
Post-test	M	54.14	75.91	66.68	77.83
	SD	27.68	21.20	32.23	27.48

Table 2
Number and percentage of participants of different genders who solved each post-test question correctly (or with error).

Question no.	Girls (N = 54)		Boys (N = 46)		χ^2
	Solved correctly	Solved with error	Solved correctly	Solved with error	
Q1	43 (79.6 %)	11 (20.4 %)	41 (89.1 %)	5 (10.9 %)	1.04
Q2	40 (74.1 %)	14 (25.9 %)	34 (73.9 %)	12 (26.1 %)	0.001
Q3	31 (57.4 %)	23 (42.6 %)	30 (65.2 %)	16 (34.8 %)	0.35
Q4	31 (57.4 %)	23 (42.6 %)	15 (32.6 %)	31 (67.4 %)	5.19*

*P < .05.

Table 3
Means and standard deviations of questions 3–4 results of participants of different genders in the two teaching approaches.

		Algebraic approach (N = 50)				Combined approach (N = 50)			
		Boys (N = 19)	Girls (N = 31)	$F(1,47)_{gender}$	η_p^2	Boys (N = 27)	Girls (N = 23)	$F(1,47)_{gender}$	η_p^2
Q3	M	31.84	61.58	2.85*	0.135	59.96	66.35	0.28	0.006
	SD	43.50	43.94			40.23	41.40		
Q4	M	20.01	54.84	7.35**	0.185	54.78	69.13	1.15	0.024
	SD	37.56	48.09			47.47	43.76		

**P < .01, *P < .05.

girls who studied using the integrated approach. Table 4 shows the findings of the chosen way to solve each question.

The chi-square test values presented in Table 5 show that boys tend to choose the functional approach: in three of the four questions, a clear dependence was found between the choice of solution method for the question and gender. Boys chose a functional solution method in all three questions, while girls preferred the algebraic solution method.

There could be multiple solutions for a question, either an algebraic or functional-graphic solution. However, the differences between the two algebraic solutions or the two combined solutions were not significant.

In the post-test, several mathematical solutions were observed (either correct or incorrect). The solutions were classified into five categories (see Table 5) according to the solution's correctness and the error type in the incorrect solutions (see examples for students' solutions in Appendix 2).

Questions 3 and 4 were the questions in the post-test in which many errors were found. In Fig. 1, you can see the distribution of the occurrences of each solution category made by each gender in each group, as observed in the fourth question of the post-test (in question 3, the distribution is similar).

The diagram in Fig. 1 shows that generally (and it reinforces data in Table 3), more girls solved the question correctly than boys: the blue bars representing the girls' correct solution are higher than the boys' blur bars. Fig. 1 also shows that regarding the girls, there is no noticeable difference between the two teaching groups: the bars that represent the girls' correct solution are almost the same. Also, girls in the combined approach group did not make comprehension errors (the yellow bar does not exist in this group) but did make such errors in the algebraic approach group. Among the boys, it seems that differences are more significant: more boys in the combined approach group than in the algebraic approach group solved question 4 correctly, more technical errors appeared in the combined group, and more misunderstandings of the problem appeared in the algebraic approach group.

In order to test the significance of these differences and whether there is a difference between the algebraic approach and the combined approach among the boys (separately) and among the girls (separately), a chi-square test was conducted in each gender group separately. No differences were found Among the girls, but there were significant differences among the boys in two questions, three and four. Table 6 shows the distribution of the various solution categories among the boys in the different teaching approach groups.

The chi-square test result indicates that among the boys, the participants who solved correctly and studied in the combined approach group were significantly higher than those who used the algebraic approach. In addition, among the boys who studied in the algebraic approach group, the rate of occurrence of misunderstanding the problem (making a comprehension error) was significantly higher than in the combined approach.

Table 4
Number and percentage of participants of each gender (from the combined group) who chose each solution method.

	Boys (N = 27)		Girls (N = 23)		χ^2
	Algebraic	Functional	Algebraic	Functional	
Question 1	8 (29.6 %)	19 (70.4 %)	11 (47.8 %)	12 (52.2 %)	1.06
Question 2	9 (33.3 %)	17 (63 %)	15 (65.2 %)	7 (30.4 %)	4.11*
Question 3	9 (33.3 %)	15 (55.6 %)	13 (56.5 %)	6 (26.1 %)	2.91*
Question 4	7 (25.9 %)	12 (44.4 %)	14 (60.9 %)	6 (26.1 %)	3.08*

*p < .05 (one-tailed).

Table 5
Solution categories.

Solution category	Description (regarding the algebraic solution)	Description (regarding the functional solution)
(a) Correct	The student defined the variables correctly according to the data in the question, completed a table with the correct data and variables, constructed the appropriate equations, solved it correctly, and made the correct conclusions.	The student defined the variables correctly according to the data in the question, constructed the appropriate functions, drew a graph, built the correct equations, solved the problem correctly, and reached the correct conclusions.
(b) Minor error	The student started the solution correctly with the correct variables, data table, and equation but made an algebraic or calculation error.	The student started the solution correctly with a correct graph and equations but made an algebraic or calculation error.
(c) Partially correct	The student started the solution correctly with the correct variables and data table but built the wrong equations and got the wrong answer.	The student started the solution correctly with a correct graph but built the wrong equations and got the wrong answer.
(d) critical error: Comprehension error	The student did not define the variables correctly or complete a table with the wrong data.	The student did not define the variables correctly or construct the wrong functions.
(e) Did not solve	The student did not solve the question at all and left it blank.	The student did not solve the question at all and left it blank.

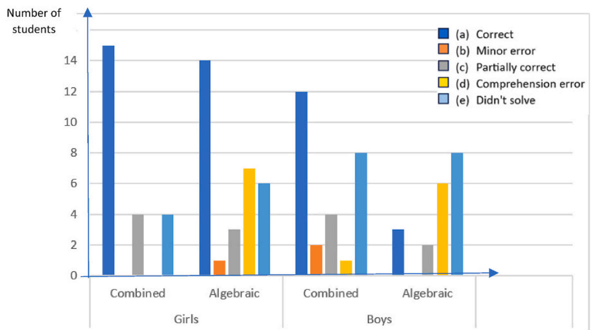

Fig. 1. Solution categories distribution in each group.

Table 6
Number and percentage of boys who made each solution category in each of the different groups.

	Solution category	Algebraic approach (N = 19)	Combined approach (N = 27)	$\chi^2(46, 4)$
Question 3	(a) Correct	5 (26.3 %)	11 (40.7 %)	8.49*
	(b) Minor error	1 (5.3 %)	4 (14.8 %)	
	(c) Partially correct	1 (5.3 %)	6 (22.2 %)	
	(d) Comprehension error	6 (31.6 %)	3 (11.1 %)	
	(e) Did not solve	6 (31.6 %)	3 (11.1 %)	
Question 4	(a) Correct	3 (15.8 %)	12 (44.4 %)	10.57*
	(b) Minor error	0 (0.0 %)	2 (7.4 %)	
	(c) Partially correct	2 (10.5 %)	4 (14.8 %)	
	(d) Comprehension error	6 (31.6 %)	1 (3.7 %)	
	(e) Did not solve	8 (42.1 %)	8 (27.6 %)	

*$p < .05$.

6. Discussion

The current study examined gender differences in solving MP and whether the differences are related to the solution approach taught in class. Several notable findings were found.

Regarding the first research question, whether there are gender differences in solving MP, the results show two main findings regarding the accuracy of students' answers and the solution strategy. The first is that girls solved significantly better than boys. Previous studies on elementary and secondary school students in lower grades found that girls have an advantage over boys in solving word problems [4,18], especially among gifted children. The present study reinforces these findings and adds new results that have not been investigated before regarding the specific type of problem (MP) and students' level of education (high school students). This finding can be explained by the fact that there may indeed be gender differences at young ages in solving word problems (as reported in previous studies). If they exist, such differences affect the continuation of the student's studies and amplify the differences at more advanced ages.

The second significant finding is the connection between the solution method (algebraic or functional-graphic) and gender: Boys were more likely to choose a functional-graphic solution method, while girls preferred the algebraic solution method. This finding reinforces the findings of previous studies that found gender differences in choosing a solution method [32] and that girls are more inclined to algorithmic strategies. The study's findings also align with previous studies that indicated that girls tend to use strategies that allow the analysis of information using verbal representations. At the same time, boys are more inclined to report strategies that involve constructing visual images and using non-verbal representations [42]. However, the influence of the teaching approach has not been studied before, and the current study's finding constitutes an innovation in this aspect.

The answer to the first research question is that girls have better attainments in solving word problems and tend to solve them algebraically. The reason for that is that girls' strengths are word representations of information and algebraic strategies. Therefore, solving word problems is a topic that fits their strengths, so they do better than boys in solving them.

Regarding the second research question, whether the teaching approach to solving MP affects the knowledge of learners of different genders, there are three main findings. The first finding is that among students who learned in the algebraic approach group, girls achieved significantly higher than boys. This finding can be explained through the two main differences described above. First, the gender difference was generally found concerning solving MP (boys tend to solve correctly less than girls), and second, boys are more inclined to solve graphically (prefer graphic solutions). Hence, the algebraic approach will amplify the existing differences between the genders.

The second finding, among boys only, is that the post-test score in the combined approach group is significantly higher than in the algebraic approach group. Also, only the boys in the combined group achieved significantly higher scores in the post-test than in the pre-test. This finding emphasizes that the intervention program combining function and algebraic solution improves the boys' performance and is more effective for boys. This finding can be explained by the fact that boys, as mentioned above, preferred the functional-graphic solution. Hence, a combined teaching approach is more suitable and understandable for boys than the algebraic approach.

The third finding concerns the type of error students make, and unlike previous studies [1], a connection between gender and error type was observed. It was found that significantly more boys who learned in the algebraic approach group misunderstood the problem and made an error that indicated a lack of conceptual understanding. This finding reinforces other researchers' suggestions [25], suggesting that the functional graphic solution may enhance conceptual understanding and help students understand the problem better.

7. Limitations

The first limitation is the participants: there is a small number of participants (100), and all of them learn in high-level math groups. This has two consequences: One is that it is difficult to generalize the findings because each group has 25 students of each gender, which is not enough to draw unequivocal conclusions. The second is that in building a future intervention program, changes and adjustments must be made so that the program is suitable for a more diverse population and not only for high-level students.

The second limitation is the intervention itself: There is only one kind of word problem (MP) and only four items in the questionnaire. Although many types of word problems can be solved graphically, and it is possible to adopt the teaching method we proposed, this study examined only one type. It is possible that different findings will be found by examining other types of problems.

8. Conclusions

Our study shows that different solution strategies taught in class may affect the different genders differently regarding the correctness of the solution, the solution strategy, or the errors the students make. Although the research is limited, it may lead us to the conclusion that different genders might need different solution strategies, so the combined approach is the better choice for teaching the subject. Since the teaching approach has not changed much for girls, and it was found that the combined approach is preferable for boys, we recommend that teachers incorporate functions into the teaching of solving word problems. The findings of this study may raise awareness of the functional approach among teachers and serve as a recommendation for teachers to incorporate functions into the teaching of the subject. These reinforce the recommendations of other researchers who recommend adapting teaching and solution methods for students of different genders due to gender differences [30,43].

9. Implications

According to some studies, gender differences in math performance are small and vary depending on the type and content of the assessment, the age and background of the participants, and the context and culture of the learning environment. However, there are still persistent gender differences in math attitudes, beliefs, and expectations, which can affect how students approach and engage with math problems. Therefore, investigating gender differences in math can help researchers and educators better understand and support the development of math skills and interests for both boys and girls. Based on that, they can design and implement effective interventions or policies that can enhance math learning and motivation for all students, especially those who are underrepresented or disadvantaged in math. The conclusion of our study shows that different solution strategies taught in class may affect the different genders differently.

Further investigations aligned with the research limitations (more participants, other types of problems, other mathematics topics, other levels of education) may highlight specific areas where curriculum or teaching strategies can be improved to better cater to the needs of all students. Recognizing potential variations in learning styles or preferences between genders can inform the development of more inclusive and effective educational approaches. The study may also be the foundation for building intervention programs aiming to promote teachers' knowledge regarding the teaching-learning of word problems. Our intervention plan can be the base for such a program and other research to do similar research with different participant groups and other problems.

Data accessibility

The datasets generated by the survey research during and/or analyzed during the current study are available in the Dataverse repository Open Science Framework
https://osf.io/79dwr/?view_only=e504acd5f6904bfb8c1d74f427f20ea3.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

Iris Schreiber: Methodology, Investigation, Formal analysis, Conceptualization. **Hagit Ashkenazi:** Methodology, Investigation, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e35610.

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