The effect of an intervention with teaching applications of mathematics on students' attitudes and achievement

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Abstract

The purpose of this study is to examine the effect of an intervention with teaching applications of mathematics in other disciplines on Israeli high-school students' motivation, achievement, and attitudes towards mathematics. The research was carried out in the 2021-2022 school year. A quasi-experimental, non-equivalent control group research design was used. The research sample was 101 students from 11th and 12th grades (17-18 years old), 50 students in the experimental group, and 51 students in the control group The research instruments were Tapia's attitude towards mathematics inventory (ATMI), mathematics achievement test in minimum-maximum problems, and classroom observation criteria. The results of the study showed that teaching applications of mathematics in other disciplines had a positive effect on students' attitudes toward mathematics, increased students' motivation for learning mathematics, engaged more pupils in the learning process, and improved student achievement in mathematics.

Keywords

Applications of mathematics, attitudes towards mathematics, mathematical achievement, motivation for learning mathematics.

Résumé

Le but de cette étude est d'examiner l'effet d'une intervention avec des applications d'enseignement des mathématiques dans d'autres disciplines sur la motivation, la réussite et les attitudes des lycéens israéliens envers les mathématiques. La recherche a été réalisée au cours de l'année scolaire 2021-2022. Un modèle de *recherche quasi expérimental et non équivalent a été utilisé pour un groupe témoin. L'échantillon de recherche était composé de 101 élèves de 11e et 12e années (17-18 ans), 50 élèves du groupe expérimental et 51 élèves du groupe témoin. Les résultats de l'étude ont montré que l'enseignement des applications des mathématiques dans d'autres disciplines avait un effet positif sur les attitudes des élèves à l'égard des mathématiques, augmentait la motivation des élèves à apprendre les mathématiques, engageait davantage d'élèves dans le processus d'apprentissage et améliorait le rendement des élèves en mathématiques.*

Mots–Clés

Applications des mathématiques, attitudes à l'égard des mathématiques, réussite en mathématiques, motivation pour l'apprentissage des mathématiques

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Introduction

Mathematics is a very important subject, and it is used in various fields such as physics, chemistry, biology, economics, engineering, and in daily life. Although maths is considered a crucial subject, it is perceived as a difficult and problematic subject among many high school students (Dulaney, 1994). Many students have difficulty in mathematics classes, and this creates increased levels of anxiety in them because they think they cannot succeed in maths. This anxiety and low self-efficacy lead to the development of negative attitudes toward mathematics lessons. Generally, high-school students' attitude towards mathematics is on a medium level (Yasar, 2016).

Students` attitudes towards mathematics play an important role in the process of learning mathematics. It has a great influence on the students' achievements in mathematics, as students' positive attitudes lead to success in learning mathematics (Gallagher & De Lisi, 1994; Michaels & Forsyth, 1978; Yasar et al., 2014). Students gradually develop negative attitudes toward math lessons in the learning process from the elementary school stage to the final grade of high school (Baykul, 1990). Thus, improving attitudes of students towards mathematics at a lower level provides a basis for a higher level of mathematics studies and causes an impact on the achievements of high school students in mathematics (Ma & Xu, 2004). Teachers and school in general should pay special attention to students' attitudes by designing school curricula and school environment, using teaching practices in response to which students form positive attitudes (Khoo & Ainley, 2005). The teaching methods used influence students' attitude for learning mathematics (Elçi, 2017).

In this regard, in the present research the use of applications of the studied mathematical notions in different disciplines is proposed as a possible method for developing a positive attitude towards mathematics in high-school students. Students' beliefs in the utility of Mathematics in their future influences their attitude towards mathematics (Zsoldos-Marchis, 2014), thus presenting applications of mathematics could make a positive change.

Israeli post-primary school teachers consider teaching of applications of mathematics in other disciplines very important, but only less than half of them include examples of applications in their teaching, and less than a third do this on a regular basis (Asli & Zsoldos-Marchis, 2021). Most of the examples for applications of the taught mathematical knowledge come from physics. Based on the teachers' responses, teaching applications of mathematics generates students' interest in mathematics by showing the importance of it in different science areas. Considering mathematics more useful could motivate students to learn and could develop a positive attitude towards it (Asli & Zsoldos-Marchis, 2021).

Theoretical background

Attitude towards mathematics

Attitudes affect everything you try. They affect your relationship with other people and your openness to new experiences. If your attitude towards a task is positive, you will probably enjoy the process of performing it and look for opportunities to do so. If your attitude is negative, you will most likely avoid or postpone the execution of the task, and if you must perform it, you probably do not enjoy it or succeed in it (Yenilmez, 2007).

There are several definitions of the attitude towards mathematics in the literature. In this study, the multidimensional definition of Neale (1969, p. 632) was selected, based on which attitude towards mathematics is "a liking or disliking of mathematics, a tendency to engage in or avoid mathematical activity, a belief that one is good or bad at mathematics, and a belief that mathematics is useful or useless". In this definition, we can identify the emotional response, behavior related to the subject, confidence in mathematics, and beliefs on the usefulness of mathematics.

As seen from the above definition, attitude towards mathematics has several components. In some literature, three components are identified: enjoyment of mathematics, value of mathematics, and confidence in mathematics (Mullis et al., 2020). Other research identified four components: motivation, enjoyment, self-confidence, and value (Davadas & Lay, 2017; Tapia, 1996), so that motivation is added as a fourth component.

These components can be identified by factor analysis on the data obtained on various attitude towards mathematics scales, but they are not isolated components, as in case of individual students, these components are interrelated (Mullis et al., 2020).

Positive attitude has many benefits for learning, it decreases anxiety (Aiken, 1976), and ensures active involvement in the learning process (Singh et al., 2002). The positive attitude could include the student in a positive cycle: a student with positive attitude towards mathematics is more motivated for learning, so actively involved in the learning process, which results in good mathematical achievement, and this feeds the positive attitude.

Teaching applications of mathematics in other disciplines

Teaching applications of mathematics is an incontestable part of mathematics education (Pollak, 1968). The most obvious application of mathematics is in everyday life (Pollak, 1969). Teaching mathematical knowledge isolated from other disciplines doesn't show to students the utility of mathematics and causes difficulties for students in applying mathematics to solve problems from other disciplines (for example, using mathematical knowledge in physics) (Woolnough, 2000). There are interconnections between the curricula of different school disciplines, especially mathematics, chemistry, and physics, but in many cases these disciplines are taught separately. Mathematics also has applications in Economy, Engineering, Computer Science, and even Biology.

Among the relations of mathematics with other school disciplines, we emphasize on the strong relation between mathematics and physics, thus mathematics has many applications in physics (Redfors et al., 2014). There are three areas connected while studying physics: the real world, the theoretical models, and mathematics (Redfors et al., 2014; Woolnough, 2000). Students are operating in these three different contexts without realizing the strong relation between them, due to the fact that there are different beliefs systems in these contexts (Woolnough, 2000). Mathematics is applied in physics lessons (for example, functions, equations, and systems of equations), but the mathematical tools sometimes are used differently, as taught in mathematics lessons – for example, variables in equations (Redish & Kuo, 2015). Also, students need to know and classify mathematical and physical models in order to solve some tasks in physics (Otero & Fanaro, 2011).

It would be interesting for students to see applications in physics during mathematics lessons through the eyes of the mathematics teacher. With some attention from the teacher, students could successfully transfer knowledge from mathematics to physics (Woolnough, 2000). These two disciplines can be also taught co-disciplinary (Otero et al., 2016). This approach would help in development of students' scientific skills and in teaching mathematics problem oriented, which could contribute to students' good results on international testing (Ciascai & Marchiș, 2009).

When teaching applications of mathematics in different disciplines, the focus moves from mathematics to the field of the application (Chick & Stacey, 2013). To solve a problem which applies some mathematical knowledge in another discipline, knowledge from both fields is required. Therefore, the application examples must be carefully selected to ensure that the students have the required knowledge in the application field. Clark (1990) emphasized the right choice of the applications presented to students. If the application is far from students' interest, it could increase the distance they feel from mathematics.

Teaching applications of mathematics has many benefits, such as developing a positive attitude towards mathematics (Asli & Zsoldos-Marchis, 2022; Kasmin et al., 2019; Miteva et al., 2022), arising students' interest for learning mathematics (Aroshas et al., 2007), showing to students the importance of the mathematical knowledge and competencies (Asli & Zsoldos-Marchis, 2021; Miteva et al., 2022), and increasing learning motivation (Aroshas et al., 2007). Applications also contribute to a deeper understanding of mathematical concepts (Härterich et al., 2012) and a better achievement in mathematics (Aroshas et al., 2007; Verner et al., 2008), developing higher order thinking skills (Yildirim & Sidekli, 2018).

Teachers have a positive attitude towards teaching applications of mathematics (Sevimli & Ünal, 2022), but they see many obstacles in applying this in mathematics classes. They are constrained by lack of scientific knowledge in the disciplines where mathematics can be applied (Asli & Zsoldos-Marchis, 2021; Sevimli & Ünal, 2022) and time limitations (Asli & Zsoldos-Marchis, 2021; Sevimli & Ünal, 2022; Wang, 2013), as the curriculum is waste and had to be master by students under the pressure of the national exams (Asli & Zsoldos-Marchis, 2023). The mathematics curriculum and textbooks do not contain examples of applications of mathematics (Sevimli & Ünal, 2022), thus teachers' effort is huge to develop adequate examples. Examples of applications from literature usually intend to present that the concerned mathematical notion can be successfully applied in other disciplines, and do not deal with the methodology of teaching those applications to students (Biehler, 1982).

The present study aims to find out the effect of teaching applications of mathematics in other disciplines *on Israeli high school students' attitudes towards mathematics, their involvement in the class activity, and the students' mathematical achievement* through experimental research. There are only few studies presenting experimental research regarding teaching applications of mathematics (for example, Aroshas et al., 2007; Härterich et al., 2012; Kasmin et al., 2019; Rooch et al., 2015; Verner et al., 2008), and all of them for higher education. Most of these studies refer to teaching mathematics to first-year students whose major is not mathematics. Usually, first-year students are disappointed with mathematics courses as they do not see how the content presented in these courses helps them in their specialization. Thus, it is important to show applications of mathematics in the specialization of the students. Most of the previous experiments are with engineering students (Aroshas et al., 2007; Härterich et al., 2012;

Kasmin et al., 2019; Rooch et al., 2015; Verner et al., 2008), and the results show that it is possible to link the mathematical content to interesting applications, and those applications can be presented on the level of first year students. One of the experiments (Kasmin et al., 2019) is with computer science students, where the applications helped students to understand why they need to learn mathematics.

As previous experiments regarding applications of mathematics in other disciplines were carried out with university students, this paper contributes with presenting an experiment with high-school students, trying to fill in some gap in the scientific literature.

Methodology

The objective of the research

This study aims to check the effect of an intervention with teaching applications of mathematics on students' attitudes towards mathematics, their involvement in the classroom activity, and their mathematics achievement.

Participants

The study involved 4 classes and 4 teachers from an Israeli high school: two 11th grades and two 12th grades classes (17-18 years old students). Each class is divided into two groups which are taught by different teachers at the same time (this is common practice for teaching mathematics in high school in Israel). Thus, one of the groups of each class was selected for the experimental group, the other one for the control group. The experimental group included 50 students, 25 students from classes 11-1 and 11-2, and 25 students from classes 12-1 and 12-2. The control group included 51 students, 25 students from classes 11-1 and 11-2 and 26 students from classes 12-1 and 12-2.

The assignment of classes and teachers to experimental and control groups is presented in Table 1.

Table 1

Assignment of classes and teachers to experimental and control groups

Teacher	Class	Group type
R	11-1 first half	Control
E	11-1 second half	Experimental
K	11-2 first half	Control
E	11-2 second half	Experimental
R	12-1 first half	Control
Re	12-1 second half	Experimental
K	12-2 first half	Control
Re	12-2 second half	Experimental

Research procedure

The research was carried out in the 2021-2022 school year in Israel. A quasi-experimental, non-equivalent control group research design was used. The duration of the research was 4 months. It consisted of three phases:

1. Pre-intervention phase: Before the intervention, the mathematics lessons were observed in the participating classes, and observation criteria sheets were filled in. Then a pretest was carried out administrating an attitude towards mathematics inventory and a mathematics test (see more details in Subsection 3.4). The duration of this phase was one month.
2. Intervention phase: The intervention (Subsection 3.6) was carried out in the experimental classes, the control classes continued instruction as before. The duration of this phase was two months.
3. Post-intervention phase: The posttest was carried out administrating an attitude towards mathematics inventory and a mathematics test. Then the mathematics lessons were observed in the participating classes, and observation criteria sheets were filled in. The duration of this phase was one month.

Research instruments

In the study, three research instruments were used: attitude towards mathematics inventory (ATMI), mathematics achievement tests, and classroom observation criteria.

The *attitude towards mathematics inventory (ATMI)* was developed by Tapia (1996). It contains 40 affirmations measured on a 5-level Likert scale (from 1 = strongly disagree to 5 = strongly agree). The affirmations could be grouped into four factors: self-confidence (for example, 'Mathematics does not scare me at all.'), value (for example, 'Mathematics is important in everyday life.', enjoyment (for example, 'I really like mathematics.'), and motivation (for example, 'I am willing to take more than the required amount of mathematics') (Tapia & Marsh, 2004). The scale can be downloaded from https://learninglab.uni-due.de/file/10259/download?token=iWLHqcrD (last check 5 May 2023). The scale was translated into Hebrew by the first author, and the translation was verified by an expert. ATMI was used as a pre- and posttest. The results of the two groups were compared on the pretest and posttest in the case of each factor. In the posttest the scale for the experimental group contained affirmations related to learning applications of mathematics during math classes (see Table 5). These affirmations are measured on a 5-level Likert scale, and they are about students' opinions on the benefits of learning applications of mathematics in other disciplines and their attitude towards these applications.

The test related application of mathematics was constructed with the involvement of the class teachers participating in the research. The test contains maximum and minimum problems. The maximum score that could have been obtained in the test was 100. The test was given to the experimental group after the intervention.

Classroom observation criteria were developed before starting the experiment. It contained criteria that refer to the teaching methods of the teachers and the activity of the students. The observation period lasted four months and was carried out in both groups. Observations started before the intervention to see the teaching methods used by the teachers and students' activity in the participating classes and continued after the intervention to see the effect of it. Below examples of criteria are given.

Give the approximate percentage of each options in case of the following criteria:

- The type of classroom organization (frontal/group/individual).
- Who solves the problems (teacher/ students in group/students individually).
- Who writes on the board (teacher/students).

Data Analysis

The data obtained with the ATMI scale and the results of the mathematics achievement tests were quantitatively analyzed using the SPSS program. Descriptive statistics (mean (M) and standard deviation (SD)) and comparisons with the t-test were used.

In addition, the results of the mathematics achievement tests were also qualitatively analyzed, identifying the main difficulties of the students regarding the tested mathematical knowledge.

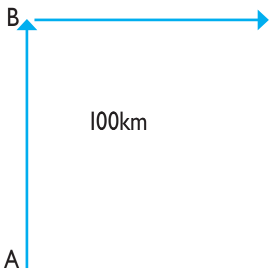
The observation data were qualitatively analyzed by categorical analysis.

Intervention

The material studied during the research period (during the observations before, during, and after the intervention) is "differential and integral calculus", in particular the following subjects: the equation of the tangent of functions, extreme points, sketching graphs of various functions, as well as maximum and minimum problems. It is important to note that the same subjects were taught in both groups (control and experimental) for 11th and for 12th grades were the same subjects and in full coordination between the teachers. The 11th and 12th grades studied the same topics of differential and integral calculus, but for different types of functions: 11th grades for polynomial, rational, and root functions, and 12th grades for logarithmic, trigonometric, exponential, and power functions.

During the intervention both groups studied maximum and minimum problems, but the control groups just solved mathematical problems (i.e. calculation of minimum and maximum points of different functions), while the experimental group also solved applications of maximum and minimum in other disciplines such as physics, construction, economics, and everyday life (i.e. they got a problem from another discipline or everyday life, they had to model the problem by a function, then to calculate the minimum or maximum points of that function). Problems of daily life were illustrated through drawings and sometimes through videos or computer simulations. The intervention plan given to teachers contained the proposed examples of applications of mathematics in other disciplines for the subject taught. The plan also recommended the use of active teaching methods.

Two examples of problems with applications of mathematics in other disciplines are given below.

Application in Physics	Application in Economics
A and B are two points in the sea, the distance between them is 100 km. Point B is north of point A.  Two ships sail from points A and B so that the first ship sails from point A to the north in the direction of point B at a speed of 10 km/h and the second ship sails from point B to the east at a speed of 20 km/h. a-Find the square of the distance between the two ships as a function of time from the moment of sailing! b-After how long from the moment of sailing will the distance between the two ships be minimal? c- What is the smallest distance between the two ships?	A group of 20 people come to eat at a luxury restaurant where a meal is 150$ per person. The owner of the restaurant offers a discount: for every additional person joining the group of 20 all the participants pay 5 dollars less. a-How many people should be in the group so that the profit of the restaurant is the maximum possible? b-How much money each of the participants will pay and what will be the restaurant's maximum income from this group?

Results

In this section, the effects of teaching the applications of mathematics in other disciplines on students' attitude towards mathematics, students' participation in class activities, and their mathematical achievement are presented.

Students' attitude towards mathematics

The *attitude towards mathematics inventory (ATMI)* was given to both groups (experimental and control) before and after the intervention. In addition to this scale at the posttest the experimental got three questions relating to the importance and the benefit of teaching applications of mathematics in other disciplines.

The responses obtained for ATMI were analyzed using SPSS program according to four categories: self-confidence (self-confidence in mathematics), value (value of mathematics), enjoyment (enjoyment in mathematics), and motivation (motivation to learn mathematics).

The analysis performed included descriptive statistics and a comparison between the groups before and after the intervention.

Table 2 contains a comparison of the results obtained by the two groups in the pre-test. In three categories (self-confidence, enjoyment, motivation) there is no significant difference between the means of the two groups. In the case of the value category, the mean of the control group is significantly higher than the mean of the experimental group [t(99)=-2.33, p=0.02], the difference between the means of the two groups is 0.37. To have not significantly different results for each category on the pretest, some participants could have been excluded. The difference of means is not so high; the significance of this difference will be analyzed in the context of the posttest. To keep the sample size, the decision was taken not to exclude any participant.

TABLE 2

Comparison of the results of the ATMI scale of the experimental and control groups by categories in the pre-test using the independent samples t-test

Category	Experimental Group			Control Group			df	p	t
	N	M	SD	N	M	SD			
Self-confidence	50	3.66	0.78	51	3.81	0.93	99	0.37	-0.88
Value	50	3.41	0.83	51	3.78	0.74	99	0.02	-2.33
Enjoyment	50	3.49	0.93	51	3.68	0.82	99	0.27	-1.09
Motivation	50	3.46	0.92	51	3.53	0.85	99	0.71	-3.68

Table 3 contains the comparison of the results obtained by the two groups in the posttest. In all categories, the experimental group has significantly higher means. The difference of means between the two groups is 0.70 for self-confidence [t(99)=5.17, p=0.00], 0.62 for value [t(99)=5.29, p=0.00], 0.61 for enjoyment [t(99)=4.67, p=0.00], and 0.7 for motivation [t(99)=5.43, p=0.00] category. The difference between the means in the posttest in the case of the value category (0.62) is higher than in case of the pretest (0.37). The mean of the experimental group increased from 3.41 to 4.31 (increased with 0.9), the control group's mean decreased from 3.79 to 3.69 (decreased with 0.10). This shows that the significant difference on the pretest in case of this category didn't influence the result.

TABLE 3

Comparison of the ATMI scale results of the experimental and control groups by categories in the post-test using independent samples t-test

Category	Experimental Group			Control Group			df	p value (Sig)	t
	N	M	SD.	N	M	SD			
Self-confidence	50	4.47	0.38	51	3.77	0.86	99	0.00	5.17
Value	50	4.31	0.40	51	3.69	0.71	99	0.00	5.29
Enjoyment	50	4.24	0.49	51	3.63	0.79	99	0.00	4.67
Motivation	50	4.18	0.45	51	3.48	0.79	99	0.00	5.43

The results of the pretest and posttest of the experimental group were compared using a paired t-test (Table 4). The results of the experimental group have been significantly improved in case of all categories: the difference between the means obtained at the pretest and posttest is 0.81 for self-confidence [t(49)=-6.73, p=0.00], 0.90 for value [t(49)=-9.04, p=0.00], 0.75 for enjoyment [t(49)=-6.40, p=0.00], and 0.72 for motivation [t(49)=5.73, p=0.00].

TABLE 4

Comparison of the ATMI scale pre- and post-test results of the experimental group by categories using paired t-test

Category	Pre-test			Post-test			df	p value (Sig)	t
	N	M	SD	N	M	SD			
Self-confidence	50	3.66	0.78	50	4.47	0.38	49	0.00	-6.73
Value	50	3.41	0.83	50	4.31	0.40	49	0.00	-9.04
Enjoyment	50	3.49	0.93	50	4.24	0.49	49	0.00	-6.40
Motivation	50	3.46	0.92	50	4.18	0.45	49	0.00	-5.73

In the following, the items related to learning applications of mathematics at the posttest of the experimental group are analyzed. The mean and standard deviation for each affirmation is presented in Table 5. In case of all the affirmations, the mean is high, between 4.30 and 4.52, which shows that students really enjoyed learning about the applications of mathematics, and they consider these beneficial.

TABLE 5

Descriptive statistics for items related to learning applications of Mathematics in the experimental group

Affirmation	N	Minimum	Maximum	M	SD
Teaching applications made me interested	50	3.00	5.00	4.52	.61
I enjoyed studying applications	50	3.00	5.00	4.52	.58
Teaching applications improve achievement	50	3.00	5.00	4.52	.65
Attitudes towards applications of mathematics	50	3.00	5.00	4.52	.48

Teaching methods and students' activity

The observation lasted for four months to describe the teaching methods used and students' activity before, during, and after the intervention. The observations were made in both groups.

From the observations, the following most important points and issues can be summarized:

Before the intervention, the *instruction* in both groups was frontal: the teachers gave explanations on the board about some theoretical aspects of the taught topic and then gave the students time to solve problems alone with the possibility to ask the teacher for help in case of a question or problem, then the problems were solved on the board. Thus, in many parts of the lessons, the students only copied what the teacher wrote and solved on the board. The teacher was at the center of the instruction, she conducted and controlled the lesson. Using this instruction, many students have difficulties in solving the problems, they are not actively participating in the lesson, and they get bored. Some of the students developed a negative attitude towards mathematics, even fear of mathematics.

During and after the intervention period. This frontal math instruction continued in the control group. Introducing problems related to the applications of mathematics in the instruction of the experimental group significantly changed the teaching methods used by the teachers. Students became more interested and motivated to learn mathematics. Students were active in classes, asked questions, they were more interested in the taught topic, and had a high motivation to learn. The attitude of the students changed positively towards mathematics.

Mathematics achievement

Mathematics scores from the first and second semester of the school year 2021-2022 were used for studying the effect of the intervention on mathematical achievement. The intervention was done in the second semester, so that the first semester's scores were used and pretest and the second semester's scores as posttest.

Table 6 shows the means and standard deviations for each group at the pretest. As the Shapiro-Wilk test shows that the data has normal distribution, independent samples t-test was used to compare means. The mean of the control group is higher with 11.66 points than the mean of the experimental group, and this difference is statistically significant [t(99)=2.622, p=0.010].

TABLE 6

Comparison of the first semester's scores of the experimental and control group

	Control group			Experimental group			t-test		
	N	Mean	Std.	N	Mean	Std.	df	p	t
First semester's scores	51	69.12	21.01	50	57.46	23.62	99	.010	2.622

Table 7 shows the means and standard deviations for each group at the posttest and the results of the comparison with the independent samples t-test. The mean of the experimental group is higher with 7.54 points than the mean of the control group, but this difference is not statistically significant [t(99)= -1.880, p=0.063]. But the score of the experimental group was lower at the pretest than the mean of the control group, the mean of the experimental group improved with 21.16, and this improvemenet is statistically significant [t(49)=- 9.378, p<.001], see Table 8.

TABLE 7

Comparison of the second semester's scores of the experimental and control group

	Control group			Experimental group			t-test		
	N	Mean	Std	N	Mean	Std	df	p	t
Second semester's scores	51	68.08	21.07	50	75.62	19.19	99	.063	-1.880

TABLE 8

Comparison of the first and second semester's scores of the experimental group

	First semester's scores			Second semester's scores			df	p	t
	N	M	SD	N	M	SD			
Experimental groups' scores	50	57.46	23.62	50	75.62	19.19	49	< .001	-9.378

Application of mathematics results

After the intervention a test on maximum and minimum problems was given to the experimental group. The mean of the experimental group was 75.64 (SD=22.33).

Discussion and conclusions

The results of the mathematics attitude inventory show that the means of the experimental group increased significantly in the case of all categories: self-confidence in mathematics, value of mathematics, enjoyment in mathematics, and motivation to learn mathematics. An increase in learning motivation was also observed in the experiment of Aroshas et al. (2007). In contrast, Rooch et al. (2015) did not observe a significant increase in students' learning motivation in their study, this could be due to the small sample size in their experiment or due to the fact, that students had to apply for participating in the project and their initial learning motivation was quite high.

The highest increase is in the case of the value category, which shows that learning applications of the studied topic in other disciplines helped students to see the usefulness of the taught mathematical knowledge. Also, in previous experiments students realize the importance of the taught mathematical knowledge in their career or in everyday life (Aroshas et al., 2007; Härterich et al., 2012; Kasmin et al., 2019; Rooch et al., 2015; Verner et al., 2008).

Based on the fact that all the categories of the ATMI test have improved, it could be stated that the experimental group's attitude towards mathematics turned into more positive, which reinforces previous results (Asli & Zsoldos-Marchis, 2021; Kasmin et al., 2019).

Analyzing the results obtained by classroom observations, it can be concluded that when teaching applications of mathematics teachers used more interactive methods which helped students in a more active participation in the classwork. The results reinforce conclusions of previous studies based on students' and teachers' opinion on teaching applications of mathematics (Asli & Zsoldos-Marchis, 2021; Miteva et al., 2022; Sevimli & Ünal, 2022), but also by the results obtained in a previous experiment (Aroshas et al., 2007). The increased activity of the students observed during and after experiment could be explained by the positive attitude towards mathematics they developed (Singh et al., 2002). Another factor influencing students' involvement and motivation could be the useful perception of mathematics, as students' motivation is strongly related with their beliefs about the utility of mathematics in life (Marchis, 2011).

The mathematical achievement of the experimental group increased significantly. This agrees with the result obtained in two previous studies (Aroshas et al., 2007; Verner et al., 2008). The increase in achievement is explained by a more positive attitude towards mathematics (Nicolaidou & Philippou, 2003), and active participation in the lessons.

In previous surveys teachers are worried that lack of scientific knowledge in the disciplines where mathematics can be applied make teaching application of mathematics difficult (Asli & Zsoldos-Marchis, 2021; Sevimli & Ünal, 2022). The results of this study show that application of mathematics can be taught successfully, as the mean of the experimental group's results on the application of mathematics test is good.

In conclusion, teaching applications of mathematics in other disciplines has a great effect on students: they develop a positive attitude towards mathematics, become more motivated for learning, and become an active participant of their learning. Teaching applications of mathematics transforms students from a passive receiver of knowledge into an active discoverer of knowledge. All of these changes have an important result, that teaching applications of mathematics in other disciplines led to a significant improvement in students' mathematics achievement.

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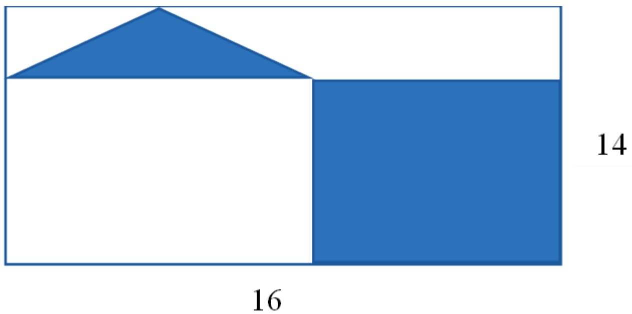
Appendix

Test on applications of mathematics
Subject: maximum and minimum problems.

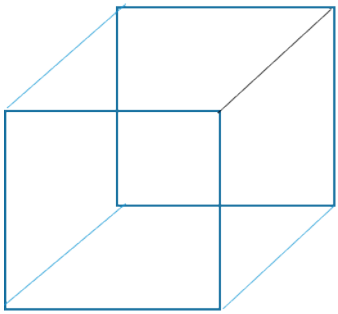
The test includes five questions, please answer four questions out of the five questions (each question 25 points).

1) The length of the road AB = 30 km, the distance AC = 10 km and the distance CB = 20 km (see the figure). A car travels the road AC at a constant speed of (48-x) km/h where 48>x>0 and the road CB at a speed of (48+2x) km/h. Find what the value of x should be so that the total travel time from A to B is minimal?

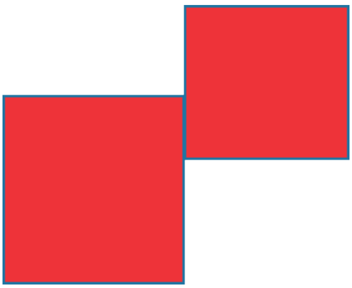
2) A merchant has a rectangular plot of land measuring 16 meters and 14 meters. The merchant wants to build out of wood: an office in the shape of a triangle and a parking lot in the shape of a square (see the figure). The price of the construction is $500 per square meter. What is the minimum price that the merchant must pay for the construction of the office and the parking?



3) We want to build a box-shaped room with a square base.
The volume of the room is 48 (see the figure).
The construction price of the walls is $300 per square meter.
The construction price of the ceiling is $400 per square meter.
The construction price of the floor is $50 per square meter.
What should be the dimensions of the room in order the price of its construction be minimal?



4) In front of you are two houses adjacent to each other as shown in the figure. The two houses are square shaped and the sum of their perimeters is 128 meters. What should be the length of the side of each house in order the sum of the areas of the two houses be minimum?



5) A group of 18 people want to travel to a certain city and stay at the Love Hotel. The price of each night at the hotel for one person is 116 dollars. The hotel has a special offer to groups: for each additional person to the group of 18 members the price per night per person is decreased with 2 dollars for each member of the group. How many people does the hotel need to receive until its profit be maximum?