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Changing students' attitudes toward mathematics through creative STEAM projects designed and executed by them (SMART program)

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Abstract: In recent years the interest in learning mathematics decreased as students do not consider mathematics important for their future and they do not perceive its value. The study reveals the relationship between mathematics and the students as an IKEA effect, that is, when the students go through the process of creating an object and investing thought and time in it, they will perceive it as worthy, as having significant value, and they will desire it more than a ready-made object.

To achieve this perception of valuable mathematics students got complex tasks (project), based on questions from the mathematics study material combined with each student's fields of interest. The aim of the research is to test if these projects contribute to a positive attitude towards learning mathematics. A one-group pretest-posttest research design was used. In the research 25 students were involved. During creating the projects, formative technological environments were created through design and handiwork, learning in groups, discourse, and meaningful feedback.

The results show that the students developed positive perceptions of mathematics. While creating the original projects the students showed motivation and responsibility for their learning and developed a sense of confidence/competence and design thinking that led to creativity and innovation.

Key words: STEAM, project-based learning, learning mathematics by creation / hands-on activities, IKEA effect in learning mathematics, attitude towards mathematics

1. Introduction

Studies show that mathematics is seen by most students as a challenging subject and many of them abandon the field for further studies. The classes emphasize memorizing and recalling information and the learning environment is usually a classroom where the teacher lectures the material to the student and the students acquire information on their own. In the lessons there is not much focus on the problem itself, more emphasis on principles. The student, for the most part, is inactive, loses interest and his internal motivation is low. (Diego-Mantecón et al.,2019; Diego-Mantecón et al., 2021).

A summary report by the Tramp Foundation in Israel on the attitudes of students in choosing excellence in mathematics (2020) aged 12-15 (300 Jewish students) highlights several main findings: 1. In motivation for investment and excellence - high students are motivated mainly by internal motivation, half of the students promised to invest in mathematics during the Corona period if the teacher explains the material well. About a third stated that experiential learning will increase the motivation to learn and not a summative test. A third of the outstanding students who had a positive attitude to mathematics claimed that what motivates them to succeed and learn advanced mathematics is to be accepted to a high level in high school, to study a scientific field, and to think about a profession in the field. Students with difficulties in mathematics - about 57% of the students stated that they experienced difficulties due to the transition to distance learning.

Test anxiety among high school students is a common phenomenon that sometimes causes damage to the performance of the test, and difficulties in learning effectively in preparation for the exam but can also be expressed in avoiding specialization in mathematics and the subjects of science, technology, and

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engineering (Li & Schoenfeld, 2019). According to a recently published report, 15-year-old students are expected not to reach the minimum proficiency level in mathematics (OECD, 2019b).

Today, workplaces seek to solve open problems through group thinking, creative and original interpretation of real situations, making assumptions, planning strategies, and validating solutions.

As a solution to the above-mentioned problems an experiment with high-school students was developed and implemented. The main idea of the intervention program is that the students are required to write creative projects aimed at making the mathematical material valuable in their eyes (OECD,2019a; Diego-Mantecón et al., 2021; Maass et al., 2019). Thus, each student could freely choose the topic of the project based on his/her personal interest and hobbies. Developing this project, the students learn visualization design in the application Rhino7+Keyshot, they will be given the opportunity to create models with a 3D printer and a laser printer to achieve meaningful learning. The role of the teacher in this teaching approach is to mediate the material to the student.

2. Theoretical backgrounds

2.1 Students' attitude to mathematics

Studies show that mathematics is seen by most students as a challenging subject and many of them abandon the field in further studies. The classes emphasize memorizing and recalling information and the learning environment, usually, is a classroom when the teacher lectures the material to the student and the students acquire information for themselves. This artificial environment, disconnected from everyday life. There is less attention to the learning nature of each learner, less learning in groups. In the lessons there is not much focus on the problem itself, more emphasis on principles. The student, for the most part, is inactive, loses interest and his internal motivation is low (PBL, Diego-Mantecón et al., 2021) .

A summary report of the Trump Foundation in Israel (2020) on student attitudes in choosing excellence in mathematics aged 12-15 (300 Jewish students) highlights a number of main findings: A. In motivation for investment and excellence - students at a high level are mainly motivated by internal motivation, half of the students promised to invest in mathematics during the Corona period, if the teacher explained the material well. About a third stated that experiential learning will increase the motivation to learn and not a summative test. About a third of the outstanding students who had positive attitudes towards mathematics, claimed that what motivates them to succeed and study advanced mathematics, is to be admitted to a high level in high school, to study a scientific field and the thought of a profession in the future. The question arises, what happens with the students at the low level or with the learning disabilities? B. Students with difficulties in mathematics - about 57% of the students stated that they experienced difficulties due to the transition to studies in the Corona format. Among the students who reported that they experienced difficulties, three quarters report difficulty concentrating during class or preparing homework. About two-thirds report difficulty in understanding the study material and an overload of the study material. About half report that there were gaps in the study material.

C. Mathematical ability or ability - the struggling students feel insecure and have difficulty learning the mathematical material. Students in a low grouping in mathematics stated that they study less mathematics than before the corona virus compared to students in a high level. Most of the respondents believe that if the studies continue in the format of a lecturing teacher, without personal attention and without active and experiential learning, they will be less successful.

2.2. A student designs a model (Ikea effect) and prepares a creative project - an intervention in the study content.

The research advocates introducing the field of design into mathematics studies in order to link mathematics to everyday life. In everyday life, we are informal designers, for example, interior design, clothing design. We have a natural need to understand how things work, thus "**engineering is fundamental**" (Li et al. 2019).

Creating projects that link mathematical subjects with the interests of the students, advocates for the introduction of Arts into STEM obtaining an approach known as **STEAM.** This approach is strongly related to creativity, ethics, aesthetics and innovation (Colucci-Gray et al., 2019; Quigley et al., 2020b.). In high schools, the field of design and design thinking are not common. Math and science are not considered areas where students are required to design. In contrast, engineering and technology are the professional fields that incorporate design as an important and unique activity (Daly et al. 2012; Haupt 2018; Simon;1996).

For design thinking to be part of mathematics classes, special training of the students and teachers and work methods with new procedures and terms are required (Banilower et al. 2013; Fisher;1990). According to the STEM approach, emphasis must be placed on the development of design thinking that will develop multiple solutions to one problem, creativity and innovation, group thinking, mathematical discourse, and interest in the subject (e.g., Honey et al. 2014; ITEA 2007; Katehi et al. 2009; NGSS Leading Countries 2013).

2.3. Design thinking

As part of writing the assignments, we used design thinking that is important for student development in the twenty-first century. Design thinking is a method defined as a human method for innovation, the purpose of which is to solve problems through creative ideas. The focus of the method is on the customer's needs and not on the needs of the organization or its technological capabilities. Today the leading organizations in the world such as Google, Nike, Apple, Disney and more, use design thinking to drive innovation in the organization. Design thinking is becoming one of the most essential work practices for an organization in the implementation of digital processes (Li et al. 2019).

In education, through task design or model design, conclusions are drawn from the particular to the general. Unlike mathematics, human experience does not translate into raw data. This thinking develops curiosity in the student and makes him be innovative, recognize patterns, use words and pictures using our natural ability to solve problems. In the standard approach, the students choose a known algorithm that the teacher showed in class, in the approach through the design, the students start asking the right questions through the process itself, from which the real needs emerge and from there the ideas are born.

For the purpose of integrating design thinking into mathematics, the researchers (Li et al. 2019), show five stages in the process of developing design thinking:

1. Empathy - understanding the needs of the user. 2. **Definition** - turning all the information and findings into a clear insight on which we are going to focus. 3. **Ideas** - brainstorming with adherence to the following rules: no criticism or any kind of judgment. 4. **Prototype** - creating a prototype of the idea with minimal investment. 5. **Test** - we test the product we made. The user experiences the use of the prototype. We watch it and finally get feedback from it**.**

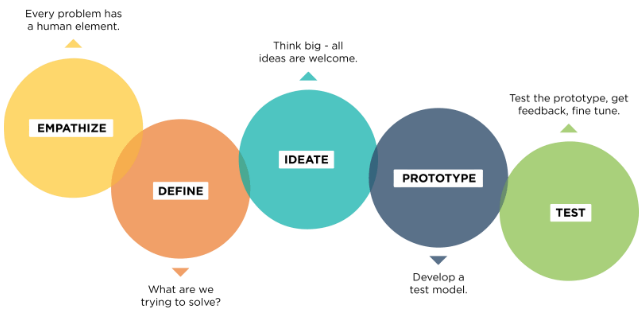

Figure 1 - Design thinking

Straker and Wrigley (2015), emphasize that integrating design thinking into the curriculum is benefic for efficiency of the projects.

It is an educational challenge, it is required to develop tasks at different levels, including experience in a technological laboratory and learning concepts at an abstract level necessary for the design process. Similarly, the researchers (Dasgupta; 2019) suggest testing additional intervention programs in order to assess student levels.

Kelly and Song (2017) added that acquiring basic knowledge and practices in **STEM** is definitely not enough. Teachers should use engineering design as an approach to improving science learning. Develop mathematical thinking beyond the initial planning tasks. Kelly and Cunningham (2019) examined how engineering design provides thinking in groups along with the following steps: 1. Building models and prototypes 2. Making compromises between criteria and constraints for engineering design challenges 3. Communication through accepted and typical verbal, written and symbolic uses in meaningful discourse. The researchers analyzed the students' products, the students' work, sectarian discourse. The results showed that the findings helped develop creativity, facilitated learning and improved students' mathematical thinking. Despite the basics of proper teaching and curriculum, design thinking education still does not necessarily emphasize mathematical and scientific concepts as a learning goal (Estapa & Tank, 2017,2022).

2.4. Project-based learning (PBL)

Definition and formative characteristics of the project-based learning (PBL), organizes the learning around projects that link the fields of learning to the real world. Learning includes complex tasks, based on challenging questions or problems, involving students in design, problem solving, decision making and research activities. The learning gives the student an opportunity to work autonomously, relatively, over time and results in the creation of actual products or displays. Research literature also indicates other characteristics, such as authentic content, authentic assessment, the mediating role of the teacher, cooperative learning, and reflection. A wide variety of the main characteristics and the lack of a unified and agreed model of PBL resulted in ambiguity regarding the definition and limits of the method. (Thomas, 2000).

Recently, researchers have applied PBL learning in STEAM where engineering and technology are central (Martín-Páez et al., 2019; Thibaut et al., 2018). Technology is seen as a tool for creating and testing artefacts and engineering is seen as a context for applying mathematical and scientific content. The researchers believe that learning in a technological laboratory will develop different learning abilities and create different approaches and solution strategies (Catarino et al., 2019; Estapa & Tank, 2017) .

Principles for designing the mathematics curriculum using the PBL model:

A. Using a leading question or questions related to the topic - a question that is the focus of the research and to which the students try to give the answer.

B. Setting the learning goals - the content studied should be authentic and related to important issues in the world outside the school walls; The learning objectives must be adjusted to the national standards. Work on the project includes the development of scientific practices.

C. Using projects to promote learning - working on projects should occupy the central place in the curriculum and not be a marginal means.

D. Allowing time for learning - learning within the PBL framework should be prolonged because students need enough time to develop in-depth learning and scientific practices, which include experimental activity.

3. Methodology

The research was conducted in 2022 in Israel.

3.1. Research scope and questions

The research aimed to study the effect of an intervention in which high-school students designed and tested creative projects according to their interest in which they have used mathematical knowledge and competencies.

The research tried to find answers to the following questions:

1. Through creative projects in mathematics that were planned and designed by the students according to their personal interest, will the students' learning became more significant?

2. Through creative projects in mathematics that were planned and designed by the students, will the students develop motivation for learning?

3. Through creative projects in mathematics that were planned and designed by the students, will the students' capability perception increase?

4. Through creative projects in mathematics that were planned and designed by the students, will the students' willingness for creative work increase?

5. Through creative projects in mathematics that were planned and designed by the students, will the students' mathematics anxiety decrease?

3.2 Intervention

The main idea of the SMART intervention program is that students write projects or project ideas for mathematical topics taught in 10th grade and combine them with their interests. They write projects in the PBL (problem-based learning) model. The program is intended for 10th grade math, mainly for the higher levels. The SMART program combines mathematics with design, science and technology. Learning in this way has been found to contribute to in-depth understanding and emphasizes authentic and relevant learning derived from the student's world (Pellegrino & Hilton, 2012). During the lessons, the students are supposed to raise authentic problems, discuss possible solutions to them, additional ideas for projects combined with their interests, choose a solution, design a product that will contribute to this solution and carry out an investigation using scientific tools

To describe the **SMART** idea, I presented in Figure 2 the theoretical structure of the program:

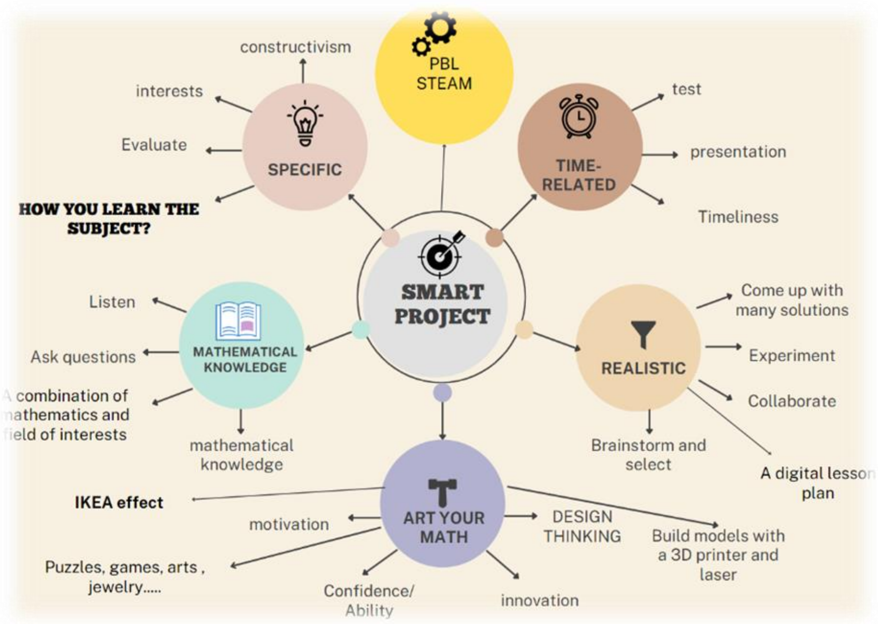

Figure 2. The theoretical structure of the SMART program

3.3 Research instrument

A mathematics attitude questionnaire was developed for this research. This scale contains 40 statements, (Fennema & Sherman, 1977; Forgasz, 1995; Leder, 1995; Lev Ari & Mittelberg, 1996; Sherman & Fennema, 1976;), for which the students were required to indicate their degree of agreement on a 5-level continuum for which the students were required to indicate their degree of agreement on a 5-level continuum ranging from 1 = completely disagree, to 5= strongly agree.

These affirmations were grouped into 6 categories based on the scales from the literature: Significant and constructive learning, Creativity encouragement, Stress and Anxiety, Motivation and interest, Learning strategies, Capability perception.

The time needed for filling in the online questionnaire was between 20-30 minutes.

The results were qualitatively analyzed with descriptive statistics (means, standard deviations) and comparison of means.

3.4 Participants

The study involved 25 10th grade students from different schools from Haifa, Israel.

4. Results

Mean and standard deviation was calculated for each category of the questionnaire on the pretest and posttest (Table 1).

Table 1. Comparing pretest and posttest results

		Pretest		Posttest			
Category	***No. of items***	***M***	***SD***	***M***	***SD***	***t***	***p***
Significant and constructive learning	7	3.78	0.87	4.16	0.91	-1.41	0.17
Creativity encouragement	3	3.80	0.75	4.20	0.86	-1.62	0.12
Stress and Anxiety	8	2.95	1.16	2.73	1.10	0.72	0.48
Learning strategies	5	-	-	4.12	1.20	-	-
Motivation and interest	14	3.06	0.51	3.47	0.76	-1.89	0.07
Capability perception	8	2.80	0.85	3.44	0.99	-2.36	0.03

According to Table 1, in case of 4 categories a positive trend was obtained. In case of the *Stress and Anxiety* category a small decrease was obtained. To verify if this increase is statistically significant, paired t-test was conducted for each dimension. There was a significant increase in the student's *motivation and interest* in Mathematics learning after the intervention program ($t(24)$ =-1.89, $p < .05$). Similarly, there was a significant increase in the student's *Sense of capability* after the intervention program ($t(24) = -2.36$, $p < .05$).

5. Discussion and conclusions

The intervention program puts the student at the center. The innovation in the research is that students are involved in their learning process. Students developed original thinking through the projects in which they combined mathematics with their interests, to understand its usefulness daily. An environment was created that allowed the dissemination of the students' free ideas. Handing the ball over to the students increased their motivation and confidence in the chosen mathematical subject or, as they confirmed, the tendency to take on tasks related to their skills and knowledge, and not to promote or create tasks in which they would feel insecure. The change is desirable for the education system today, in Israel. From this, it is suggested to examine what is the desired way to share the community of mathematics teachers, the school management, and the stakeholders in the program. And accordingly, to establish a technological learning environment that includes compatible equipment and an annual curriculum with an organized budget.

The shortcomings of the study that only tested 25 students from different schools, it does not present criteria for evaluating the projects and more categories are needed, therefore another, larger study is needed to prove that the intervention program improves the students' attitudes towards mathematics and the trend is indeed positive.

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Appendix. An example of a project developed by students

Throwing a light bulb ball from a cannon - A combination of physics and functions

Students worked in a group of four studying physics and mathematics at a high level.

Step A **-S**pecific - Uriel's interests: physics-volcano eruption, basketball:

Step B: **M**athematical Knowledge

Uriel studies the subject of the parabola in mathematics: extreme points, slope of the tangent at points on the parabola graph, axis of symmetry, symmetrical points, horizontal and vertical shifts, etc. Geometry - radius, circumference of a circle, area of a circle, overlap of triangles. Trigonometry - the tangent of the angle, the Pythagorean theorem.

Uriel studies physics: horizontal throw of a ball, inclined throw (movement of a ball thrown into a basket, movement of a tennis ball after a hit, movement of a bomb after the bomber releases it, etc.). free fall.

Step C-**A**rt your math

Uriel plans questions for the class including building the model with his four friends studying physics

In Figure 3 is from physics: the initial speed V0 is at angle 0 (the angle will change during the movement) horizontal shot is a special case.

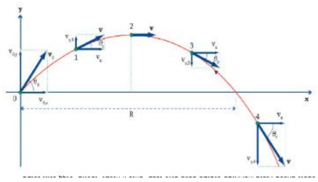

Figure 3. Movement of a ball

Examples of questions asked by Ariel: A. Describe the movement of the ball (on the horizontal axis a movement equal to speed. On the vertical axis the body rises and then falls a movement equal to acceleration. B. Is the trajectory a parabola? Why? (The speed at this point is only in the horizontal direction, hence the problem is the same as a horizontal shot from point 2 and therefore it is a parabola) C. Look at point number 2 at the top of the track, what does it mean? (or where is the apex of the parabola?)

In mathematics: the function is given: $f(x) = -(x-3)^2+24$(Figure 4).

A. Give an example of a function that moves 3 units to the left on the x-axis? B. What is the axis of symmetry? C. What is the maximum point of the function and what does it mean? D. What is the slope of the tangent at the points of symmetry… E. What is the equation of the tangent at the extreme point?

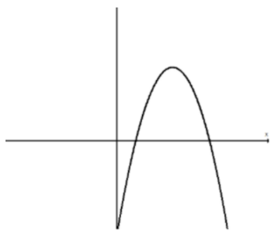

Figure 4. Graphic of the function

On the board in the classroom: Uriel shows the formula for a free throw and asks: What needs to be corrected so that the equations are correct for a shot on a slope?

(19)	$a_y = -g$	(15)	$a_x = 0$	תאוצה
(20)	$v_y = v_0 \sin\theta_0 - gt$	(16)	$v_x = v_0 \cos\theta_0$	מהירות
(21)	$y = (v_0 \sin\theta_0)\cdot t - \frac{1}{2}gt^2$	(17)	$x = (v_0 \cos\theta_0)\cdot t$	מקום

When Uriel asks the students: What is the trajectory of the movement (that is, the equation of y as a function of x)? The result is an equation identical to the parabola equation that the students learned in math. The students understand that only the markings are different.

$$y = -\frac{g}{2v_0^2 \cos^2\theta_0}x^2 + (\tan\theta_0)\cdot x$$

Uriel mentions how to find the magnitude and direction of the velocity at every moment:

$$(23) \qquad \boxed{v = \sqrt{v_x^2 + v_y^2}} \qquad \text{גודל המהירות:}$$

$$(24) \qquad \tan\theta = \frac{v_y}{v_x} \qquad \text{כיוון המהירות ביחס לציר האופקי:}$$

Step D - **R**ealistic

A question from everyday life: A player hits a ball that is on a cliff at an angle of 400 above the horizontal direction, with an initial speed of 35 m/s.

1. After how long will the ball reach its maximum height?

2. What is the maximum height, what is the point on the graph?

3. After how long does the ball reach its initial level, what is the point?

4. What distance does the ball travel during this time? (Copy = 0, another point of intersection with the x-axis. Why did it go twice as long as the time in section 1? There is symmetry in the movement up and down - you can show this in a time-velocity graph with overlapping triangles).

Designing rings in the Rhino 7 software and printed them on a 3D printer. A practical solution. Cannon ball shooting, team work.

Step E. - **T**ime Related

Questions that guided Ariel in creating the lesson: Which method was more suitable for the problem? The traditional or the creation of your lesson and can this method be used to solve other issues?

- How did you feel during the planning of the lesson and its presentation?
- How did you check that the solution is correct?
- What were the difficulties in planning the lesson and what do you think are the benefits