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ON INTEGRATION OF STEM MODULES IN MATHEMATICS EDUCATION

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Abstract. Student motivation has emerged as a major issue in mathematics education in recent years. Utilizing the capabilities of contemporary technology and the accessibility of a STEM environment is crucial for the creation and application of educational materials. Integration of the created resources will increase the interest of students to pursue in-depth studies of science and math. In this paper are presented the results of the conducted study on the effectiveness of using problem-based learning (PBL) modules to learn mathematics. The study was carried out in Israel with the participation of teachers and ninth graders. As part of our research, we created a novel program and conducted an experimental study, evaluated its impacts on the designated target groups, and analyzed how the program affected student subgroups. Pre- and post-program questionnaires measured ability feeling, relevance perception, and motivation. The results of the analysis of the students indicate a considerable rise in the motivating factors associated with self-esteem and the utility of mathematics training.

Keywords: STEM; mathematics; motivation; problem-based learning; PBL

1. Background The main purpose of the international studies of the Program for International Student Assessment (PISA) and the International Mathematics and Science Study (TIMSS) is to assess various aspects of how students learn and compare education systems in different countries.

Based on the results of the PISA and TIMSS studies in recent years, government institutions, partners from the field of higher education, and other fields set themselves the goal of increasing reading, mathematics, and science literacy.

In general, this includes (Tramonti 2020):

- Encouraging a positive attitude towards STEM
- Increasing awareness of science in society;
- Modernization of the learning process in natural sciences at school;
- Stimulating students' interest in STEM disciplines and, as a result, increasing students' orientation to professions in STEM fields;
- Achieving gender equality in educational institutions and STEM-related professions.

In this context, the need to modernize teaching methods to stimulate students' curiosity and motivate them in the educational process is outlined. This determines the need for systematic support for teachers who teach in a STEM environment. In recent years, efforts have been made to create an integrated learning environment for a new generation in Bulgarian schools (construction of STEM centers and classrooms). In this regard, the presented research is relevant and would contribute to the exchange of experiences and good practices both for supporting teachers in mathematics education and for student motivation.

In Bulgaria, there is experience with the creation of resources focused on the research approach to mathematics education. Geometric figures are used in dynamic software for solving tasks related to games (Chehlarova 2021; Chehlarova 2022); in the study and restoration of artifacts (Chehlarova 2021); when applying technologies such as augmented and virtual reality (Chehlarova & Chehlarova 2020), etc. STEM educational resources are promoted in Bulgaria and by IMI-BAS as part of the international STEMPD-Net network of leading European centers for the professional development of STEM teachers (Chehlarova et al. 2018; Chehlarova et al. 2021).

Numerous researchers are interested in STEM education in Israel. STEM courses – science, technology, engineering, and mathematics – are regarded as foundational subjects in the school system. Nevertheless, during the last ten years, difficulties have been noticed in their study.

To promote STEM learning, many curricula and experimental STEM teaching strategies have been created in Israel (Kearney 2016). However, despite all these investments in the development of STEM skills, mathematics and science subjects in schools are still perceived by students as difficult and uninteresting, and there are even significant gender differences in these subjects (Rap 2022).

According to Landman's research (Landman 2017), junior high school and the transfer from junior high to high school represent the primary bottlenecks for high-level mathematics and STEM courses in general, particularly in the state of Israel.

Students in Israel have become less motivated to pursue advanced mathematics studies in recent years, primarily due to a lack of awareness of the advantages and practical applications of this field.

In middle school, STEM and math skills work hand in hand (English 2016, Leung 2020). Increasing the amount of time students spend studying in junior high school math classes shows how applicable mathematics is to real-world situations, and how STEM subjects are used in the workplace, help students develop their problem-solving abilities, and boost teacher satisfaction with the subject. Most importantly – it assists more students to learn STEM and advanced mathematics in high school.

Numerous studies show that a student's transition from junior high to high school is crucial. The sharp decline in the proportion of children enrolled in advanced math classes is due to the following reasons (Kearney 2016; Landman 2017):

- insufficient knowledge of STEM professions in general and the opportunities they provide for the future realization of students;
- insufficient justification of the need for the study of mathematics and natural sciences;

- lack of motivation to invest time and effort in learning mathematics and natural sciences;
- insufficient confidence from teachers in students' abilities;
- steering female students into non-science careers due to prejudice.

We can identify three factors that influence students' decisions to study these subjects at the secondary level: understanding of the importance of the subject, understanding of the effectiveness of studying these subjects for realization, and motivation to invest effort and time in learning.

2. The pedagogical idea and STEM modules

The primary hypothesis of the study is that we can positively influence students' decisions to pursue math and science by encouraging them to participate in inclusive STEM subjects that are relevant to their everyday lives in ninth grade. We can also influence students' attitudes towards these subjects, and more specifically their perception of importance, their sense of competence, and their motivation. We combined problem-based learning with the study of realistic topics based on STEM knowledge and skills to experiment. We also explored the impact of this combination of learning and engagement with these topics on student and teacher perceptions and its influence on choices for further mathematics study.

Five STEM-based modules were developed to implement the experimental learning. The modules are about realistic topics and are aligned with the learning content studied in the 9th grade (solar energy; flat screen TV; "iron drome" system; GPS; car safety systems).

The modules are about realistic topics and are aligned with the learning content studied in the 9th grade. During the development and implementation of the training modules, requirements for:

- illustrating the process of transition from science to technology (Falloon et al. 2020; Julia & Antoli 2019);
- acquiring practical experience in the laboratory or through simulation;
- integrating natural sciences;
- mathematics or other subjects from the curriculum for 9 class;
- combining knowledge from academic disciplines, general knowledge, and skills for independent learning;
- individual approach in assigning tasks to students according to their level, which guarantees their successful implementation;
- learning in small groups with a PBL approach;
- summarizing task that connects knowledge in science and mathematics with the main problem addressed in the module.

A schematic pedagogical structure is shown on fig. 1.

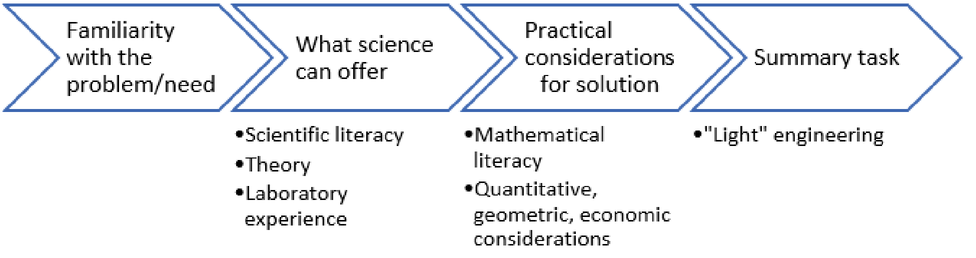

Figure 1. Schematic pedagogical structure

Three to four lessons are scheduled for each module. During instruction, children are split up into groups of two to three and given assignments to accomplish. Teachers of science, math, and language are present to assist and direct students as needed.

The mathematics and science teachers participating in the experiment underwent preliminary training to successfully apply interdisciplinary, multidisciplinary, and PBL techniques (Kelley & Knowles 2020; Brand 2020).

An example of a STEM module (see fig. 2 and fig. 3) is: FLAT SCREEN TVS: how do they work? What is color and 4K, and what does math look like on the screen?

- Opening: historical overview of the development of flat screens.
- Dimensions of screens in inches. The meaning (diagonal) and converting units to cm. Ratio 3:4 and 9:16. Finding the dimensions of the screen, length x width, and area from the diagonal and the ratio using the Pythagorean theorem.
- Pixel definition, colored pixel structure. Building a color from the 3 basic RGB colors.
- Laboratory experiment (virtual): combining primary colors in different intensities to build new colors.
- Different resolution settings HD, 4K, 8K. Meaning about the required pixel size at each screen size. And how does it compare to the separation ability of the human eye. The relationship between pixel size and viewing distance.
- Setting the primary color intensity as a number $0 - 255$. 3 numbers to represent color. Memory size required to store image.
- Image refresh rate, the diagnostic ability of the human eye. Create a video part of a sequence of images. Eadweard Muybridge's Experiment: Studies in Motion

- Calculating the size of an image file, a full-length movie in 4K resolution, and understanding the need for video compression.

A taste of the activity:

Each colored pixel consists of 3 LEDs, red, green and blue.
Each LED can be set to a different brightness. The color seen is the mixing of the colors.
The pixel appears white when all colors are at maximum intensity.
How do you think a black pixel is represented?
How do you think a red pixel will represent? green? blue?
A widget that illustrates the assembly of colors from the basic colors:
Choose RGB and play with the lights' intensities
https://phet.colorado.edu/sims/html/color-vision/latest/color-vision_en.html

Figure 2. Flat-screen TV module: the assembly of colors

- How many bytes of memory cells are required per pixel?
- How many memory cells are required to display an image in the different resolutions?

Technology name	No. of pixels on width	No. of pixels on height	Total number of pixels	Number of memory cells required for a complete image (exact calculation)	Number of memory cells required for a complete image (in abbreviated writing)
FHD (Full HD)	1920	1080			
UHD 4K (Ultra HD)	3840	2160			
8K	7680	4320			

- Why does the higher resolution image require more memory?
- Will a larger screen require more memory?

Figure 3. Flat-screen TV module: memory size calculation

During the 2022 – 2023 academic year, the study was carried out in 6 middle schools. 584 9th-grade students participated in the program, including 266 boys and 318 girls.

3. Results

Students completed motivational questionnaires before and after the intervention program (Fiorella et al. 2021). The questionnaires contained 19 questions testing 5 motivational components. We calculated the average of all responses to the questions related to the same motivational component. For some components, the standard deviation was also calculated to test the significance of the responses.

As part of the questionnaires, students also answered questions about the importance of studying mathematics before and after the intervention program. The answers to these questions were analyzed to check if there were repetitions, what they were, and how many times they were repeated in the students' answers.

As part of the evaluation of the effectiveness of the intervention program, students' motivational components for learning mathematics were examined using the questionnaires. The value scale ranges from 1 to 5, where 1 is the lowest value of the agreement and 5 is the highest value of the agreement.

We can divide the data analysis into two categories of motivation components:

1. The components related to the relevance of the studied material – the factors addressed by the intervention plan:

- intrinsic value
- utility value

2. The learner-based components – the factors that are not relevant to the intervention plan:

- test anxiety
- self-regulation
- self-efficacy

Table 1 shows the average values of the motivation components, divided into boys and girls, and subdivided into high- and low-level students in mathematics.

Table 1. Values of the motivation components before and after the intervention program, subdivided into subgroups

Population	no.	**Intrinsic value**		**Utility value**		**Test anxiety**		**Self-regulation**		**Self-efficacy**	
		B	A	B	A	B	A	B	A	B	A
All	584	3.0	3.8	3.5	3.5	3.5	3.5	3.8	4.0	3.7	3.1
Male	266	3.1	3.6	3.6	3.3	3.2	3.3	3.7	3.7	3.8	3.2
Female	318	2.9	4.1	3.5	3.7	3.8	3.7	4.0	4.2	3.6	3.1
HLA	456	3.2	3.9	3.7	3.5	3.6	3.5	3.9	4.0	3.8	3.2
HLM	213	3.2	3.7	3.6	3.4	3.2	3.4	3.7	3.7	3.8	3.4
HLF	243	3.2	4.0	3.7	3.7	3.8	3.6	4.1	4.3	3.8	3.0
LLA	128	2.5	3.6	3.3	3.4	3.5	3.3	3.7	3.9	3.3	2.9
LLM	57	2.7	3.0	3.5	3.1	3.2	3.0	3.6	3.6	3.6	2.6
LLF	71	2.3	4.4	3.1	3.8	3.7	3.8	3.7	4.2	3.1	3.3

Legend: B – before; A – after; HLA – high level all; HLM – high level male; HLF – high level female; LLA – low level all; LLM – low level male; LLF – low level female.

The components related to the relevance of the studied material – the factors addressed by the intervention plan:

- **intrinsic value:** from the data, it appears that the values of intrinsic value increased significantly in all population groups, and especially among girls. For example, scores increased from 3 to 3.8 in the general population, an increase of approximately 26%, and from 2.4 to 4.1 in the female population, an increase of approximately 70%;
- **utility value:** no significant changes were found, except in the group of girls studying at low levels, where there was a significant increase from 3.1 to 3.8, corresponding to an increase of about 23%;
- **test anxiety:** no significant changes were found;
- **self-regulation:** a slight increase was found mainly in girls and students with low learning levels;
- **self-efficacy:** a decrease was observed in all populations, except for girls studying at a low level. The results are lower, probably due to the increase in the level of studies experienced during the year and it is possible that the complexity of the STEM units also contributed to this.

To better understand the impact of the program on the intrinsic value component, which is the key component targeted by the program, a comparison was made between the mean and standard deviation before and after the intervention program in the different populations (table 2).

Table 2. Mean and standard deviation of the values of the "intrinsic value" before/after the intervention program in the segmentation by subgroups

Population	no.	**Average**		**Standard deviation**	
		before	after	before	after
all	584	3	3.8	1.2	0.9
male	266	3.1	3.6	1.2	1
female	318	2.9	4.1	1.2	0.7
high level – all	456	3.2	3.9	1.1	0.9
high level – male	213	3.2	3.7	1.1	1
high level – female	243	3.2	4	1.2	0.8
low level – all	128	2.5	3.6	1.1	0.9
low level – male	57	2.7	3	1.2	0.7
low level – female	71	2.3	4.4	1	0.6

From the analysis of the data, it is clear that the average sense of intrinsic value has increased for all, while the standard deviation has decreased, and the significance has increased. The most significant change is in the female population, where the mean score increased from 2.9 to 4.1 and the standard deviation decreased from 1.2 to 0.7. When girls are divided into subgroups, it can be seen that girls studying at a high level increased from 3.2 to 4, while the standard deviation decreased from 1.2 to 0.8, and girls studying at a low level increased from 2.3 to 4.4, while the standard deviation decreased from 1 to 0.6.

From the analysis of these data, it is clear that the intervention program increases the sense of intrinsic value of studying mathematics while decreasing the differences between students' feelings.

The results of the studied indicators by groups are presented in the fig. 4 – 6.

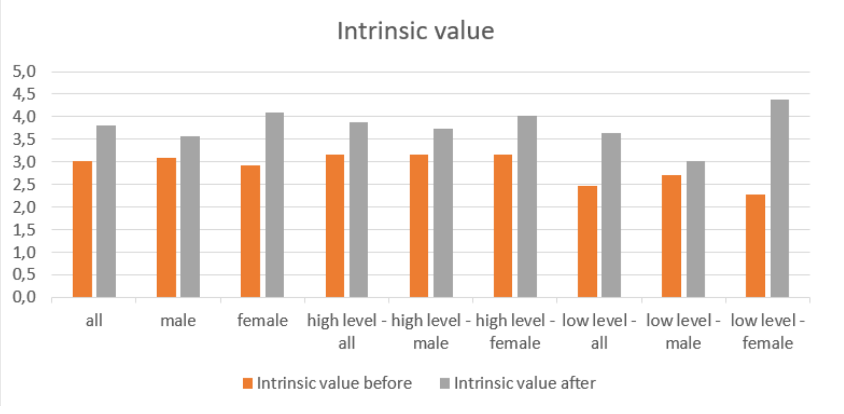

Figure 4. "Intrinsic value" values before/after the intervention program in the segmentation by subgroups

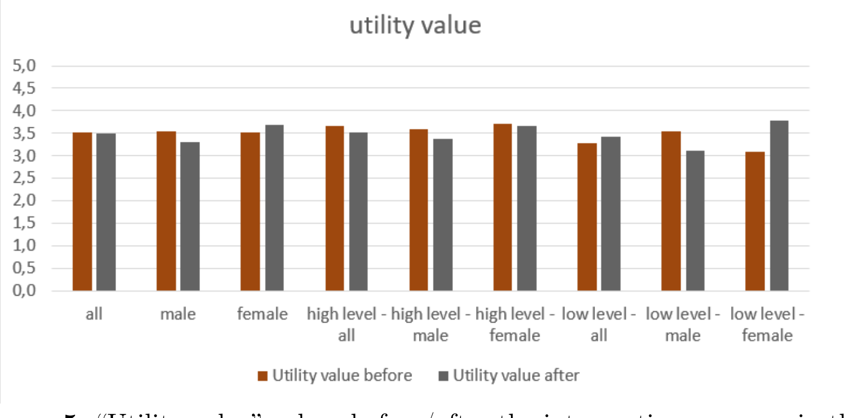

Figure 5. "Utility value" values before/after the intervention program in the segmentation by subgroups

Students were asked an open-ended question, "Why do you think it is important to study mathematics?". We conducted a thematic analysis of responses to this question among students who indicated before and after the intervention program that studying mathematics was important to one degree or another.

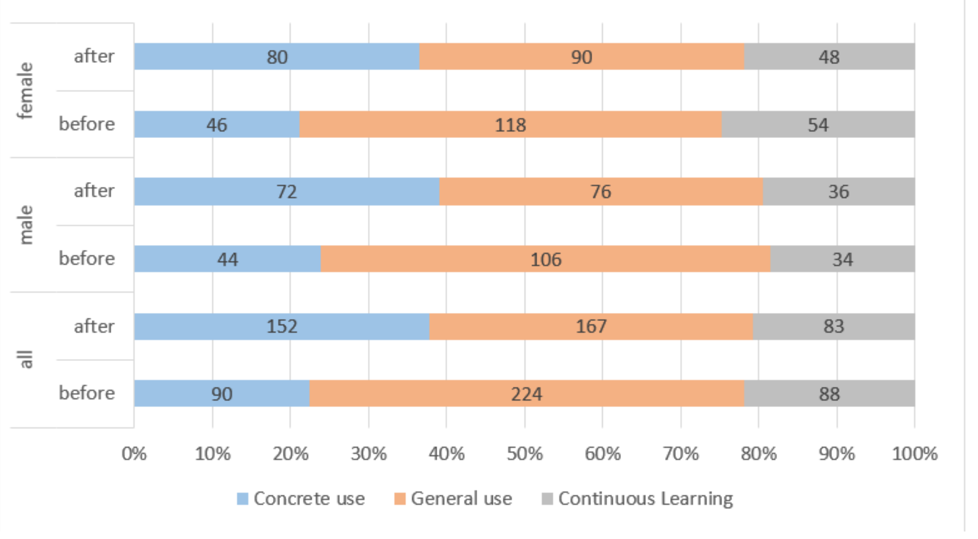

Figure 6. Students' stated reasons for the importance of studying mathematics by cluster, before and after the program, broken down by gender

From the analysis of these data, it can be concluded that the intervention program increases the motivational components related to the relevance of the subject matter.

4. Conclusion

The study aimed to verify whether the integration of STEM lessons during ninth-grade mathematics classes can increase students' motivation to study mathematics by increasing their sense of the value and usefulness of the subject.

Analysis of the results shows that the motivational components related to self-esteem and usefulness of mathematics instruction increased significantly. Self-esteem increased by 26% for the general population and 70% for girls. The sense of usefulness increased by 23% among girls studying at a low level.

The increase in self-esteem in studying mathematics is significant, both in terms of increasing the mean score and decreasing the dispersion, and it is seen in all subgroups of the study, i.e., boys and girls, low-level learners, and high-level learners.

Students' reasons for studying mathematics evolved following the program from general statements such as "it will help in life" to more concrete statements such as "mathematics is useful in daily life". This phenomenon is also observed in all subgroups of the study.

In conclusion, it is quite clear that the program is achieving its goals, strengthening students' sense of the value of studying mathematics in 9th grade, and thus helping to increase their motivation to study mathematics.

When students realized that math is not just solving known exercises, and math careers are not just math teachers, but math is the language of high-tech life, their motivation to learn and endeavor in math learning is growing.

It is worthwhile to develop more STEM units of this type, and it is important to also choose topics that teenage girls care about to further strengthen their sense of relevance.

Appendix A. Students' periodic questionnaire:

No.	Dimension	Question	N 1	R 2	S 3	U 4	A 5
1	*Intrinsic value*	I enjoy learning math					
2	*Test anxiety*	I am nervous about how I will do on the math tests					
3	*Self-regulation*	If I am having trouble learning the math, I try to figure out why					
4	*Test anxiety*	I become anxious when it is time to take a math test					
5	*Self-regulation*	I put enough effort into learning the math					
6	*Self-regulation*	I use strategies that ensure I learn math well					
7	*Utility value*	I think about how learning math can help me get a good job					
8	*Utility value*	I think about how the math I learn will be helpful to me					
9	*Test anxiety*	I worry about failing math tests					
10	*Test anxiety*	I am concerned that the other students are better at math					
11	*Utility value*	I think about how learning math can help my career					
12	*Utility value*	I think about how I will use the math I learn					
13	*Self-efficacy*	I am confident I will do well on math assignments and projects					
14	*Intrinsic value*	I find learning math interesting					
15	*Self-efficacy*	I believe I can master the knowledge and skills in the math course					
16	*Self-regulation*	I prepare well for math tests and quizzes					
17	*Intrinsic value*	I like math that challenges me					
18	*Self-efficacy*	I am confident I will do well on math tests					
19	*Self-efficacy*	I believe I can earn a grade of "A" in the math course					

Legend: N – never; R – rarely; S – sometimes; U – usually; A – always.

Appendix B. Students' periodic interview:
1. Is it important to study mathematics? Please detail and explain.
2. Is it important to study science? Please detail and explain.
3. Can I succeed in studying mathematics? Please detail and explain.
4. Can I succeed in studying science? Please detail and explain.

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