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USING THE RASPBERRY Pi MICROCOMPUTERS IN STEM EDUCATION IN TECHNICALLY ORIENTED HIGH SCHOOLS

Abstract: The article deals with learning using the project-based method in STEM education. The article describes the use of ICT technologies, specifically Raspberry Pi microcomputers in bending experiment. The bending experiment was designed for students of technically oriented high schools. Pedagogical research was conducted to determine whether the knowledge and skills of students who have been educated by the project-based method in STEM education are more complex, more systematic and more permanent than the knowledge and skills of students taught by standard forms of teaching. The article presents the results of pedagogical research, which lasted for three years. The results confirm that project-based learning and using ICT in STEM education developed complex knowledge and skills in STEM education. Comprehensive knowledge and problem-solving skills are important for the sustainable development of technological education.

Keywords: STEM education, project-based learning, bending experiment, Raspberry Pi, pedagogical research

Introduction

At present, it is necessary to prepare students with a certain vision of the future, however, given that we do not know exactly where society will go, and even the whole world, it is necessary for students to learn to think comprehensively and connect elements of the mosaic as a whole. So, their skills will be better, and their ability to solve problems will increase. An important element of education is the combination of knowledge from natural sciences, mathematics, information technology and engineering sciences, and these disciplines should be meaningfully combined, so that the student or graduate can use their knowledge in practice. The education supporting above mentioned is based STEM education (Science, Technology, Engineering, and Mathematics). Many authors define STEM teaching using the definition we quote here: "STEM education is an interdisciplinary approach to learning where rigorous academic concepts are coupled with real-world lessons as students apply science, technology, engineering, and mathematics in contexts that make connections between school, community, work, and the global enterprise enabling the development of STEM literacy and with it the ability to compete in the new economy" [1]. At present, a number of authors deal with the issue of STEM teaching (see for example [2-11]), which applies various approaches both from the

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point of view of research and from the point of view of the application of STEM teaching in pedagogical practice.

If we return to the abbreviation STEM we will see that letter S which means, which includes not only physics but also chemistry and, more broadly, biology and ecology. At the same time, we can say that while the problems of teaching physics are strongly intertwined with the teaching of mechanics and electrical engineering, the issue of teaching chemistry is intertwined with the teaching of materials sciences. These subjects are also of interest to the study of many subject didactics. These subject didactics address a whole range of issues from school experiments and textbooks to the classroom climate [12-14]. Given the current problems of environmental pollution and the need to achieve emission reductions, it is also desirable to link STEM teaching with ecology and environmental protection teaching. This issue is again significantly related to the teaching of chemistry [15-17].

In Czech Republic existed many of technically oriented high schools, whose curriculum is devoted to mechanical engineering or electrical engineering (Czech name for this high-schools is ”Stredni prumyslova skola“). According to the classification based on terminology used in the Bologna Process documents, these are schools corresponding to higher secondary schools.

This type of school is attended by students for four years. Students start attending this type of school at the age of fifteen. Nowadays more and more high schools implement to their curriculum modern interdisciplinary oriented disciplines such as mechatronics.

However, learning at these schools is still based on traditional approaches. It should also be emphasised that even in the case of teaching interdisciplinary subjects (such as mechatronics), teachers use classical learning methods and do not combine knowledge from different subjects effectively.

The typical composition of the school’s subjects focused in technically oriented high school is shown in Table 1. This table was compiled on the basis of an analysis of accreditation materials, class books and school yearbooks of individual technical secondary schools operating in the Czech Republic in the period 1971 to 2020. The number of hours listed in the table may vary slightly from school to school, as these are the most common hourly allowances for individual subjects. The content of some technical subjects may also vary from school to school, which is often due to the fact that a school cooperates with one of the local companies. This cooperation between individual schools and local employers was particularly strong in the 1970s and 1980s. The subjects most significantly affected by the school-employer interaction are included in the table under the name of engineering.

In the table, we have compared the situation in 1971, 1992, 2005 and 2018. The subject’s structure corresponds to the learning realised from the 1990 to the present. This curriculum is still modified from sixties of twenty century. Prior 1990 no computer sciences were learned at the high school. However, this does not mean that they cannot get acquainted with computer technology at any high school. At some electrical engineering high schools, students were able to become acquainted with the first computers in laboratory classes dedicated to low-current electronics. Most often, however, young people were able to get acquainted with computer technology within the activities organised by the so-called “houses of science and technology” within the hobby activities. Two types of computers were developed and manufactured in Czechoslovakia for educational purposes. One of them was the IQ-151, which made it possible to work with the BASIC programming language. About two thousand, of these computers out of the four thousand originally ordered were delivered to schools. This computer has been used mainly in universities. The second computer that was used for teaching was PMI-80, a single-board microcomputer produced by Tesla Piestany [18-20].

From 1991 information technology and computer science subject are introduced to learning at high school education, but on the contrary, the donation of science and technology subjects (physics, mechanics, engineering, technical drawing, geometry) decreases (Table 1).

In this table we can see changes in time allocations of individual subjects in the study program of a high school focused on mechanical engineering. When we talk about the structure of subjects taught at this type of high schools, it is necessary to realize that the student encounters computer technology in several areas:

a) informatics as part of general education,
b) computer technology as a tool used in design - CAD programs,
c) preparation of students for operating CNC machines,
d) robotics and automation.

The following subjects correspond to these areas of study in Table 1: Computer science and informatics; Robotics and automation; CAD design; CNC machinery.

Table 1
The typical composition of the school's subjects focused in technically oriented high school - curriculum based on mechanical engineering

	1971				**1992**				**2005**				**2018**			
Grade	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Subject																
Mother tongue	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Mathematics	4	4	4	4	4	4	3	3	4	4	3	3	3	3	2	2
Foreign language	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Physics	2	2			2	2			2	1			2			
Chemistry	2				2				1				1			
Social science	1	1			1	1			1	1			1	1		
Mechanics	3	3	3		2	2	2		2	2	2		2	2		
Engineering		2	3	3		2	2	2		2	2	2	2	2		
Machine design					3			2	2			2			2	2
Metrology and measurement			2	2				3		2	2				2	
Mechanical technology	3	3	4	4	4	4	4	4	4	4	3	3	3	3	3	3
Technical drawing	3	2			4	2			3				1			
CAD design								4		2	2	2	1	2		
Descriptive geometry	3	2				2										
Electrotechnics		2	2			2	2			2	2			2	2	
Robotics and automation							2	3			2	2			5	4
Computer science and informatics						2	2		2	2	2	3	3	3	3	3
Workshop practice	3	3	6	6	3	3	3		3	2			2	2		
CNC machinery							1				3	3		3	3	3
Economics					2			1	1		2	2		2	2	2
Total time donation	28	28	28	28	26	30	28	27	26	28	29	26	25	29	28	23

We will now look at a pair of closely related subjects in the Table 1, these subjects are ”Technical Drawing” and ”CAD Design”. We used these two names to distinguish lessons in which students learn to draw technical drawings by hand on paper and lessons in which students learn to create technical documentation using a CAD program. In fact, we would usually find only a subject called ”technical graphics” in the curricula at present, which includes both of these terms. In the past, the subject was usually referred to as technical drawing, and students worked with a pen and ink and drew drawings on paper. The relevant subject with this name was and still is taught in the first two years of study. Skills obtained in lessons of ”Technical drawing” are intensively used and further developed in practical exercise connected with subjects such as ”machine parts” or ”construction and operation of machines”, the theoretical part of these subjects is referred to in the table as ”engineering”. As we can see in the table, in the 90s of the twentieth century, students became acquainted with CAD or computer-aided design only at the end of their studies. Here it would be appropriate to say that the work on technical drawings and design of machine sets has always represented the majority of homework of students of schools with engineering focus. We are all the more surprised by the fact, that donation of the subjects of technical graphics and CAD design is also decreasing in the curriculum.

Materials and methods

Learning of mechanics at technically oriented high school

Students at high school are already familiar with the most basic form of the Hooke’s law. Mostly it is in the 1st grade (technical high school with curriculum oriented on mechanical engineering) or the 2nd grade (in the case of curriculum based electrotechnics). First, students are only familiar with the basic form of this law for the tensional loading. Further, the high school curriculum differs strongly according to the school orientation. Technically oriented schools, especially schools focused on mechanical engineering place considerable emphasis at the learning of mechanics. At these schools, mechanics is taught as a separate subject for two and mostly three grades. The students will learn about process of deformation in the elastic area, meaning of concepts such as yield stress, ultimate stress and Young’s modulus E. The students are learned to solve simple tasks such as beam deflection in these different cases: cantilever beam, beam simply supported at ends, these beams are under load of both concentrated load and uniformly distributed load or load distributed by some function (most often linear). Course of mechanics is in all these cases reasonably supplied by practical learning in the laboratory. The demonstration experiments have great impact on the students. Many school labs have a tension testing machine available or are able to perform other tests of mechanical properties of materials [21-26]. These devices are ideal to demonstrate Hooke’s law, i.e. linear growth of deformation to the yield value σ_Y and the ultimate strength σ_U. Other experiments are possible realized with much professional equipment. Despite this fact, they are often neglected in learning. Such experiments are described in this paper, in the following paragraph

Project-based method of learning

The most frequently implemented elasticity experiment at technically oriented high schools is tension experiment. In the following the student’s project aimed at determining the modulus of elasticity from the bending experiment will be shown. The student’s project is based on project-based method of learning [27-31]. This experiment was designed by university students - prospective teachers, of study program teaching of technical subjects for basic course of mechanics and robotics. These students have their praxis teachers at technical high school (higher secondary school with curriculum based on mechanical engineering) and they prepared this experiment as projects for students of the second grade.

Mechanics and theory of elasticity

Theory of the tension experiment

The experimental sample (flat bar or beam) is loaded by tensional forces to the final rupture. The acting forces are relatively high and testing device requires strong reliable frame. The experiment is mostly performed to final rupture of the sample. The experiment is based on simple formula [32]:

$$\varepsilon = \frac{\sigma}{\mathrm{E}} = \frac{F_T}{S \cdot \mathrm{E}} \tag{1}$$

where: F_T is tensile force which cause elongation of the beam, S is cross section, E is modulus of elasticity, σ is tensile stress and ε is relative elongation defined as ratio between increments of length ΔL and original length L_0 of sample - see Figure 1:

$$\varepsilon = \frac{\Delta L}{L_0} \tag{2}$$

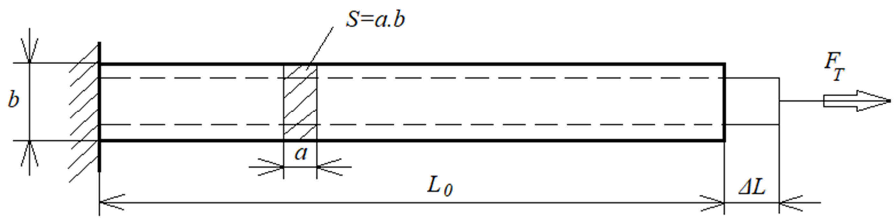

Fig. 1. The tension experiment: L_0 - initial length of beam, ΔL - length increment of the beam, S - cross-section of the beam, F_T - loading force

The value ΔL can be measured using a sensor controlled by a microcomputer.

The elasticity modulus E can be easily calculated from Equations (1) and (2):

$$\mathrm{E} = \frac{F_T \cdot L_0}{S \cdot \Delta L} \tag{3}$$

While the machines used for tensile experiment used in technical laboratories often work with hydraulics, in a school experiment we derive the tension force using weights. Tensile force F_T will be now:

$$F_T = m \cdot \mathrm{g} \tag{4}$$

where m is mass of weight and g gravitational acceleration. Due to the fact that in this way the students will not be able to derive the forces needed to significantly stretch the metal samples, the experiment should be performed on a plastic rod.

Main disadvantage of this experiment is fact, that it is necessary to measure considerably long samples (about two meters and more), because the extension must be detectable by standard sensors.

Theory of the bending experiment

Although the bending experiment is more complicated mathematically than tension experiment, the advantage of this experiment is that the bending can be easily measured by standard sensors with standard bending force caused by ordinary weight. The bending experiment enables measurement of the Young's modulus E for metal's sample.

Figure 2 shows beam supported at ends. This beam is loaded by the force located right in the middle. When the beam is loaded by bending force, it bends. Students can easily observe the decrease of the middle part of the beam. This sag we will call deflection of the beam.

The deflection ΔY can be calculated by equation [33]:

$$\Delta Y = \frac{F_B \cdot L^3}{48 \cdot \mathrm{E} \cdot I} \tag{5}$$

where ΔY is deflection, L is length of beam (respectively distance between supports) and I is the cross-section moment of inertia (this quantity is also called the second moment of area).

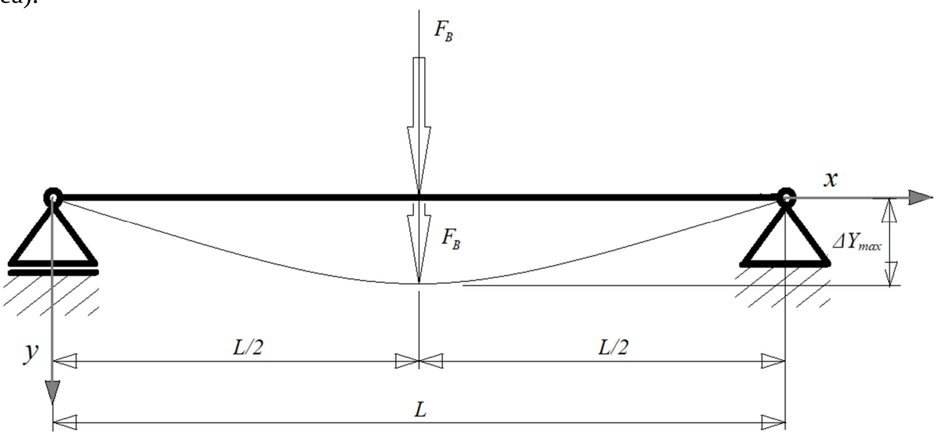

Fig. 2. The bending experiment: L - initial length of beam, ΔY_{max} - maximal deflection (sag of the beam), F_B - bending force

For teaching purposes, it is best to use a bar of rectangular cross-section with side length a and b. In this example, we can best explain to students the physical significance of the cross-sectional moment of inertia. Both sides of the cross-section are significantly different, b is much smaller than a. Such a bar bends slightly if the loading force is perpendicular to side with length a. The deflection is thus easily visible and measurable. Conversely, if the loading force acts perpendicular to side b, the deflection is not observable. In this way, the teacher can easily explain to students the meaning of the power in the formula for the cross-sectional modulus of inertia [33]:

$$I = \frac{a \cdot b^3}{12} \tag{6}$$

By comparing the Equation (6) and observing the experiment, the students clearly deduce that the resistance that the bar puts to the bending force increases with increasing thickness of the amplified side. In the same way we can then explain the meaning of k the resistance moment W.

The Young's modulus E can be calculated from Equation (5) and (6):

$$\mathrm{E} = \frac{F_B \cdot L^3}{4 \cdot \Delta L \cdot a \cdot b^3}. \tag{7}$$

The bending force is again induced by the weights:

$$F_B = m \cdot \mathrm{g} \tag{8}$$

Generally, the deflection can be measured not only in the centre of the beam, but also in other points of the beam. Moreover, the bending force can be applied even in any point of the beam. The situation is shown in Figure 3. The value of y is then the general deflection at a point in the distance x from the support, which we have already selected as the origin of the coordinate system.

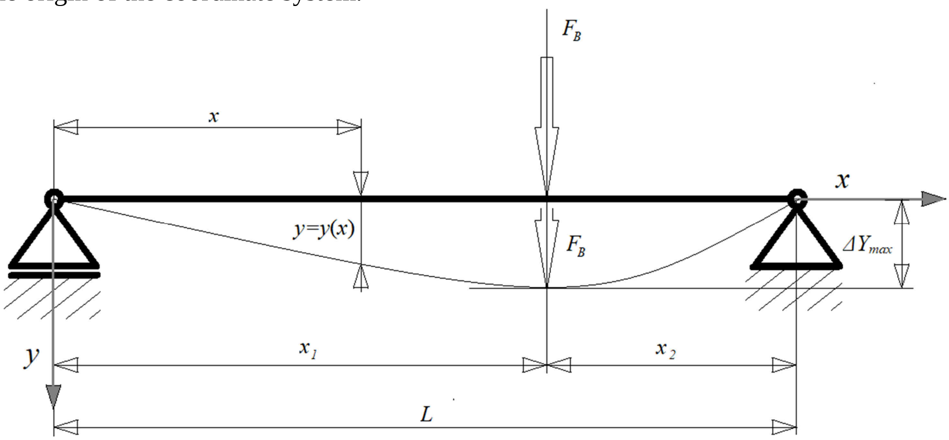

Fig. 3. The uncentred bending experiment: L - initial length of beam, ΔY_{max} - maximal deflection, F_B - bending force, x - point of deflection measurement, y - measured deflection at distance x from the beginning of the coordinate system, x_1 - point of bending force acting

In this case, the deflection can be determined using differential equation [37]:

$$F_B = \frac{d^2 y(x)}{dx^2} = \frac{F_B(x) \cdot x}{E(x) \cdot I(x)} \tag{9}$$

It is clear, that the equation (9) is too complicated to be solved by high-school students. Despite this fact, the general deflection of the beam is discussed in high school. Generally, students receive a list of basic solutions - typically in a table, with a sketch of these specific beams. Then, students simply substitute numerical values into formulas. Some teachers require knowledge of these tables by heart. Which, in general, cannot be considered as suitable method for learning and knowledge testing. In this case, students have this knowledge stored only in short-term memory and there will be no actual acquisition of the curriculum.

Automation of experiments

Raspberry Pi microcomputers

Recently a number of inexpensive learning platforms have emerged in the world, such as Raspberry Pi. Raspberry Pi is particularly widespread, and its advantage is modular character. The name is used for both, opensource software and hardware developed by Raspberry Pi Foundation [34-41]. There is a whole range of Raspberry Pi microcontrollers and microcontroller kits.

These microcontrollers differ in performance and other parameters, as well as in use. These single-board microcontrollers for building digital devices and interactive objects can control small robots or different type of mechanism based on stepper motors and the sensors for measurement of physical quantities. These tools are most often known due to their use on various walking robots. However, all these sensors can be effectively utilised in the school laboratory in physics.

The Raspberry Pi was especially developed for education. One advantage for educational exploitation of Raspberry Pi is the fact, that hardware components are mostly cheap. So cheap, that it is possible to be used by students at home.

The Raspberry Pi used number different of measurement devices and detectors not only to determine basic electrical quantities such electric-current or voltage, but also more sophisticated measurement sensors such as ultrasonic ranging detector for non-contact measurement and obstacles detection. There are also different types motion sensors and two or triple axis accelerometers [42, 43]. Also, sensors for measurement humidity and temperature of environment are available. The operating system used by Raspberry Pi is Raspberry Pi OS its older versions were called Raspbian. This operating system is based on Debian 32-bit. However, other OS are also commonly used. Main programing languages for Raspberry are Python and Scratch. It should be noted here that Scratch is often used to teach the basics of algorithms not only in high schools but even in primary schools.

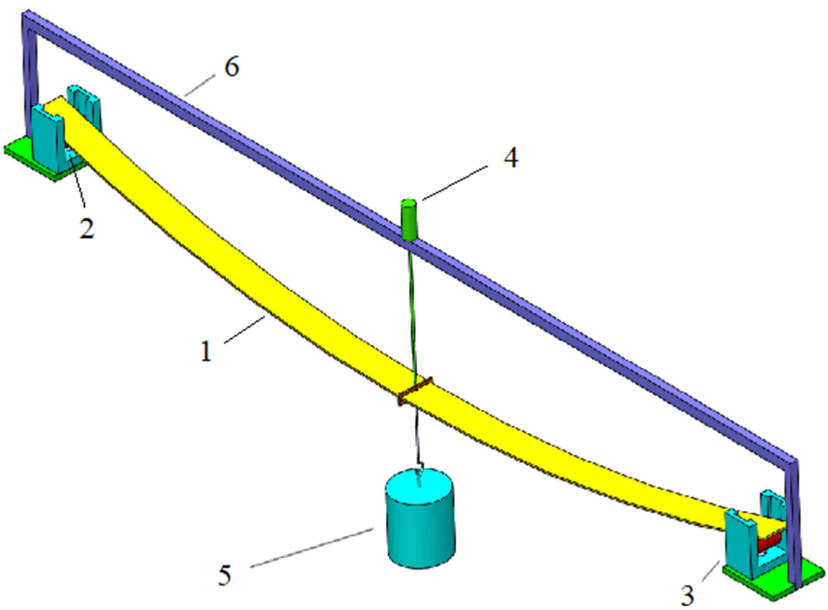

Fig. 4. The 3D model of testing device with multiple pieces of sensor (the other sensors in the line are drawn in a thin line): 1 - sample beam, 2 - movable support, 3 - fixed support, 4 - sensor, 5 - weight, 6 - frame

Bending experiment based on Raspberry Pi microcomputers

The experimental device consists of a frame on which the support of the gauge is placed. The loading and hence the deflection rate are controlled manually. The easiest way to achieve a certain load on the beam is to hang the weight on the beam. The deviation value is then also deducted manually.

However, the whole process of the measurement can be automated. First, the deflection can be measured by a position sensor that communicate with the computer.

If relatively large deflection is measured, ultrasonic sensor can be used for measurement. The sensor is placed on the frame above the bent beam. The sensor transmits information to the microcomputer information about the drop of the beam underneath (Fig. 4).

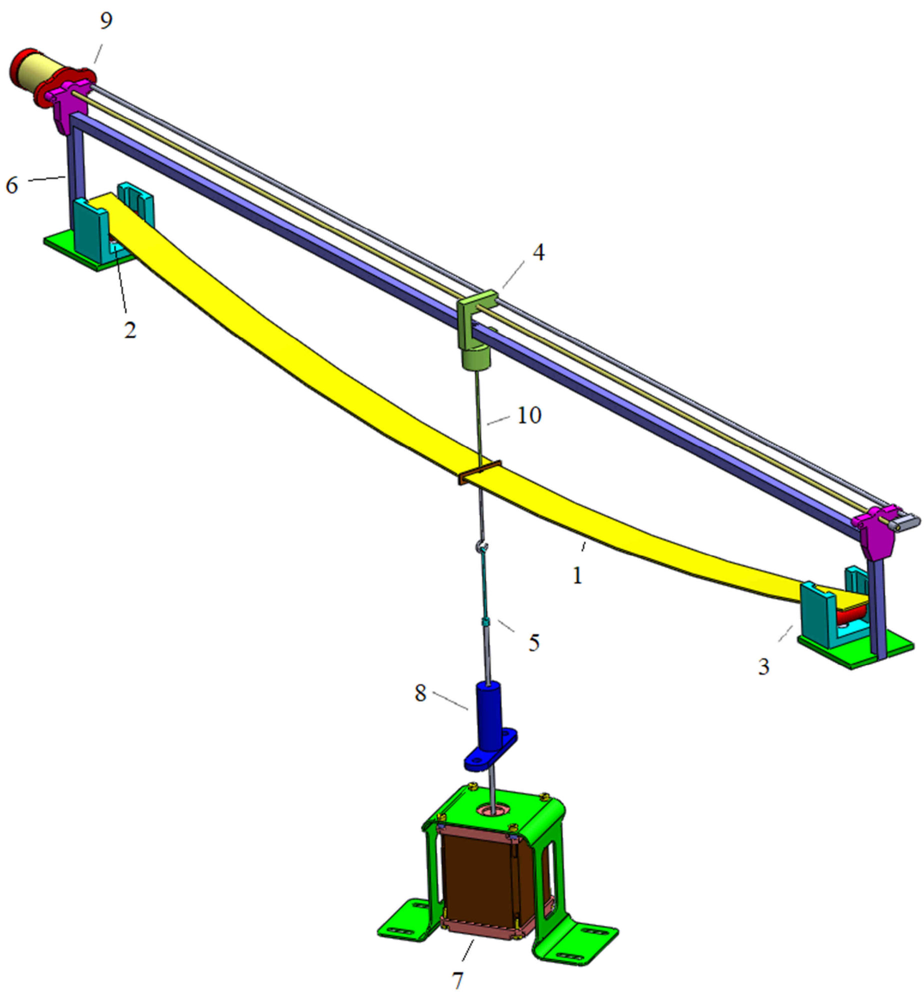

Fig. 5. The 3D model of testing device with movable sensor and loading mechanism: 1 - sample beam, 2 - movable support, 3 - fixed support, 4 - y-axis feed sensor, 5 - loading mechanism, 6 - frame, 7 - stepper motor, 8 - ball screw, 9 - position sensor in the direction of x-axis, 10 - upper hinge

The elastic modulus can be calculated from the deflection even if the deflection is not measured in the centre of the beam as well as the bending force is not acting in the centre of the beam, see Equation (9). It would be advisable, if the device will be able to measure the deflection for more than one point on the entire length of beam. The simplest experimental solution is to place multiple sensors on the frame.

The other experimental solution is placed the sensor on the movable platform and scan the surface with it. The movement can be secured by ball screw or trapezoidal screw and stepper motor. These elements can be obtained as accessories for robotic kit. The measurement assembly with movable sensor is shown in Figure 5. The loading process can be automatized. The bending force can be measured by electronic force-meter.

Pedagogical research

Research question

Within the research the answer to research question was found out. The research question is: "Are knowledge and skills of students who have been educated by the project-based method in STEM education more complex, more systematic and more permanent than the knowledge and skills of students taught by standard forms of teaching?"

Research methodology

The research was conducted in the years 2017-2019. The research was carried out in technical high schools (high schools with specialisation in mechanical engineering) within three years research project.

Experimental group (EG) of students were taught for three years in this way:

- about 40 % of working time was taught in learning blocks of 5-6 hours devoted to work on the projects - project-based method in STEM education;
- remaining time was devoted to standard form of lessons in classes based on the teacher's interpretation, as well as on individual work of students consisting of counting examples, etc.

Control group (CG) of students was taught by standard form of learning for three years.

The knowledge and skills of students was monitored:

1. after the first year of the study,
2. after the third year of the (at the end of the project).

Testing covered all areas of STEM education, i.e.:

1. Science - knowledge and skills from mechanics and physics;
2. Technology - skills i.e. in programming, robotics, mechanical technology;
3. Engineering - design of mechanical parts, application of sensors for measurement;
4. Mathematics - i.e. application of mathematics for numerical problem solving.

Results

The answers to the research questions were found out by pedagogical research. Students were divided to two groups:

- Experimental group of students (EG), 63 students of technically high schools;
- Control group of students (CG), 57 students of technically high schools.

The research was carried out in technical high schools within three years research project detailed described in paragraph ”Pedagogical Research”.

The results of the research are shown in Tables 2 and 3. Subjects tested in these two tables corresponds to the testing in areas listened in previous paragraph. Student testing was based on an in-depth assessment of students’ skills and knowledge. Thus, students were not only tested for their ability to solve typical problems characteristic of school written work, which is a typical basic limitation of classical classification and testing of students in school practice. Nor was it a simple testing of so-called study prerequisites. Students were partially evaluated on the basis of their ability to solve larger tasks corresponding to the tasks that graduates of technical schools have to solve in practice. Such tasks are interdisciplinary in nature. In solving such tasks, the student must be able to effectively use knowledge from various fields. The skills and knowledge of the students were therefore evaluated from several perspectives, so that the researchers gained the widest possible overview of the achieved abilities, skills and knowledge of the students.

The scale of testing is from value 1 to value 10, where 10 is the best. The Table 2 shows research results after the first year of project education. The Table 3 shows research results after the third year of project education (end of the project).

Table 2

Research results after the first year of project education

Type of test	**Mechanics/ Physics**		**Mathematics**		**Programming/ Robotics**		**Mechanical technology/ Engineering**	
Group	EG	CG	EG	CG	EG	CG	EG	CG
Test with choice of answers from areas	7.5	7.6	7.2	8.0	7.2	6.5	8.3	5.6
Test of solution of the examples from student’s textbook from areas	7.5	7.9	5.5	8.3			7.2	6.5
Test of script writing	7.2	4.2			8.3	6.3	8.1	5.5
Test of numerical solution of bending experiment in simulation tool	6.3	2.5					6.3	4.2
Solution of the small projects	8.2	3.2	7.2	5.3	9.1	7.2	8.2	5.8

The average values of testing values after the first year are:

- average of all testing values:
  - experimental group: 7.5
  - control group: 5.9
- average of the last row (solution of the small projects):
  - experimental group: 8.2
  - control group: 5.4

The average values of testing values after the third year are:

- average of all testing values:
  - experimental group: 7.2
  - control group: 5.6

- average of the last row (solution of the small projects):
  experimental group: 7.7
  control group: 4.8

Table 3

Research results after the first year of project education

Type of test	Mechanics/ Physics		Mathematics		Programming/ Robotics		Mechanical technology/ Engineering	
Group	EG	CG	EG	CG	EG	CG	EG	CG
Test with choice of answers from areas	7.4	7.2	7.2	7.9	7.0	5.7	8.3	5.1
Test of solution of the examples from student's textbook from areas	7.6	7.2	5.6	8.2			7.4	6.5
Test of script writing	6.4	3.5			8.0	6.4	7.4	5.8
Test of numerical solution of bending experiment in simulation tool	5.7	2.0					6.7	4.2
Solution of the small projects	7.5	3.2	7.1	4.7	8.5	5.9	7.7	5.5

Discussion

The project-based method in STEM education as well as multiple test methods used for testing of students were presented in the paper. The multiple testing enables covering more aspects of students' knowledge and skills. Even better, it is not enough to use only one test method. It should be noted that teachers use only one formal test very often. It should be noted that teachers often prepare students for school tests, not for solving real problems. And this obviously leads to erroneous conclusions in the application of teaching methods as well as to mistakes in principles of education.

The research survey compared the project-based method in STEM education with standard from of STEM education. The results of the survey show fact that students' results of the control group (group of students that was taught by standard form of lessons for three years) are better in activities requiring routine repetitive operations or memory knowledge of the facts. This is especially true when solving examples from mathematics and mechanics (test of solution of the examples from student's textbook). On the contrary, students of the experimental group (group of students that was taught by project-based method in STEM education) achieved better results in the areas of script writing and in solving small projects, where "logical" thinking, a comprehensive and systematic approach to problem solving and the ability to work independently are required.

The research survey confirms that small engineering projects and are important as it cover development of knowledge and skills of students from several areas. In addition, the student's abilities and skills are developed to indicate a problem and to create a proposal for the overall solution.

The results of presented research survey, in particular the results of testing students after three years, confirmed that knowledge and skills of students who have been educated by the project-based method in STEM education more complex, more systematic and more permanent than the knowledge and skills of students taught by standard forms of teaching.

The self-regulation of the educational process is performed in the case of project-based method in STEM education as well as in other alternative methods. The self-regulation affects speed of learning and determination of both short-term goals as well as ultimate goals for individual students and also small groups. One of the positive consequences of self-regulation is the fact that a student who is slower in achieving goals is behind other students in a certain area, but he does not have significant gaps in the logical structure of consecutive knowledge and skills. During the further educational process, the students is able to at least partially replace these shortcomings. In the case of classical teaching methods, the deficit of skills and knowledge, combined with the student's inability to quickly follow up on continuing teaching (or new information), lead to a rapid increase in student demotivation. This demotivation is then one of the most significant factors in the final failure of students. Self-regulation is effectively applied in teaching from primary school pupils to university students. Of course, self-regulation can also be applied in more conservative teaching.

The issue of self-regulation and its many other impacts on the educational process in the case of project-based science education in STEM education is discussed in a number of papers such as [44-49]. An recently published article „Scientific Performance and Mapping of the Term STEM in Education on the Web of Science" [45] provides interesting summary of work devoted to self-regulation in teaching. It can be said that the results of the research survey published in this article confirm that the knowledge about process of self-regulation is in accordance with the knowledge of the already mentioned authors. Although it must be said that the aim of this work was not a deeper study of the influence of self-regulation in the educational process.

A very important issue in the teaching and learning is sustainability of the educational process. The sustainability of the STEM education has not yet been sufficiently mapped in the literature, as the paper cited above shows [50]. On the other hand, it can be said that the result of the students testing after three-year long period presented in this paper confirm that the project-based method in STEM education has a high degree of sustainability. Our results correlate, for example, with [51, 52].

Students, after finishing their high studies will either continue their studies at university or will go into practice. In both cases, they must be able to work independently and think and solve problems, which is the only sustainability of technological development and adaptation to constantly changing conditions - and this can only be achieved by combined teaching method described in this article. The skills and ability to solve problems enable graduates to adapt and face new challenges.

Conclusion

Over the last 30 years, there has been a significant decrease in the number of teaching hours devoted to lessons of mathematics, physics and mechanics at secondary technical schools at the expense of hours devoted to computer science, programming and robotics. Although the introduction of the teaching of these new subjects was necessary and knowledge in the field of information technology is absolutely necessary for graduates today, it should be borne in mind that a decline in knowledge in mathematics, physics and other sciences is undesirable for high school graduates. This problem cannot be solved by simply increasing the teaching hours, because it is also necessary to pay attention to the mental hygiene of students, who cannot be overburdened. For this reason, it is necessary to appropriately link the individual subjects and to acquaint and practice the required subject in other subjects than those in which it was taught. The concept of STEM teaching here provides us with the opportunity to expand the knowledge and skills of students in the work on a wide range of technical projects. The student acquires knowledge of programming, mathematics and mechanics in a single project. One of such projects was described in this article and at the same time the positive effect of teaching conceived in this way was confirmed. The research included two groups, with a group of students who devoted 60 % of their time to classical teaching and 40 % of their time working on interdisciplinary projects achieving slightly better results than students from the control group whose teaching was organized in a conventional manner. Differences in student outcomes in both groups may seem insignificant in some cases, see Table 3, but a very important factor from a practical point of view is the sustainability of skills and work habits, together with the fact that students are well aware of the interdisciplinary nature of technical issues. The results presented in this article correlate well with the conclusions presented in the article written by Rodríguez-García et al. [51] or Mendes et al. [52]. It is important that the skills acquired in this way enable school graduates to adapt well both at work and in further study.

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