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The implementation of STE(A)M education through Scratch projects

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Abstract. The present research is motivated by the necessity of introducing modern methodologies corresponding to the study's content into the educational process. The work aims to use Scratch projects for the organization of students' educational activities, as well as for their creative self-realization. Authors realize STE(A)M-approach in the educational activity by facilities of Scratch-projects. The high-level block-based visual programming language could be an auxiliary technology for a teacher and an independent developing tool for students. The research revealed the main themes that became the basis for the development of the author's course "Creative Self-Fulfilment in Scratch". This contributes to the development of students' creativity. The content of the course is extended with projects in algebra, geometry, physics and musical culture. Each of these projects demonstrates the unity of technology and creativity.

Dedicated to the memory of Professor Yurii Ramskyi

1. Introduction and problem statement

Is the inventor a vocation, talent, or hard work? Many our students construct robots, work with artificial intelligence, and demonstrate that everybody can become an inventor in the modern world! Development of such intellectual potential is simply only possible with material support and educational reforms (the project integrated studies approach). The importance of this is based on the fact that human activities in various spheres are often based on planning. The skills of independent getting of knowledge, systematization, the knowledge about orientation in informative space, and the ability to catch a problem and decide all become exactly through the project realization. It is efficient to use this method to construct individual education plans for every future specialist. This improves the quality of studies and moves the development of educational technologies forward, primarily related to the STE(A)M technology [1].

STEM education is one of the essential areas of the educational reform of the XXI century. Modern initiatives in the field of STEM require the development of a model for transforming

education that corresponds to the contemporary demands of society. There is a need to transform the existing model of training, first of all, pedagogical staff from classical education to innovative STEM education [2, 3]. Institutions and scholars are searching for new approaches to prepare people for solving real problems of the surrounding world through different STEM approaches in education [4–6].

It is known that STE(A)M is the modern approach to studies that combines natural sciences, technologies, engineering, art, and mathematics. These industries are "professions of the future" that are similarly named. A perspective of STE(A)M education is the development of the talent of students and the stimulation of the appearance of new ideas and skills. It helps them to adapt themselves to the modern world. For the successful realization of an STE(A)M project, such terms are needed:

- presence of a meaningful problem in a creative, research plan;
- clear raising of key and thematic questions;
- practical meaningfulness of the expected results;
- unassisted work of participants;
- structuring of substantial content of part of a project (stages, tasks, distribution of roles, and others like that);
- use of research methods;
- application of computer technologies.

2. Apparatus criticus

The present research is motivated by the necessity of introducing modern methodologies corresponding to the study's content into the educational process.

The aim of this work is the use of Scratch projects for the organization of students' educational activities and their creative self-realization.

Achievement of the goal of the research is possible through the decision of such tasks:

1. Analysis of apparatus criticus;
2. A selection of educational resources for an acquaintance with the environment of Scratch;
3. Research of the application of Scratch-projects for the study of mathematics, physics, art;
4. The usage of Scratch-projects for the presentation of own ideas.

The research object is Scratch technology.

The subject of scientific research is the realization of STE(A)M approach in the educational activity by facilities of Scratch projects.

For achievement of the goal here was used the complex research methods: a) theoretical – an analysis of scientific and technical literature, generalization, and design of processes at the study of separate themes from natural sciences; b) empiric – observation, analysis of the experience of the use of technology of Scratch.

Approbation of research realized within the limits of activity of STEM center of the our Faculty.

3. Research results

3.1. Analysis of basic concepts of research

Student-centered learnings the process-oriented to forming such a model of studies in an Institution of higher learning at that essential knowledge, abilities, and skills that the bread-winner of higher education must seize in the process of acquisition of professional competencies are sent to the satisfaction of his own necessities and provide his highly sought at the market of

labor, high capacity for employment. An example of the realization of such studies through the technology of "small steps" can be found in [7].

Providing diverse personality development leads to forming creative, professionally competent social mobile specialists. Only such people can realize themselves in any sphere of activity [8]. To rear a capacity for generating ideas, non-standard decisions possible at a systematic approach and from an early age. Effective for this purpose is the use of Scratch projects [9]. Implementation of activity approach phases is reasonable for an author in the study of informatics using project methodologies in the Scratch environment during the controlled distance studies.

Moreover, results by Cárdenas-Cobo et al. [10] confirmed an acceptable level of satisfaction in the group that used Scratch as a technological tool for learning. This is consistent with certain experiences reported in [11–14].

Computer programming can help children develop problem-solving and analytical skills. Thus, many countries have included computer science in the curriculum of the primary school [15, 16]. The analysis of results shows that pre-service teachers appreciated the collaborative work, the freedom to code an app following their own interests, and the use of engaging software.

An animation programming of the Scratch environment appeared due to the rapid development of educational programmatic products and their competition. The technology combines programming, graphic arts, design, and creativity. In addition, it can be actual, as for schoolchildren and students. The feature of this environment is the possibility to create cartoons, animations, and even the simplest games, informative models of natural processes. And it is already one direction of the basis for STE(A)M-approach studies.

Demonstrating the approach is relevant to a teaching approach in general programming courses for the first-year non-IT students at Tallinn University of Technology, Estonia. The authors suggest ways to achieve better results in programming issues that are usually complicated for beginners [17, 18]. The main aim of the chosen teaching approach in the course is to raise motivation and keep the learners' interest in the programming field at a high level.

We will note that visual programming environments are the most acceptable for the development of electronic informational models. Automatic educational systems based on multimedia technologies are the perfect means of study. The combined use of computer graphics, animation, video, sound, and other multimedia components all gives unique possibilities to do an object that is studied, maximally evident, and that is why clear and accessible [19].

STE(A)M approach in the organization of educational activity gives an opportunity uniquely to connect technologies, science, and work. Facilities of Scratch projects can bring all of them up.

3.2. Development of the distancing course "Creative self-realization in Scratch"

As we mentioned, Scratch was an effective tool for students of different ages. Therefore, this environment is especially effective for future teachers – students of a pedagogical institution of higher learning. Here is, for example, devised the course [20].

The distance course consists of a few blocks. Employments provide for demonstrating and studying theoretical material, creating the project in the Scratch environment, mastery, and evaluation using test tasks.

This course introduces you to programming for beginners with one of the simplest programming languages. Mastering it, everybody can create computer programs and connect the graphic blocks of code, for example, to create animation, games, and the construction of interactive histories. The task of the course is to compel students to think like programmers and software engineers. A critical moment of this course is the development of creative projects.

The basic components, of course, are:

- developments of lectures. Lecture topics were determined by the research described below (figure 1);
- video lessons. The material is designed as an instruction for working in the environment (figure 2);
- tests. The construction of most questions consists in choosing one or more answer options (figure 3);
- projects. The created projects concern the study of mathematics, physics, and art (figure 4);
- interactive. Interactive tasks for mastering the material are here (figure 5).

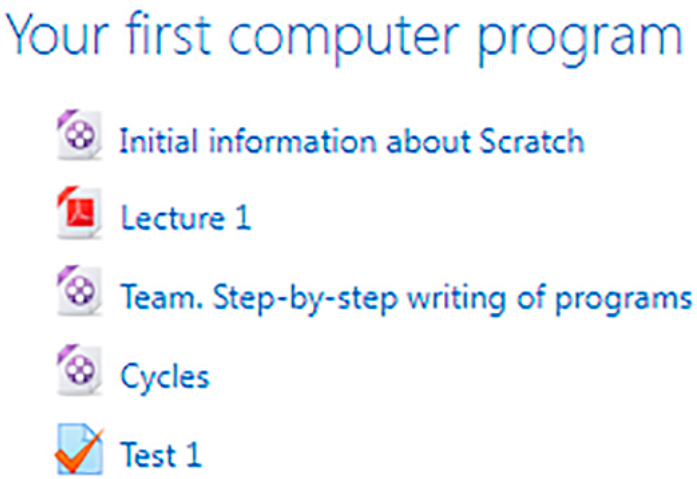

Figure 1. An example of Moodle educational resources for studying a separate module.

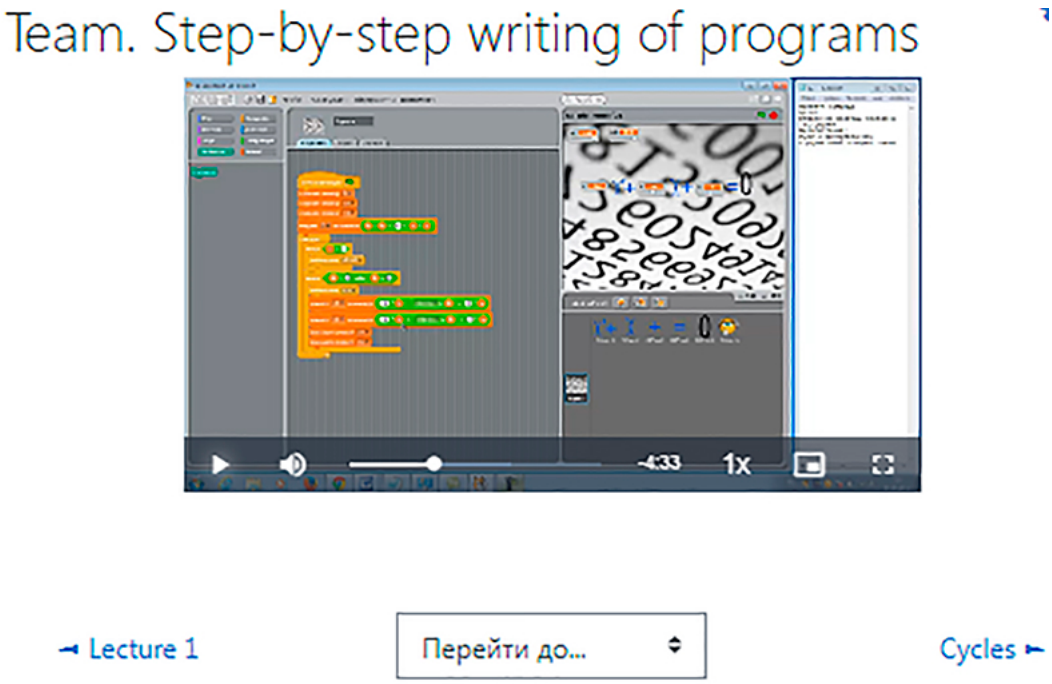

Figure 2. Demonstration of the video lesson in the player window.

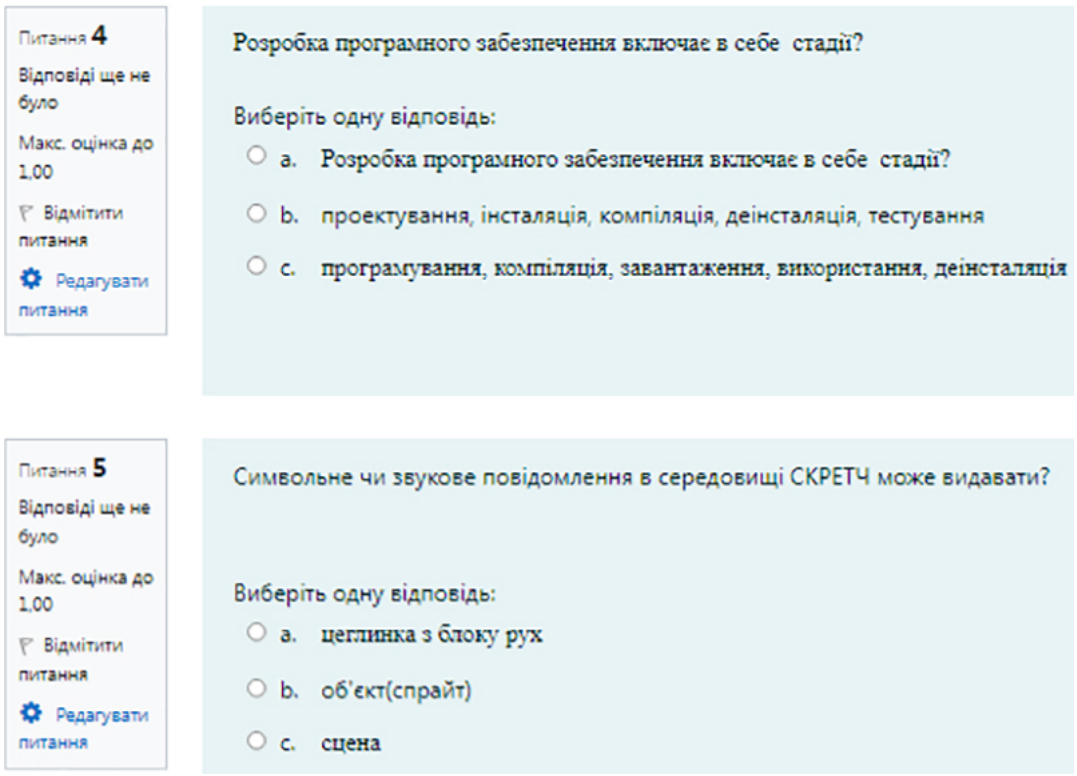

Figure 3. Control questions for choosing one correct answer to Ukrainian-language tasks.

3.3. Scratch-projects for the study of mathematics, physics, and art

The aims and maintenance of teaching informatics have considerably changed over time: from a variant course to invariant, from propaedeutic to base, and from an acquaintance of ICT to the formation of base knowledge and abilities. Capturing algorithmic thinking takes time and effort. For this purpose, it is necessary to prematurely learn to forecast the situations that can happen in the future and envisage in plans correct behavior in these situations. On the other hand, as well as other human skills, algorithmic thinking can be developed and trained through the purposefully neat system of exercises and carefully thought-out set of educational projects.

3.3.1. Scratch-projects in mathematics

1. The formula for finding the roots of a quadratic equation.
   The aims of the project are:
   - to obtain mastering of maintenance of concept “discriminant of the quadratic equation”, the formula of discriminant and chart of the display of formulas for solving of quadratic equations of general view, and also formulas of roots of quadratic equations;
   - to form primary abilities to find the discriminant of the quadratic equation after formulas, after his value determines the number of decisions of affected quadratic and calculate the roots of affected quadratic.

   Scratch projects can be applied for clearness for a teacher or as a result of mastering program material students in their implementation.
   This project is clarity or a simple toy that explores the existence of roots in a quadratic equation. The principle is quite simple. Use a discriminant! And the hero of the “Clever Smile” talks: “roots exist” or “roots don’t exist” (figure 6).

Figure 4. An example of the project implementation algorithm in the Scratch environment.

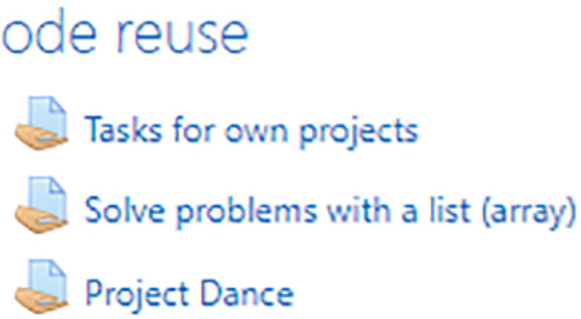

Figure 5. Some interactive tasks.

A course for comparison of the task is done in the programming of Pascal language, too.

2. The next mathematical project is “Similarity of triangles”.
   Here are used the operators of branching: “If-Then-Else” and the simple operating under the inequalities (figure 7).
   A project determines the necessary and sufficient condition for the existence of a triangle after the check of the lengths of three sides of the triangle. Here is executed the inequality of the triangle. The object of implementation is a girl who helps you decide on the task. The user only enters the lengths of the sides of the triangle. Finally, the put algorithm of actions is implemented to calculate inequalities (figure 7).
   The use of similar auxiliary facilities of such type in mathematics lessons is necessary because it is an effective means of activating and supporting educational-cognitive activity. In this case, exactly, an educational process tests quality changes, becomes considerably more attractive, and, for students and teachers, pleases them from communication, labor, and

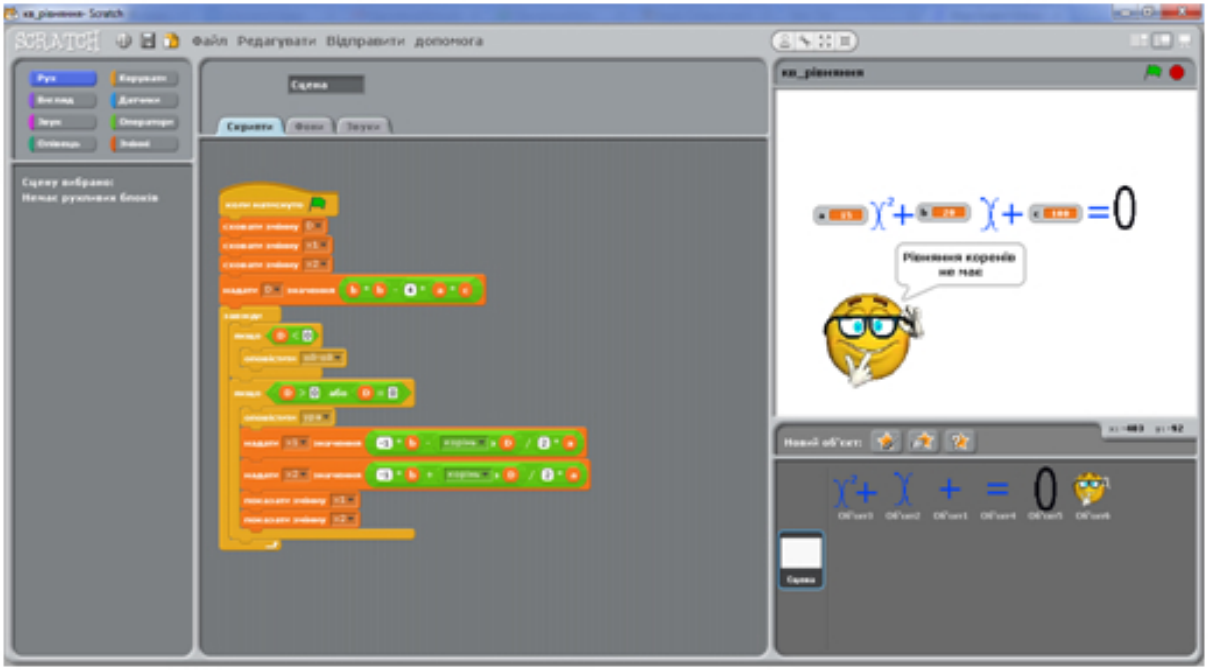

Figure 6. Algebraic project on finding roots of the quadratic equation.

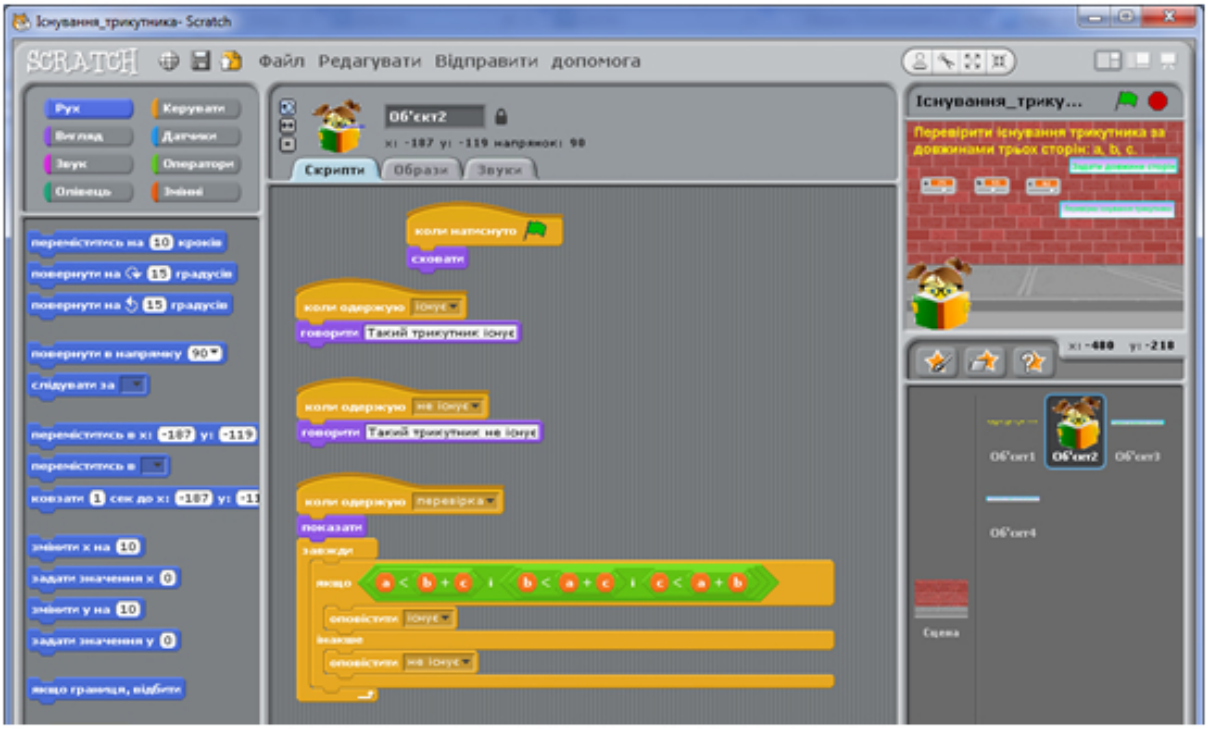

Figure 7. Using branched structures to check triangle inequalities.

purchasing knowledge. The use of Scratch brings in studies fundamentally new cognitive facilities. It assists a transition from the explanatory-concordance type of educational process to new and active ones that the use of various kinds promotes.

3.3.2. Scratch-projects from physics. Scratch assists in creating a variety of subject activities for students, allows the development of the child's personality, and promotes motivation to receive quality education. The use of such projects in the study of physics allows for designing and demonstrating processes inaccessible for supervision in the conditions of the class of physics.

Scratch projects as auxiliary facilities in the study of physics also serve evidently as an explanation of new material and as a research laboratory that will execute the same work only in virtuality but will be reasonable and confirmed by the previous laboratory.

1. Determination of equalization of thermal balance.
   The task of this project is to check the correctness of the experiment, draw up the heat balance equation, and determine the temperature of the resulting mixture. Figure 8 shows the use of value assignment operands in the Scratch environment to solve this problem. Its result will determine the efficiency of the heater. As you can see in figure 9, we use a timer to simulate a natural process in this project.

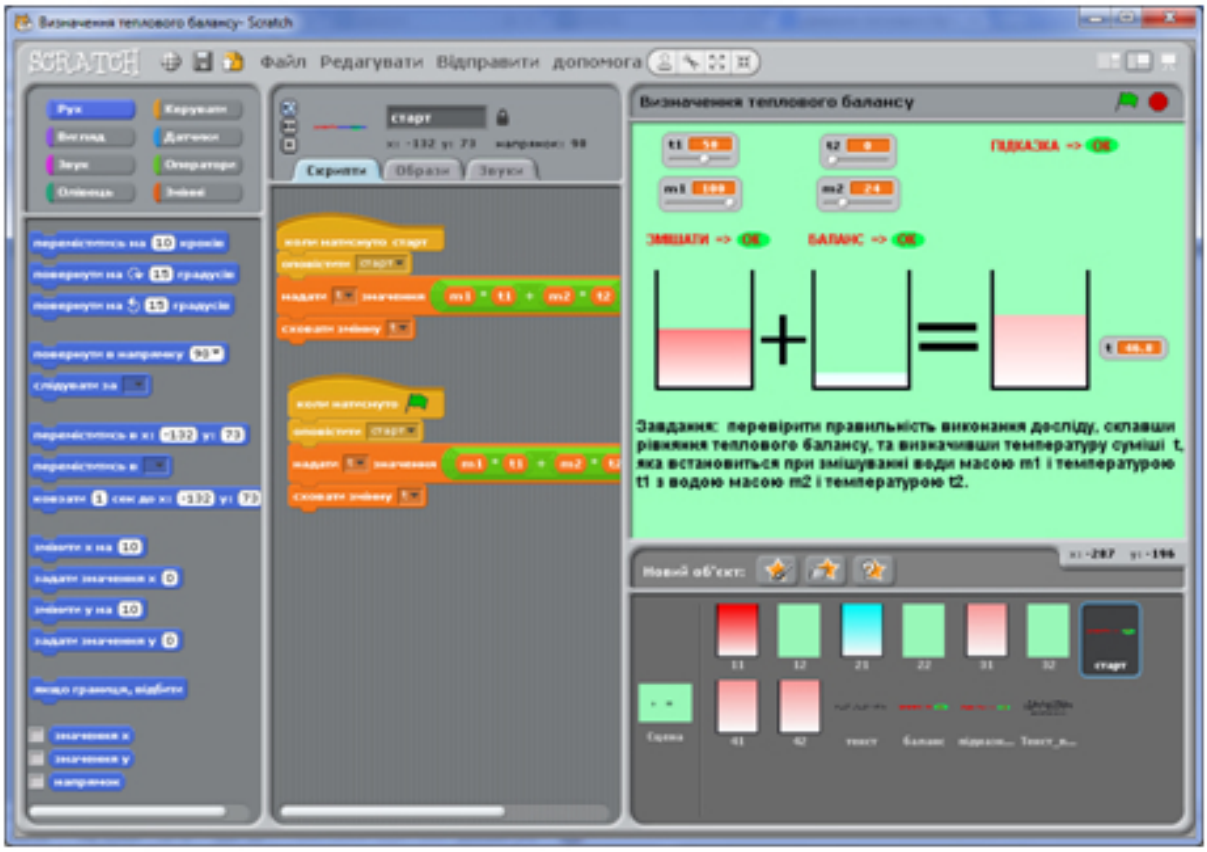

Figure 8. Using assignment operands to determine the temperature when mixing two liquids with different temperatures.

2. The motion of the body horizontally hurled.
   The free-falling direction of gravity coincides with the direction of speed. A body moves rectilinearly and uniformly accelerated. As a result of adding these motions, get a curvilinear speed-up motion (a trajectory is a parabola). Such tasks can easily be realized in Scratch (figure 10). Moreover, an unambiguous concept decision does not eliminate the different creative approaches of the project.

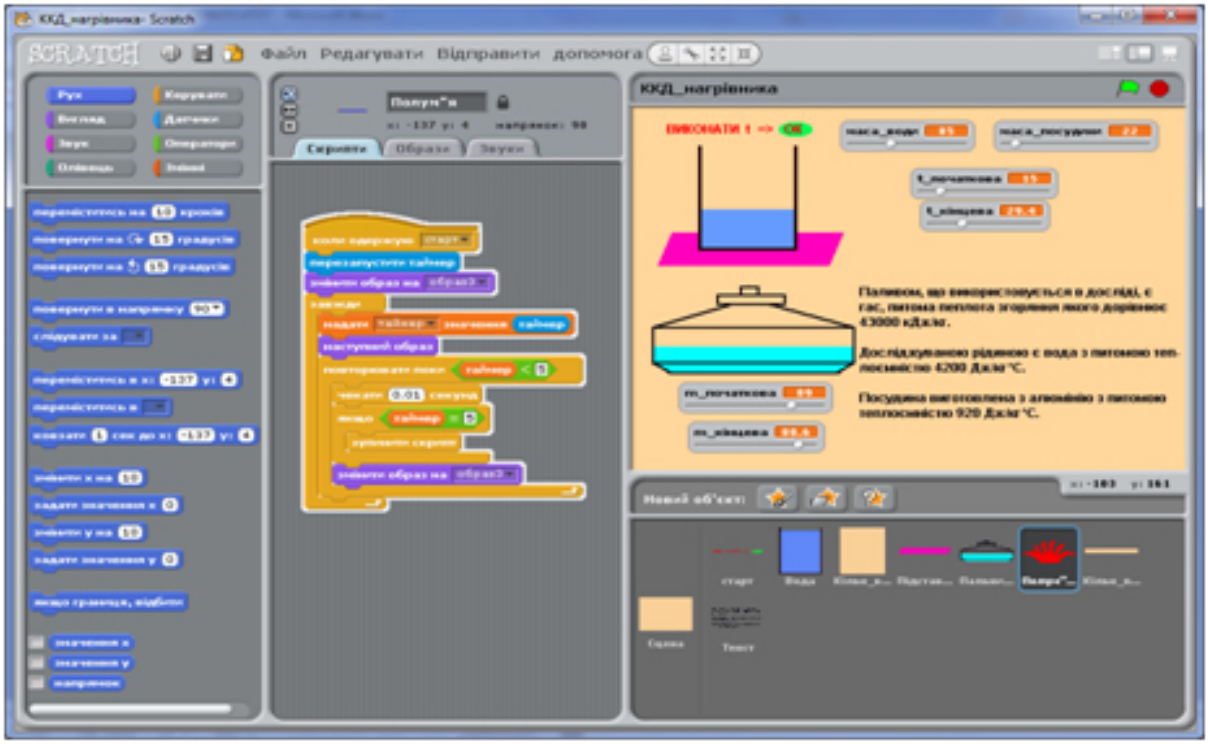

Figure 9. The use of timers in the algorithm for determining the efficiency of the heater.

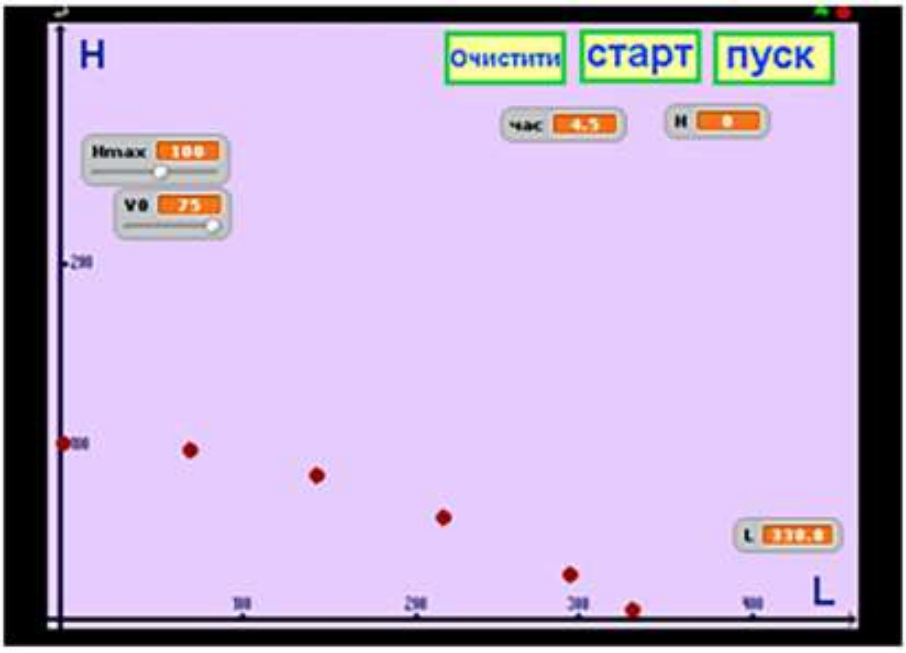

Figure 10. Construction of the trajectory of the movement in the Scratch project according to several parameters.

3.3.3. Artistic projects of Scratch. Using digital instruments to create and process multimedia data translates the study of artistic disciplines to a new level. Among directions of organization

of educational activity: music (forming of record library, editing of sound), perception, song work (karaoke, creation of phonogram, adjusting of speed and key of songs), and video editing (video clips).

- Virtual tuner
  The project aims to work out a tuner that will help with the guitar's tuning. Realization of the project does not require material charges.
  Thus, a project shows the programmatic version of an electronic tuner for tuning six guitar strings in the key (E4, H3, G3, D3, A2, E2) (see Figure 11 in Ukrainian). The program is simple, and the principle of its work is like an ordinary tuner. Every note has an identical code: an instrument is set by the number 26 (a guitar with steel strings), and the number 64 sets the numerical order of notes. 3-times means that a note unit 3 sounds, then 1 unit is a break, and 3 units sound farther.

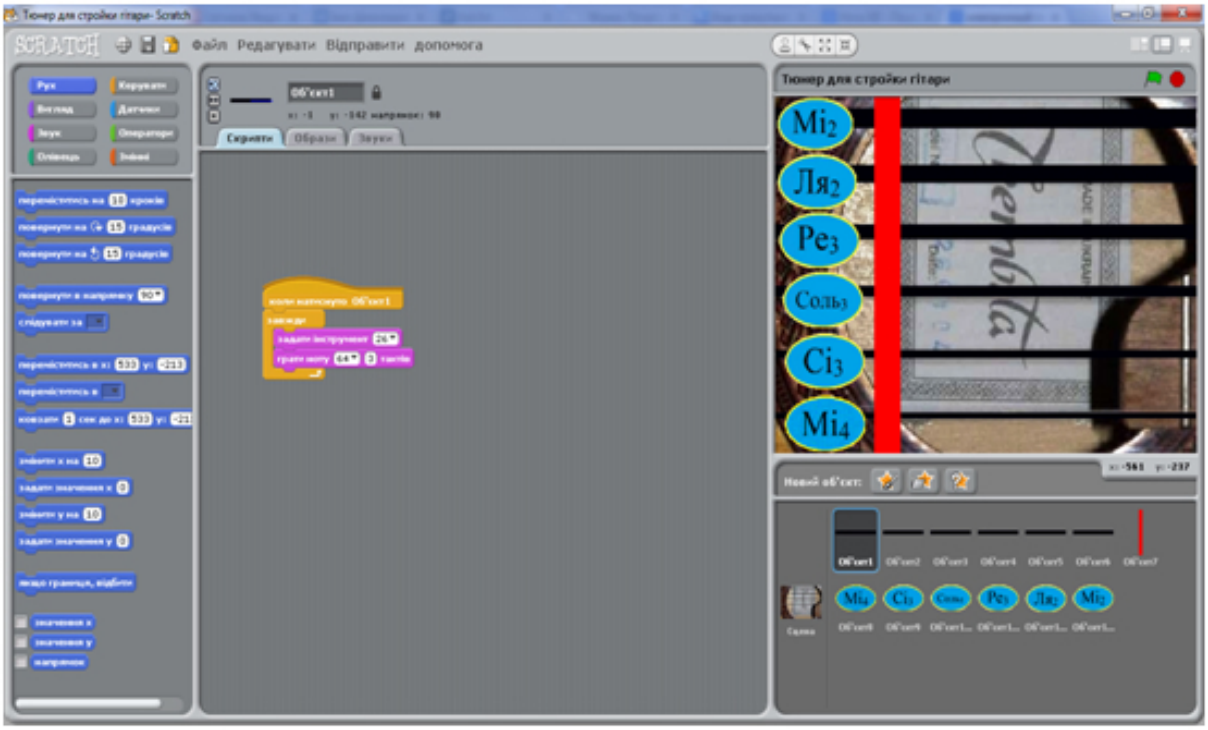

Figure 11. Setting up a virtual tuner.

4. Experimental research

The main goal of our experimental research was to clarify the maintenance of the course "Creative self-realization in Scratch" in terms of the credit-module system in the searching stage of the experiment. To achieve this aim, we used expert estimations.

All the fundamental questions of the questionnaire of the mentioned course were numbered after the increase of signs. Experts were selected from the teachers of informatics of the city Ternopil and Ternopil region. Then we offered them to specify the place of semantic themes, which are the most necessary for the study of programming and mastering the Scratch technology. The value of "1" was assigned as the most crucial topic in the opinion of the expert, and "10" is the least important.

The results of experiment for "Creative self-realization in Scratch" were implemented in course for students: "Computer information technologies in education and science".

To avoid the psychological prompt that could influence a choice of the expert of a certain sequence of ranking, the offered themes in every card with questionnaire (table 1) were numbered in a randomized sequence.

Table 1. A card of questionnaire with the list of themes.

No	Theme	Place
1.	Basic constructions of programming: following, branching, cycle	
2.	General development of projects is in the programming of the Scratch environment	
3.	Use of Control unit in the environment of Scratch as libraries of basic commands	
4.	Documentation, instructions, and testing of own programmatic products	
5.	Work with operators with the basis of mathematical thinking in programming	
6.	Searching optimization of projects	
7.	Bases of development of projects in the industry of programming as a help to other areas of science	
8.	Use of variables, subroutines	
9.	Technologies of development of auxiliary program are in life	
10.	Facilities for testing of scripts of programs	

The results of the expert survey are presented in table 2.

The most obvious indicator of the evaluation of a theme is its total rank, which all experts determine [21]

$$S_j = \sum_{i=1}^{20} R_{i,j}, \tag{1}$$

where $R_{i,j}$ is the indicator set by the i-th expert, $0 \leq i \leq 20$, for the j-th theme, $1 \leq j \leq 10$.

However, such aggregate ranks are objective if there is some level of agreement between experts. The degree of such agreement is described by the concordance coefficient W. For each theme, we find the difference between the total indicators $\sum_{j=1}^{m} R_{i,j}$ and value $\frac{m\cdot(n+1)}{2}$:

$$d_j = \sum_{i=1}^{20} R_{i,j} - 0.5 \cdot (m \cdot (n+1)),$$

where m is the quantity of experts, $1 \leq i \leq 20$, $m = 20$ and n is the quantity of theme and $1 \leq j \leq 10$, $n = 10$.

We find the sum of the squares of the values obtained from the equation (1)

$$S(d^2) = \sum_{i=1}^{n} d_j^2 = \sum_{j=1}^{n} \Big(\sum_{i=1}^{m} R_{i,j} - 0,5 \cdot (m \cdot (n+1)) \Big)^2 \tag{2}$$

The maximum value of the quantity $S(d^2)$

$$S_{max}(d^2) = \frac{1}{12} \cdot m^2 (n^3 \ - -n)$$

Table 2. Survey results.

Expert	T 1	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9	T 10
1	5	4	8	2	3	7	9	1	6	10
2	4	3	6	1	5	8	10	7	2	9
3	2	4	10	3	1	8	9	6	7	5
4	3	5	7	1	4	9	8	2	10	6
5	1	5	7	2	3	10	8	6	4	9
6	4	7	5	6	2	8	9	1	3	10
7	1	5	8	3	6	10	9	7	2	4
8	5	6	8	7	1	9	10	3	2	4
9	2	3	9	4	1	6	10	5	7	8
10	4	6	7	3	2	8	9	1	5	10
11	3	7	6	2	4	8	10	5	9	1
12	3	6	8	4	5	7	10	2	1	9
13	1	5	6	2	7	8	10	3	4	9
14	6	3	7	1	5	9	8	2	4	10
15	5	4	10	3	8	7	9	2	1	6
26	1	2	7	5	3	6	10	8	4	9
17	2	1	8	4	5	9	10	3	6	7
18	4	8	6	1	7	10	9	3	2	5
19	2	7	10	3	4	6	9	5	1	8
20	1	3	8	4	7	10	9	2	5	6

Table 3. Rating results.

	T 1	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9	T 10
S_j	59	94	151	61	83	163	185	74	85	145
d_j	-51	-16	41	-49	-27	53	75	-36	-25	35

is achieved if all experts evaluate the criteria (themes) equally.

The concordance coefficient is equal to:

$$W = \frac{S(d^2)}{S_{max}(d^2)} = \frac{12 \cdot S(d^2)}{m^2(n^3 - n)}. \tag{3}$$

We find the values of the total ranks and d_j, $1 \leq j \leq 10$ (table 3):

From equations (2) and (3) we find the coefficient of the concordance of $W = 0,583$. This size always is between 0 and 1. If $W = 0$, then connections between the ranking of experts do not exist. Next, if $W = 1$, then connections between the ranking become completely gathered. The obtained here coefficient W is equal to $0,583$, which substantially differs from zero. So, it is possible to assert that an objective concordance exists between the experts. However, this value of the coefficient W is not a criterion of objectivity since it can be obtained as a result of randomly assigning ranks to one or another topic.

The value $m \cdot (n-1) \cdot W$ is distributed according to the χ^2 law with $n-1$ degrees of freedom. Using the relation

$$\chi^2_W = \frac{12 \cdot S(d^2)}{m \cdot n \cdot (n+1)},$$

we find the value $\chi^2_W = 104,99$. If we compare this with the value from Table 3 for $i = n-1 = 9$ degrees of freedom and a significance level equal of 0.05, we get $\chi^2_W = 104.99 > \chi^2_t = 16.92$, from which we conclude that there is agreement between the experts.

Due to the results of the questionnaire, the most essential themes for holding a special course are the following:

1. Basic constructions of programming: following, branching, cycle;
2. Documentation, instructions, and testing of own programmatic products;
3. Use of variables, subroutines.

Another way of using Scratch technology is to present novel conceptions. There was performed a questionnaire with the following points of view:

1. What communication technologies can be used for visualization and demonstration of various things, working results, investigations, and project performances?
2. What basic descriptions can technology own for the best presentation of ideas/results, etc.?
3. Are you familiar with the Scratch environment?
4. How can you apply Scratch-project for the realization of ideas?
5. How do the performances of speakers who used projects in the presentation of Scratch-, differ?
6. Do you see the advantages in applying Scratch projects for your presentation?
7. What kind of disadvantages in applying Scratch-projects do you see?

It is worth noting that we surveyed the prism of STE(A)M education. The results showed that the Scratch technology can be one of the basic ones in this direction. First, the implementation of projects in the natural sciences looks very obvious. Second, mastering Scratch as a technology allows students to learn basic algorithmic constructions. Thirdly, the use of various blocks and their creative combination promotes the development of technical creativity. Fourth, working with media data makes it possible to create interesting artistic projects. Fifth, mastering algorithmic structures is impossible without understanding the mathematical apparatus.

Among the characteristics necessary for the best presentation of their ideas, respondents singled out the possibility of a non-standard approach and creative implementation. Developing projects in Scratch is a great way to demonstrate your own solutions.

As part of the training "Digital technologies in education and science" for a group of master's students of Ternopil National Pedagogical University named after Volodymyr Hnatyuk, students were enrolled in the course "Creative self-realization in Scratch" and invited to develop their projects using Scratch. All educational materials for acquiring labor skills under this program were available during the course. Video lessons made it possible to get to know the unknown and test the possibilities of technology at a time convenient for master's students. The topics of the projects covered physical and mathematical, natural, artistic, and philological disciplines. Performances in which speakers used this digital technology looked qualitatively at the highest level. Master's students noted new opportunities for the implementation of their projects.

5. Conclusions

The need for digital competencies is acute today. Their development is influenced by a number of factors, in particular, the improvement of the content of higher education. One of the ways to improve is to create courses that are of interest to students. The developed educational course "Creative self-realization in Scratch" implements the STE(A)M-approach in the organization of educational and cognitive activities of students of Ternopil National Pedagogical University named after Volodymyr Hnatyuk University. The content of the course was selected through

an experimental study. It is hosted on the Moodle platform used at the Volodymyr Hnatiuk National Pedagogical University in Ternopil. Its components include lecture materials, video lessons, tests, etc. The emphasis is on project activities. It is advisable to master the Scratch technology by implementing creative projects in mathematics, physics, music, etc. These disciplines perfectly combine technology and creativity. It has been established that using Scratch technology allows us to express our thoughts and ideas non-standardly. The development of interactive interaction interests the listeners and activates the perception of the outlined question. In addition, there is a study of technologies and the formation of an algorithmic thinking style. In such a way, digital skills are formed. Introducing such courses into the educational process confirms the STE(A)M approach to education.

In the future, it is planned to expand the scope of Scratch projects.

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