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STEM PROJECT AS A MEANS OF LEARNING MODELING FOR PRE-SERVICE MATHEMATICS AND COMPUTER SCIENCE TEACHERS

Abstract. Modern science operates with various methods, among which modeling is one of the most popular. The development of information technology allows the study of analogues (models) with the most significant characteristics of the real object. Modeling activities have been considered as useful teaching method in STEM education. Cloud services (like GeoGebra) are effective means for STEM education. The paper features a methodology of forming modeling skills based on STEM projects, which is grounded on modeling interesting curves of Analytic Geometry course. The content of the methodology is a course in Computer Modeling, which includes a module "STEM education and modeling". The module idea is based on the formation of skills required to model interesting curves (ellipse, hyperbola, parabola, conchoid of Nicomedes, limaçon of Pascal, strophoid, cissoid of Diocles, lemniscate of Bernoulli, Cassini oval, cycloidal curves, folium of Descartes, witch of Agnesi, logarithmic spiral). The methodology provides 4 steps (Step 1 – the teacher offers an example of a STEM project, which is discussed in class and solved by the teacher using GeoGebra; Step 2 – students are divided into groups of 3-4 people; Step 3 – the teacher offers a short STEM project (7-10 days), in which students model the curve; Step 4 – students offer their own STEM project (15-20 days), the solution of which is based on the modeling of an interesting curve). To test the effectiveness of the developed methodology, a pedagogical experiment was organized (2019-2021), which was joined by Master's students majoring in "Secondary Education (Mathematics)" and "Secondary Education (Computer Science)". Makarenko Sumy State Pedagogical University (Ukraine) was the experimental base. The effectiveness of the proposed methodology is proved by the sign test at the significant level of 0.05.

Keywords: modeling skills; formation of modeling skills; teachers; STEM; STEM project; GeoGebra; curve.

1. INTRODUCTION

Statement of the problem. Modern science operates with various methods, among which modeling is one of the most popular. The development of information technology allows the study of analogues (models) with the most significant characteristics of the real object.

Modeling activities have been considered as a useful teaching method in STEM education [1]. Models and modelling can be used as a basis to foster an integrated and authentic STEM education and STEM literacy [2]. Mathematical modeling findings may contribute to theoretical conceptualization of STEM education [3].

According to Ukraine’s Concept of Development of Natural Sciences and Mathematics Education (STEM education) [4], STEM education is a holistic system of Natural Sciences and Mathematics educational fields, the purpose of which is the development of a personality through the formation of competencies, Natural Sciences worldview and life values using a transdisciplinary approach to learning based on practical application of scientific, mathematical, and engineering knowledge to solve practical problems for further use of this knowledge and skills in professional activities.

The introduction of STEM education is entrusted to teachers of Natural Sciences and Mathematics. This confirms the importance of modeling skills for teachers in the context of successful implementation of STEM education in professional activities.

Analysis of the recent research and publications. Formation of Mathematics teachers’ modeling skills is the subject of a number of studies.

The importance of developing constructive skills of youth is emphasized in the findings of E. Laksha [5], N. Kononenko [6], T. Ivanina [7], and the formation of modeling skills is associated with the formation of research skills [8].

The development of computer technology led to the emergence of specialized environments, where it became possible to model various objects (processes) based on a constructive approach. At the same time, the widespread use of smartphones and tablets, which have access to the Internet, has led to the emergence of cloud services, which also allow you to model objects of different nature [9; 10].

STEM education, which combines Natural Sciences, Mathematics and Technologies, involves the use of specialized software for its support. This is confirmed by a number of findings. N. Budinski considers GeoGebra an effective tool for STEM education [11]. T. Kramarenko, O. Pylypenko, V. Zaselskiy [12] studied the possibilities of GeoGebra AR in teaching Mathematics using the STEM approach.

Currently, there exist such mathematics modeling environments as Maple [13], CoCalc [14], GeoGebra [15; 16]. Particularly, in [17] the methodology of formation of skills required to model interesting curves based on GeoGebra cloud service with a constructive approach is substantiated.

Thus, the analysis of recent research showed the existence of findings that substantiate the importance of modeling skills for STEM education, confirm the feasibility of using specialized mathematics software for STEM education, but demonstrated the lack of established approaches to using STEM projects as a means of pre-service teachers’ modeling skills formation.

The goal of the paper is to describe a method of using STEM projects as a means of pre-service teachers’ modeling skills formation and confirm its effectiveness.

2. RESEARCH METHODOLOGY

Theoretical methods (analysis of the results of scientific research on the specifics of the STEM education implementation, on the specifics of the modeling skills formation based on specialized software, analysis of empirical experience of teachers in the implementation of STEM) were used to develop methods of using STEM projects in educational institutions of different levels.

To test the effectiveness of the developed methodology, a pedagogical experiment was organized (2019-2021), which involved Master's students majoring in "Secondary Education (Mathematics)" and "Secondary Education (Computer Science)".

Makarenko Sumy State Pedagogical University was the experimental base. The total number of respondents was 51 students.

The proposed methodology was implemented in the special course "Computer modeling" with a module "STEM education and modeling": total of 18 hours, 6 class hours.

We had two tests based on the results of the first project and the results of the second project.

Duration of the projects was 1-3 weeks. Each project was presented as a separate case (applied problem), the solution of which is based on the modeling of an interesting curve.

The results of each project were evaluated by the following indicators (Table 1).

Table 1

Project evaluation indicators

№	Indicator	Mark
1	Ability to determine (formulate) the analytical relations between the elements (construct a mathematical model of the problem)	2
2	Ability to take into account the geometric (constructive) relations between the elements (the ability to construct a geometric model of the problem)	2
3	Ability to write an algorithm for a model construction	1
4	Ability to use GeoGebra computer tools ("Trace", "Locus", etc.)	1
5	Ability to interpret modeling results	1
6	Project presentation with case studies	3

According to the goals of the experiment and the sign test, we formulated two hypotheses:

H_0: the method of using STEM projects does not impact the formation of modeling skills;

H_a: the method of using STEM projects impacts the formation of modeling skills.

The hypotheses were tested by the sign test, because the results of the tests were dependent, and the marks were calculated additively [18].

3. RESULTS OF THE RESEARCH

3.1. STEM education around the world and features of its implementation in Ukraine

If we analyze the scientific findings related to STEM education in general, we come to the conclusion that the interpretation of STEM education is not unambiguous. So, in [19] STEM education is an integrated course that combines two or more STEM fields (science, technology, engineering and mathematics). O. Martyniuk [20], N. Balyk, G. Shmyger [21] interpret STEM education as a series of curricula that develop practice-oriented skills using information technology. In [22; 23] STEM education is considered as an educational process based on a transdisciplinary approach to knowledge transfer and aimed at developing critical thinking and cognitive flexibility in solving problem-oriented tasks. The interpretation of this concept is different in [24; 25], where STEM education is interpreted as a technology of personalized learning based on the integration of the content of Natural Sciences and Mathematics. In [26] we have confirmation of the use of both project-based learning and solving interdisciplinary cases [27].

These and other interpretations suggest that an interdisciplinary approach is important for the characterization of STEM education, it integrates mathematics, science and technology and focuses on self-acquisition of knowledge to solve real problems. M. Romero-Ariza, A. Quesada, A. Abril consider that the use of realistic contexts brings a sense of meaning and purpose to the learning taking place, increasing students' motivation and engagement [28].

We analyzed STEM education forms in the world and identified the most common:

– solving practical cases in the field [29] and at home [30];
– practical classes using narrative and interdisciplinary approaches in senior school [31];
– special courses [32];

– consulting in the project activities [33].

In Ukraine, according to the Concept of STEM education development for the period up to 2027 [4], the leading STEM-education forms are STEM cases, STEM contextual tasks, STEM projects, coaching training, which fully correlates with the forms that have proven their effectiveness in international educational platforms. At the same time, it should be emphasized that the content analysis of Ukrainian educational resources shows in favor of project-based learning as a form of STEM education, which prompted our choice of STEM projects in the context of pre-service teachers' modeling skills formation. An additional argument in favour of the decision is that the experience of participating in STEM projects will allow students to implement STEM projects in their future professional activities.

3.2. Description of the proposed methodology

Any technique involves five elements (Figure 1): purpose, content, forms, methods and means.

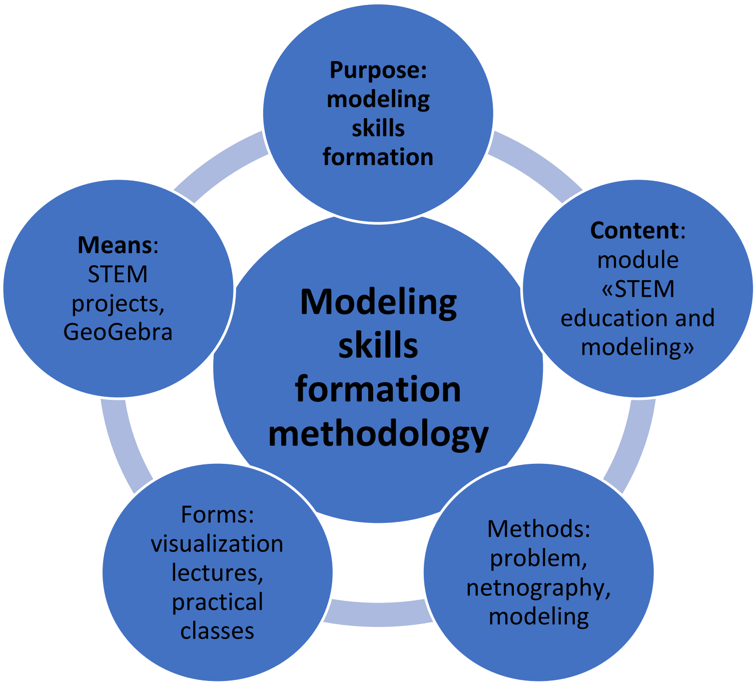

Fig. 1. Components of the proposed methodology

The purpose of the proposed methodology is to form pre-service teachers' modeling skills based on the implementation of STEM projects.

The content of the proposed methodology is the course "Computer Modeling", which provides a module "STEM education and modeling" (18 hours – 2 lecture hours, 4 practical class hours).

The module idea is based on the formation of skills required to model interesting curves (ellipse, hyperbola, parabola, conchoid of Nicomedes, limaçon of Pascal, strophoid, cissoid of Diocles, lemniscate of Bernoulli, Cassini oval, cycloidal curves, folium of Descartes, witch of Agnesi, logarithmic spiral).

The form of realization of the methodology is visualization lectures and practical classes.

Such teaching methods as problem method, netnography method, modeling method are used.

STEM projects and GeoGebra mathematics software are the teaching means.

Basic knowledge of Analytic Geometry is required for the implementation of STEM projects.

The methodology of using STEM projects for pre-service teachers' modeling skills formation is as follows. At the first lesson a practical problem (STEM project), which is discussed and solved together with the teacher, is offered. At this stage, the method of netnography is used. Then students are divided into groups. Each group is offered some STEM project, which requires teamwork. Students have to use mathematics software (GeoGebra) to model a curve which is a solution to the problem (STEM project). They also have to present the problem, its mathematical basis and the chosen solution. At this stage, the problem method is used. The first project is for 7-10 days, after which there is a public project presentation. In the process of project presentation, the strengths and weaknesses of the chosen solution are discussed. Then, to consolidate the STEM projects skills, focused on the development of modeling skills, students are invited to develop and implement another STEM project, the solution of which requires modeling an interesting curve. The duration of the project increases (15-20 days). If according to the results of the first project or in the process of its implementation the modeling of curves was incorrect or students had difficulties with modeling, they were recommended to study the module "Modeling interesting curves", which is described in [17].

Briefly, the methodology can be described as follows:

Step 1 – the teacher offers an example of a STEM project, which is discussed in class and the solution of which is proposed by the teacher in the classroom using GeoGebra. Students have to develop an algorithm for constructing the model presented by the teacher.

Step 2 – students are divided into groups of 3-4 people.

Step 3 – the teacher offers a short STEM project (7-10 days), to solve which it is necessary to model an interesting curve. Based on the results of the project activity, the project is presented and discussed, the strengths and weaknesses of the constructed models are determined. If the modeling of the practical problem solution occurred with errors or the students are not able to model the curve on their own, they are recommended to study "Modeling of interesting curves".

Step 4 – students offer their own STEM project (15-20 days), the solution of which is based on the modeling of an interesting curve. The project is presented.

We will briefly demonstrate the practical application of the developed methodology.

The teacher formulates the problem. Develop a springboard for a skate park that could be overcome in the shortest time.

Mathematical model. In the vertical plane, two points A and B are given, which do not lie on the same vertical axis. Determine the curve, descending which under the influence of its own weight, the material point will pass from A to B in the shortest time.

History of the discovery of the curve (netnography method). Galileo Galilei was the first to study the cycloid in 1590, and named it. In 1696, I. Bernoulli formulated the problem of finding the curve of the fastest descent – "brachystochron" (from Greek "βράχιστος" – the shortest and "χρόνος" – time), i.e. the curve of the shortest time.

It is clear that the shortest path from point A to point B is the segment AB. However, with such a straight line, the speed is gained slowly and the time spent on the descent is greater. Moreover, "brachystochron" also has another remarkable property: a heavy body placed at any point in the arch of the cycloid reaches the horizontal at the same time.

G. Leibniz, I. Newton, G. Lopital and J. Bernoulli were the mathematicians who solved this problem. They proved that the required curve is an inverted cycloid. The methods developed by these scientists in solving the problem of "brachystochron" launched a new direction in mathematics – calculus of variations.

Definition of the curve. A cycloid (from Greek κυκλοειδήσ – round) is a curve generated by the point of a circle rolling in a straight line.

Then the teacher demonstrates an example of a ready-made model of a cycloid (Fig. 2-3), and offers to describe the algorithm for its construction to students.

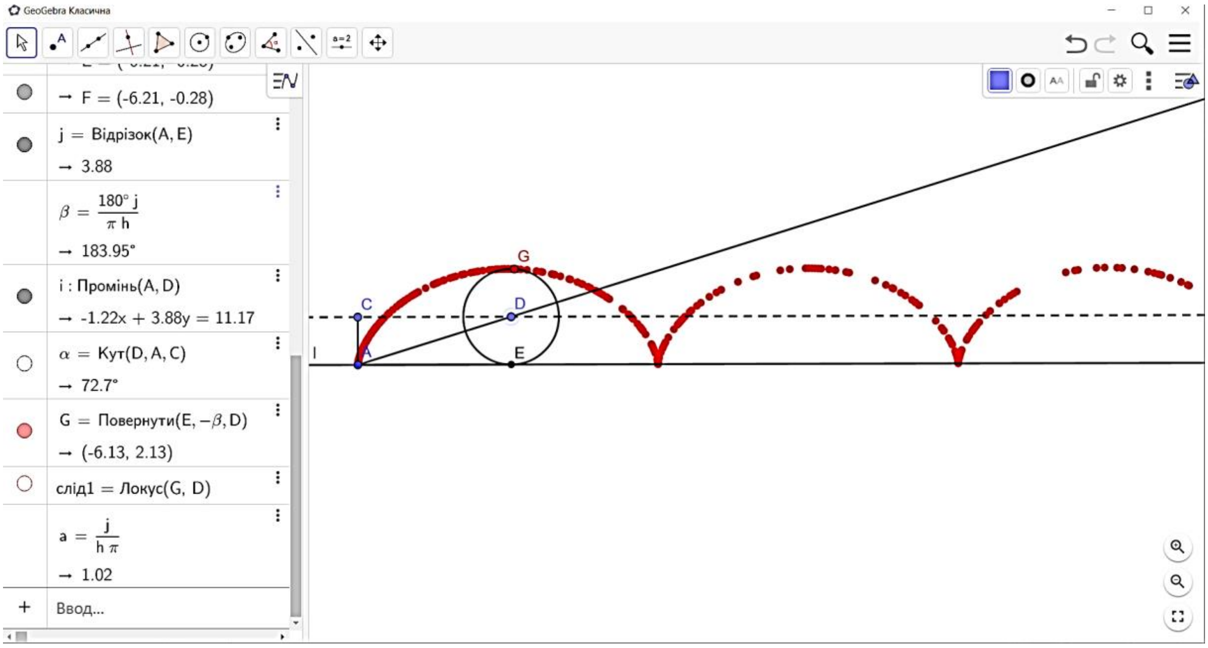

Fig. 2. Construction of a cycloid using Trace tool

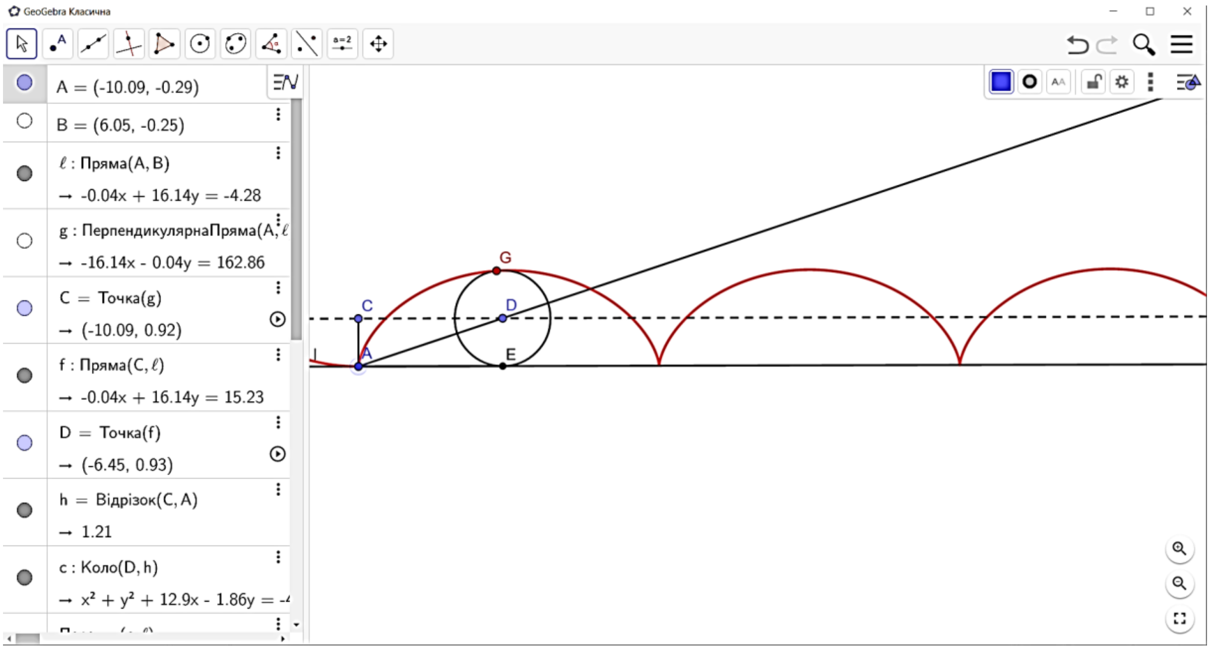

Fig. 3. Construction of a cycloid using Locus tool

After the discussion, students are expected to suggest the following algorithm.

Let the circle ω roll on the line *l*. Construct a curve generated by a point lying on the circle ω.

Algorithm for a cycloid model constructing

1. Construct a line *l*.
2. Construct a point *A* on the line *l* and construct a line through it, perpendicular to the line *l*.
3. Construct an arbitrary point *C* on the perpendicular line and construct a line *g* passing through it, parallel to *l* (dashed line).
4. Construct an arbitrary point D on the parallel line *g*.

5. Construct the circle ω with centre *D* and radius AC.
6. Construct the point *E* – the point of tangency of the circle ω with the line *l*.
7. Suppose that in the initial position the centre *D* of the circle ω coincides with the point *C*. If we move the point *D* along the line *g,* it will move, and the line *l* will remain tangent to it. Make the circle ω rotate around it when moving the centre to create the illusion that the circle ω is rolling on the line *l.* Only one point *G* of the circle ω needs to be investigated. Suppose that at the initial moment this point coincides with the point *E,* i.e., is the point of tangency of the circle ω and the line *l.* If the circle ω is shifted by the segment *AE,* then the desired point *G* of the circle will rotate around the point *D* by the angle φ□∠*EDG*, i.e. will be shifted by the length of the arc *EG*.
8. Construct the point *G*, which is obtained from the point *E* by rotating around the point *D* by the angle $\frac{180^0 \cdot AE}{\pi \cdot DE}$.
9. Hide the point *E.*
10. Make the point *G* leave a trace by rolling the point *D* on the line *l* (Fig. 2).
11. Use the Locus tool: the point *G* is the “pencil point”, the point *D* is the “driver point" (Fig. 3).

Next, the lecturer offers students to explore the analytical equation of the curve, which is described through the parameter.

Let the line along which the circle of radius r rolls be the abscissa, then the parametric equation of the cycloid is

$$\{x = rt - rsint\ y = r - rcost\ .$$

Study of the curve and establishment of properties (problem method). When a cycloid is constructed, we pass to establishment of its properties at the level of practical research.

Cycloid is periodic function along the abscissa, with a period of 2πr. Period limits are special points (return points) t=2πk, where k is an arbitrary integer.

To tangent to the cycloid at any point A, it is sufficient to connect this point with the upper point of the circle. When the point A is connected to the lower point of the circle, we get the normal.

The length of the cycloid arch is 8r.

The area under each arch of the cycloid is three times larger than the area of the circle which generates it.

The radius of curvature of the first arch of the cycloid is $4rsin\frac{t}{2}$.

The "inverted" cycloid is the fastest descent curve (brachystochron). Moreover, it also has the property of tautochrony (from Greek "ταυτιζοξ" – the same, "χρόνος" – time): a heavy body, which is placed anywhere in the arch of the cycloid, reaches the horizontal at the same time.

The period of oscillation of a material point sliding on an inverted cycloid does not depend on the amplitude, this fact was used by Huygens to create an accurate mechanical clock.

The cycloid evolute is a cycloid congruent with the original, namely shifted parallel so that the vertices pass into the "tip".

After the lecture, students are invited to split into groups and join the STEM projects.

1. The calculation of the action of the kneading machine consists of a description of the trajectory of the point belonging to the working body. The trajectory of the working body does not always fill the container with the substance, as a result, the mixing time increases, which leads to unnecessary energy consumption. Determine the optimal trajectory of the point of the mixer working body [34] (the curve is an epicycloid).

2. Determine the shape of audio tracks on CDs and DVDs (the curve is Archimedes' spiral).

3. Determine the most optimal shape of the tramway in places where the tram makes a turn of small radius (the curve is lemniscate of Bernoulli).

4. Determine the shape of the rotating knife profile of the cutting machine so that the cutting angle, i.e. the angle between the knife blade and the direction of its rotation speed, remains constant along the entire edge of the movable knife to ensure minimum wear (the curve is logarithmic spiral).

5. Determine the curve that determines the pattern of the microphone, i.e. the area of possible location of the sound source, within which there is no significant loss of microphone efficiency (the curve is cardioid).

At the same time consultations are possible. If the teacher sees that the models are not correct or the modeling process is difficult for students, the students are encouraged to study the module "Modeling interesting curves" [17].

In 7-10 days students have to present the projects and discuss them.

At the next stage, students are invited to develop their own STEM project, which takes 15-20 days to complete. A required condition of the creative task is that the solution of the STEM project should be based on the modeling of an interesting curve.

3.3. Statistical analysis of results

The methodology of using STEM projects as a means of pre-service teachers' modeling skills formation has proven its effectiveness. Two tests were made: after the implementation of the first project and after the implementation of the second project. The marks were calculated according to the indicators in Table 1. Based on these marks, we determined the number of respondents whose overall score decreased ("-"), did not change ("0") and increased ("+"). The dynamics of marks is shown in Table 2.

Table 2

Dynamics of results

Dynamics	Positive, «+»	Without changes, «0»	Negative, «–»	Number of changes, n=«–»+«+»
Number of respondents	16	32	3	19

According to the decision-making rule [18] we have: $n=19$ (as the number of changes in the results, the last column of Table 2), $T_{exp}=16$ (as positive dynamics or the number of "+" signs). Then for the significance level of 0.05 the area of acceptance of the null hypothesis is the interval $[6, 14]$.

Since $T_{exp}=16$ goes beyond the interval, we accept the alternative hypothesis with the conclusion that the developed methodology of using STEM projects contributes to the pre-service teachers' modeling skills formation.

4. CONCLUSIONS AND PROSPECTS FOR FURTHER RESEARCH

According to the analysis of scientific findings, it is confirmed that STEM education is an interdisciplinary approach that integrates Mathematics, Science and Technology, and encourages students to independently acquire knowledge through solving real problems. The most common forms of implementing STEM education are solving practical cases in the field; practical classes using narrative and interdisciplinary approaches in senior school; special courses; consulting in the process of project activities.

In Ukraine, the leading forms of STEM education are STEM cases, STEM contextual problems, STEM projects, coaching training. Content analysis of Ukrainian educational resources also shows that project-based learning as a form of STEM education is in focus.

To support STEM education, information technologies are involved, which enable the organization of independent search and development of cognitive skills of young people.

The proposed methodology of modeling skills formation based on STEM projects is based on modeling interesting curves of Analytic Geometry course and provides 4 steps (Step 1 – the teacher offers an example of STEM project, which is discussed in class and solved by the teacher using GeoGebra; Step 2 – students are divided into groups of 3-4 people; Step 3 – the teacher offers a short STEM project (7-10 days), in which students model the curve; Step 4 – students offer their own STEM project (15-20 days) , the solution of which is based on the modeling of an interesting curve). Its effectiveness is proved by the sign test at the significant level of 0.05.

The conducted pedagogical experiment additionally confirmed that the use of GeoGebra to support STEM projects is an effective means of forming pre-service mathematics and computer science teachers' modeling skills.

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STEM ПРОЄКТ ЯК ЗАСІБ НАВЧАННЯ МОДЕЛЮВАННЯ МАЙБУТНІХ ВЧИТЕЛІВ МАТЕМАТИКИ ТА ІНФОРМАТИКИ

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Анотація. Наука сьогодні оперує різноманітними методами, серед яких провідним слід визнати моделювання, яке завдяки розвитку інформаційних технологій уможливлює дослідження аналогів (моделей) з найсуттєвішими характеристиками реального об’єкта. Моделювання розглядається як корисний метод навчання STEM-освіті. Хмарні сервіси (наприклад, GeoGebra) є ефективним засобом навчання STEM. Авторська методика формування вмінь моделювати на основі STEM-проєктів базується на моделюванні цікавих кривих курсу аналітичної геометрії. Авторська методика реалізована під час вивчення дисципліни «Комп’ютерне моделювання», у якій передбачено модуль «STEM-освіта і моделювання». Ідея реалізації модуля спирається на формування вмінь моделювати цікаві криві (еліпс, гіпербола, парабола як криві другого порядку та конхоїда Нікомеда, равлик Паскаля, строфоїда, циссоїда Діоклеса, лемніската Бернуллі, лінія Кассіні, циклоїда, лист Декарта, локон Аньєзі, логарифмічна спіраль). Методика передбачає 4 кроки (1 крок – викладачем пропонується приклад STEM-проєкту, який обговорюється на занятті і розв’язання якого пропонується викладачем з використанням GeoGebra; 2 крок – студенти розбиваються на групи з 3-4 осіб; 3 крок – викладач пропонує короткий STEM-проєкт (7-10 днів), за яким студенти самостійно моделюють криву; 4 крок – студенти пропонують власний STEM-проєкт (15-20 днів), розв’язання якого базується на моделюванні цікавої кривої). Для перевірки ефективності розробленої методики організовано педагогічний експеримент (2019-2021 р.р.), до якого долучились студенти магістратури «Середня освіта (Математика)» та «Середня освіта (Інформатика)». Експериментальною базою був Сумський державний педагогічний університет імені А. С. Макаренка (Україна). Ефективність авторської методики було підтвердженоза критерієм знаків на рівні значущості 0,05.

Ключові слова: уміння моделювати; формування вмінь моделювати; учителі; STEM; STEM-проєкт; GeoGebra; криві.