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Use of STEAM education elements and tools in primary school mathematics*

Abstract. The spread of personal IT devices among today's schoolchildren and the unrestricted use of various gadgets explain the ideology of educational changes regarding the end-to-end application of information and communication technologies in the educational process. As part of the Ukrainian school's modernization, the STEAM concept plays a unique role. It ensures the appropriate introduction of the latest technologies into educational practice, focused on the intensification of the educational process, improvement of the forms and methods of the organization of education, and the expansion of the range of practical implementation of the skills acquired by schoolchildren. The article shows how the introduction of elements of STEAM education during mathematical primary school lessons can be supported by using specialized STEAM tools to engage students' cognitive activity. During the execution of STEAM projects, students master many types and forms, ways, methods, and techniques of communication implementation successfully used in further work in other disciplines and beyond the school. The article highlights the didactic possibilities of STEAM tools as instrumental support for using elements of STEAM education in teaching mathematics in primary school. Instrumental support plays a vital role in achieving positive results in implementing STEAM education, which provides the opportunity to implement inquiry-based learning and experimental activities for primary school students in mathematics lessons.

Introduction

One of the priority educational trends of the 21st century consists of the acquisition of mathematical literacy by the younger generation – the ability to formulate, apply, and interpret mathematics in various contexts – to use mathematical concepts, procedures, facts, and tools to describe, explain, and predict phenomena;

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therefore, mathematical literacy becomes an evident and necessary condition for understanding mathematics in the world (PISA, 2017), in particular:

- formation of spatiotemporal intuition and the concept of a model of a subject, object, or phenomenon;
- creation of theorems-assumptions about subjects, objects, phenomena of the surrounding reality, their analysis;
- improvement of abstract and spatial thinking; the ability to draw conclusions based on evidence;
- understanding the complex interactions between different categories, etc.

The Concept of the Development of Pedagogical Education indicates that given the trends of transformation of modern society in the content of school mathematics education, more attention should be paid to the development of universal competencies of students and the creation of conditions for them to acquire the ability to learn continuously throughout their lives. According to the Concept of the New Ukrainian School, the comprehensive use of ICT in mathematics education is recognized as a tool for forming the younger generation's essential competencies for our century. New target orientations necessitate introducing innovative educational practices that consider modern schoolchildren's needs and requests and the peculiarities of their psychological and cognitive spheres. That is why implementing the Concept of the New Ukrainian School supports STEAM education and practical issues regarding the use of STEAM education in teaching mathematics; it also requires further research and scientific development.

STEAM education is designed to be engaging and fun. It helps foster a love of mathematics in students, which can stay with them throughout their academic and professional careers, making them lifelong learners (Elyon, 2023).

Today, support for STEAM education, prioritizing students' interest in mathematics, is carried out at the state level in many countries. In Ukraine, STEAM education at the state level implements STEAM laboratories and virtual STEAM centers. Thus, to support and develop STEAM education, the Small Academy of Sciences of Ukraine (`https://stemua.science/`) offers remote and face-to-face professional methodical and technological assistance organizing STEAM trainings. Schoolchildren work on various STEAM projects, in particular, "Study of oscillations of a student ruler using a smartphone," within which students get acquainted with the theoretical foundations of the oscillation process, conduct numerous experiments, and learn to plot a graph of the dependence of the frequency of oscillations on the length of the free edge. The STEAM project "Determining spring stiffness using mathematical pendulums" is aimed at schoolchildren conducting experiments with a spring of unknown stiffness placed between two mathematical pendulums, etc.

The open educational resource "The Concord Consortium" (`https://learn.concord.org/`) contains various interactive simulators in mathematics, which provide opportunities, in particular, to analyze dynamic models of different mathematical concepts, perform calculations, model and experiment with phenomena, processes, and many more. Thus, the Math Modeling with R (RMath)

section provides for the involvement of schoolchildren in solving real problems with the help of mathematical modeling. RMath delivers a platform for successfully integrating mathematics with computer science for calculations, data analysis, and graphing. The resource "Next Generation Science Standards" – NGSS (`https://www.nextgenscience.org/`) offers a range of high-quality resources that empower educators to help bring STEAM education, and students will develop an in-depth understanding of content and develop critical skills – communication, collaboration, inquiry, problem solving, and flexibility – that will serve them throughout their educational and professional lives. STEAM Collection (`https://oercommons.org/curated-collections/377`) features curriculum materials integrating STEAM – Science, Technology, Engineering, Art, and Math. A STEAM program encourages students to think critically and use engineering or technology in imaginative designs or creative approaches to real-world problems while building on students' mathematics and science foundations. STEM Learning (`https://www.stem.org.uk/primary`) supports primary teachers by offering over 14,000 free, quality-assured digital STEM education resources to help educators inspire elementary school students about STEM. Figure 1 provides examples of primary math resource collections.

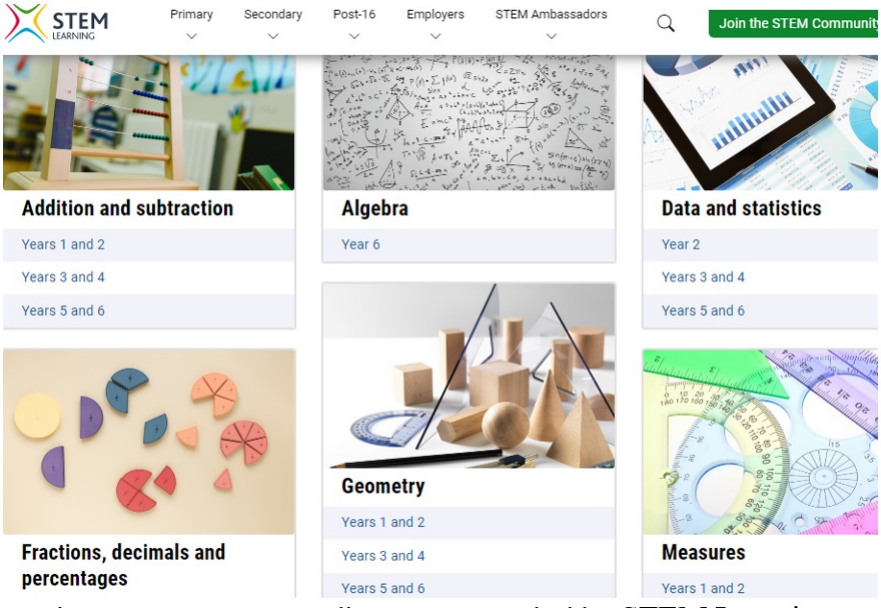

Figure 1: Primary mathematics resource collections provided by STEM Learning project (STEM Learning, online resources)

To improve the quality of Ukrainian STEAM education, the STEM coalition (`http://STEMcoalition.org.ua/`) initiates the unification of educational institutions. It implements such areas of work as increasing the number of girls and women in STEAM. The virtual science-oriented laboratory complex of the Na-

tional Academy of Medical Sciences "Ex Lab" (`http://exlab.com.ua/`) offers access to new knowledge through research and experiments. The virtual "Open Educational Laboratory" (`http://manlab.inhost.com.ua/`) aims to develop students' needs for creative self-realization and professional self-determination, improve teachers' professional competence in organizing students' research and experimental activities, etc.

Various aspects of the implementation of STEAM education have attracted the attention of scientists, pedagogues-practitioners such as N. Balyk, O. Barna, O. Dzyuba, D. Elyon, V. Geiger, M. Goos, S. Kyrylenko, K. Maass, I. Palamarchuk, M. Romero Ariza, D. Vasylieva, I. Slipukhina, O. Stryzhak, H. Shmyger, and others. The majority of scientific research highlights the theoretical aspects of the implementation of STEAM education in school mathematics practice, researching the foreign and domestic experience of implementing STEAM education ideas in mathematics lessons, revealing approaches to training future mathematics teachers to use elements of STEAM education in the educational process, etc. However, an essential role in achieving positive results of the implementation of STEAM education in mathematics lessons belongs to its instrumental support, which provides the opportunity to implement research and experimental, inventive activities of students during mathematical preparation and development of mathematical literacy. In this perspective, instrumental support for the use of elements of STEAM education in the teaching of mathematics in elementary school deserves special attention because an attitude towards school mathematics education forms in students of this age category, the foundation for success in the study of mathematics is laid throughout all years of study both at school and in higher education institutions.

The article aims to highlight the didactic capabilities of STEAM tools as instrumental support for using STEAM education elements in teaching mathematics in elementary school.

Educational potential of selected STEAM tools

The main idea of STEAM education is that an educational process is an interdisciplinary approach; it requires students' involvement in the multifaceted study of phenomena and methods of the surrounding world in solving actual problem-oriented tasks and relying on students' independent activity using information and communication technologies (Elyon, 2023).

Mathematics is often mentioned as underpinning other disciplines of STEM because it serves as a language for science, engineering, and technology. That explains the focus on the mathematics curriculum and provides mathematical tools for learning other disciplines (Vasylieva, Hodovaniuk, 2022; Schmidt, Houang, 2007). At the same time, implementing elements of STEAM education in mathematics lessons involves using specialized STEAM tools – the latest didactic tools for students' experimental and research activities. Today, a mathematics teacher can use a sufficient number of STEAM tools to organize experiments and research. Using powerful tools in STEAM projects is impossible without creating a particular atmosphere of creativity and freedom, where each student freely expresses his ideas and emotions, is not afraid to make a mistake, and feels safe and con-

fident. All these tools give students pleasure from learning mathematics and not only solve the proposed mathematical problems but also independently formulate problems, ask questions, and be curious and courageous. For example, in elementary school, it is helpful to use the Game STEM Set Learning Resources – "Mouse in the Ma-ze" (Figure 2).

Figure 2: STEM Set Learning Resources – "Mouse in the Maze"

The work of elementary school students involves creating an algorithm for the route of a mouse robot. The leading element in working with the robot-mouse is the cognitive activity of students because, in the process of learning, elementary school students can not only reproduce the maze according to the scheme and program the robot to execute it but also offer their ideas for the routes of the maze, taking into account the functionality of the set (for example, the mouse can remember only up to 40 teams, perform revolutions at 900, etc.). Group project activity becomes the main format when students create their labyrinths. While working with the STEM Set, students acquire general skills and abilities, including:

- the ability to read and present information presented in various forms (for example, information consists of a diagram or command signs);

Ability to build interpersonal relationships and present oneself as a team member (during group competitions in planning and creating labyrinths).

When analyzing the goals of primary education from the perspective of the development of the New Ukrainian School, one should consider that the emphasis on such skills is present in all areas of education. Thus, within the mathematical educational department, schoolchildren learn to read information presented in various forms (scheme, table, drawing) and choose a convenient form of information presentation (Ukrainian Primary Education, online resources).

The variety of STEAM tools and their powerful functionality create favorable conditions for students not only to master mathematical literacy but also to enjoy learning and their achievements in completing tasks, correcting errors, and overcoming difficulties. For example, STEM Set Learning Resources – "Robot Botley" from Learning Resources or programmable bee-robot "Bee-Bot" from TTS Group Ltd (Figure 3) provides opportunities in an exciting game form to form the ability of younger schoolchildren to distinguish geometric shapes by their essential features, to establish the relative placement of objects on a plane and in space; make Math-Tangram from geometric ob-jects (mathematical educational department, the content line "Geometric figures") (Ukrainian Primary Education, online resources) and much more. Please note that the role of online STEAM resources is growing in conditions of forced distance learning in Ukraine.

Smartphones have become part of Ukrainian elementary school students' daily lives today. BYD (Bring Your Device) is an active attempt to incorporate these IT devices into education. BYD is causing a significant shift in education and distance learning by allowing more students to access course materials via mobile technology (Shuler, Winters, West, 2013). As mobile access and ownership increase, BYOD holds promise for learners in Ukraine. From the perspective of STEAM education, the use of BY-OD brings many valuable opportunities, such as:

- instrumental support for elementary school students' cognitive activities beyond the school premises;
- creating a unified information and educational digital space for organizing the quality work of elementary school students – virtual classes, virtual boards – allow students to quickly get the necessary information in real-time;
- real-time collaboration with group members or project participants, regardless of their location, etc.

The use of the BYD concept as a universal tool for implementing STEAM education enables the realization of the following principles of math learning at a higher level: visualization, accessibili-ty, awareness, and, most importantly, fostering elementary school students' interest in acquiring math knowledge and promoting their cognitive activity and initiative. In particular, the online re-source "Abcya" (https://www.abcya.com) contains interactive Math-Tangram simulators (Figu-re 4). Working with such a resource is similar to practical work with the "Bee-Bot" robot.

The work of elementary school students with such STEAM tools provides an opportunity to learn the conceptual apparatus and corresponding methods of step-by-step activity at an intuitive-practical level both in mathematics lessons, for example, when conducting graphic dictations, and in other disciplines, in particular, in computer science lessons (Figure 5) as a component of robot game environment for elementary school students (Shim, 2016). Programming games help elementary school students improve their math skills, strengthen memory, and increase logical thinking skills. There are some coding games for elementary school students: "Scratch", "Lightbot", "Kodable", and "Code.org." It is essential that in

Figure 3: The task "Math-Tangram" "Bee-Bot" from TTS Group Ltd

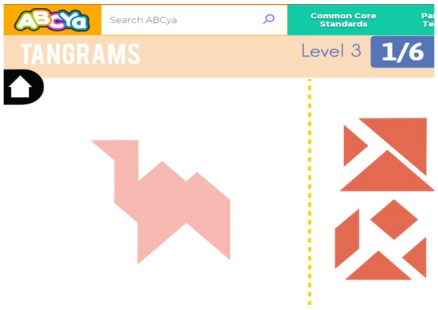

Figure 4: Online-resource "Abcya"

mathematics lessons, the solution of graphic dictations can also be presented as a series of problems to be solved (Figure 6).

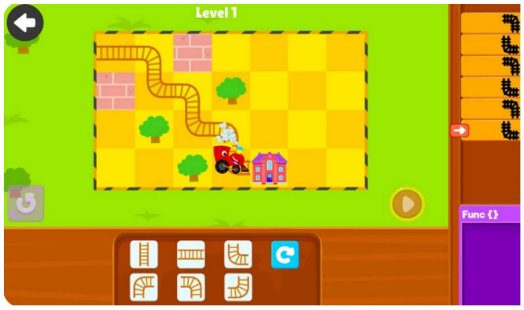

Figure 5: A practical task for building a movement algorithm. Online-resource "Coding Games For Kids"

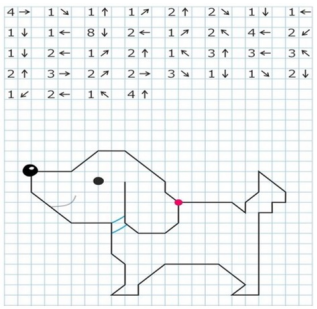

Figure 6: Graphic dictation

The type diversity of online resource links teachers use at different lesson stages at elementary school (Olefirenko, Kostikova, et al., 2020). In this regard, it is essential to search for ways to maintain the interest of younger students in learning mathematics at each educational stage and to lay the foundation for their future success in acquiring new knowledge. The use of modern online resources contributes to the formation and development of persistent cognitive interest in mathematics in students of primary school age for the following reasons (Andriievska, Olefirenko, 2016):

- positive emotional attitude of elementary school students toward working with online resources;
- Utilization of complex math tasks that can have multiple solution methods (increasing the complexity of tasks each time, offering problem-solving opportunities that require creativity and cleverness);

- Providing timely assistance, which allows not only to avoid knowledge gaps but also to gain confidence and belief in one's abilities;
- organization of practical activities with objects of study, enabling students to imagine and predict the full range of possible consequences of their actions, thereby expanding the scope of theoretical and practical knowledge and interdisciplinary skills;
- Organization of systematic and purposeful independent work.

An additional motivational factor can be opening a gaming component during mathematical problem-solving for younger students, with the possibility of winning the game or receiving a bonus, prize, and so on (Figure 7).

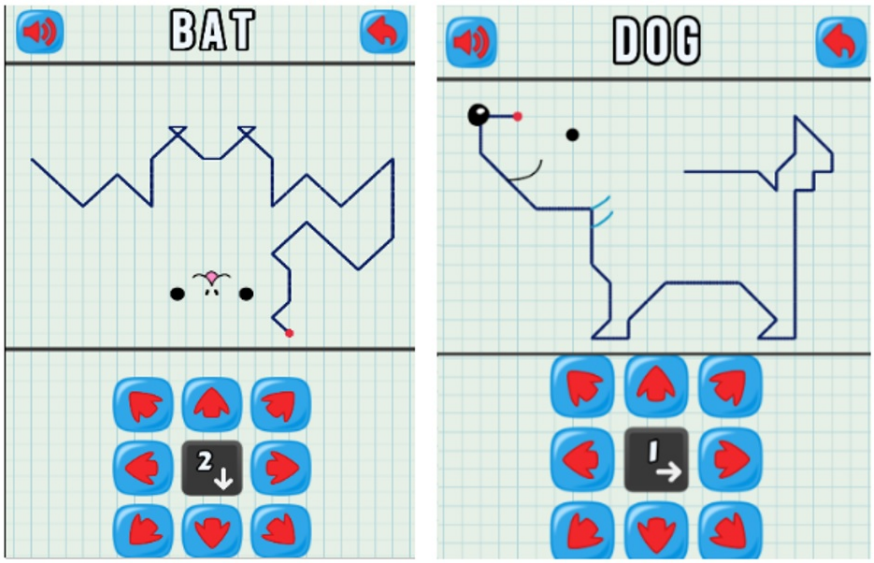

Figure 7: Cokogames: Graphic Dictation

Among the advantages of using online STEAM resources, one can also highlight (Andriievska, Olefirenko, 2016):

- Using online STEAM resources that offer elementary school students the opportunity to solve a large number of similar mathematical problems in a short time;
- schematic presentation of educational material;
- organizing each elementary school student's activities along their learning trajectory, depending on their abilities, knowledge, and the need for in-depth learning;
- Providing timely assistance to elementary school students (which can be implicit, upon request, provided by the program's character, etc.);

- Swift access for elementary school students to the necessary materials – in one resource, there can be a model for the student to experiment with, additional examples, textual explanations, in-depth materials, and more.

The online resource "Bee-Bot" (`https://www.terrapinlogo.com/emu/beebot.html`) contains interactive mathematics simulators (Figure 8). Working with such a resource is similar to practical work with the "Bee-Bot" robot.

Figure 8: Online-resource "Bee-Bot"

Expanding the range of tools to support the use of elements of STEAM education in teaching mathematics, the electronic designer "Artec Push-Button Programmable Robot" deserves special attention. It aims to master students' mathematical literacy and informatics (Figure 9). For work with the designer, the workbook "Artec WorkSheet" (Push-Button Programmable Robot, online resource) offers a series of experimental and research exercises, for example, constructing and measuring angles (Figure 10), determining the distance, etc.

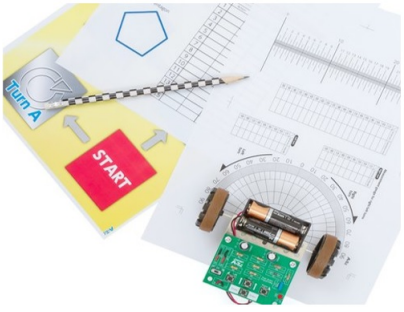

Figure 9: Artec Programmable Robot

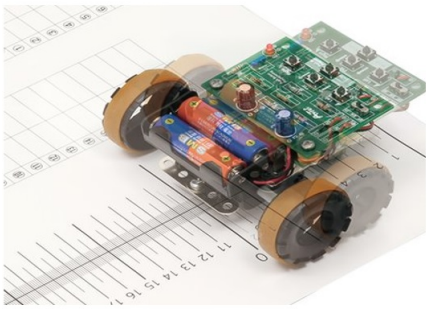

Figure 10: Practical task (Artec Programmable Robot)

In such work, younger schoolchildren learn, for example, that the figure "triangle" is the most rigid figure of all geometric figures, and one of the exciting projects works of students is the STEAM project "Corners around us" (Figure 11–12). The practical results of work on the project are:

- actualization of knowledge about geometric figures;
- actualization of knowledge about the concept of "angle" and its elements – vertex, sides;
- mastering the skills of drawing angles, recognizing angles in polygons;
- expanding students' knowledge about the use of triangles in various spheres of our life (familiarization with various building structures (bridges, architectural monuments, etc.), their analysis of the use of triangles in construction and the meaning of "angle" in multiple structures);
- Increasing interest in mathematics through research tasks, etc.

The research tasks have different implementation directions. For example, to update their knowledge of the concept of "corner," students study the geometry of Ukrainian embroidery (names, days of the week, words encoded in embroidery (Figure 11), symbols of Ukrainian embroidery (Figure 12), etc.).

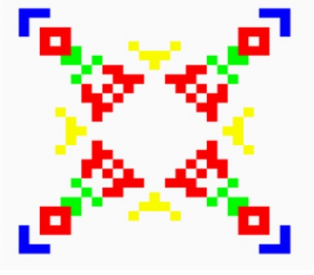

Figure 11: Coded word "School" (Ornament, online resource)

Figure 12: Practical task (Symbolism of Ukrainian (Sacred symbolism of Ukrainian embroidery, online resource)

Various disciplines are involved in the implementation of the project. In particular, students can recreate an e-ornament during computer science lessons. The peculiarity of creating such an ornament is that schoolchildren freely experiment with individual elements: change the color or size of the elements, replace the elements, add or remove parts of the ornament, etc. Repetitive details of the ornament enable accessible copies and movements while changing the inclination angle. In addition, the created details of the ornament, like the ornament itself, can be saved in color or monochrome and used in the further work of schoolchildren.

Of particular value are research tasks, the results of which are significant for children not only within the educational process but also outside of it. For example, students were especially interested in researching the correct working posture when using a computer, researching the angles of inclination of the body relative to the computer, etc. (Figure 13). This task continues when studying the "comfortable seat angle," particularly in a car or bus, how to choose the "correct" work chair, etc. Thus, schoolchildren will learn that lowering the head when working at an

angle of 150 contributes to a load on the spine of 12 kg at 300-18 kg. Practically, students and the teacher determine the most optimal posture when working at the computer, learn about the consequences of the "wrong" working posture, and much more

Figure 13: Correct posture at work at a computer (Kamińska, Tokarski, 2016)

As part of the STEAM project "Corners Around Us," elementary school students are offered research tasks in various spheres of human activity. For example, students learn that the angular coefficient of stability determines the construction of cranes. Practically, students explore this assumption using accurate models. Another enjoyable task is to study the convenience and "correctness" of choosing a book stand (the book stand should have several angles of inclination, which allows you to place books at the angle required for reading), etc. Practical orientation in STEAM education increases the need for practice based on knowledge, new skills, and research. STEAM education eliminates the gap between the theoretical solution of the problem and the practical implementation of acquired knowledge. Therefore, more is needed to give knowledge today. It is necessary to create special conditions under which the young generation acquires the ability to use knowledge in real-life situations and real-world problems. For example, the STEAM project "The problem of the waste is one of the global environmental problems of the modern world." During the project, elementary school students investigate the development of the problem in the history of humanity and the state of the problem in the world in the context of the family's everyday life. Using actual scientific data, elementary school students visualize this information to investigate earth processes in Math (Bilousova, Andriievska, 2017). With the help of ICTs, students visualize the data in different forms (preparing charts and comparative histograms representing the number of illegal landfills relative to the population in the city, etc.). In this project, elementary school students use math to identify the causes of illicit landfills in Ukraine. The STEAM project "The problem of the waste is one of the global environmental problems of the modern world," based on the theme of math (math modeling; elementary statistics, submission of data,

etc.), allows students to study math in the world problems while analyzing statistical evidence, presenting numerical data in graphical form, etc. and understand the importance of math and its applications in every aspect of our life.

Conclusions and perspectives for further research

Thus, the use of specialized tools opens broad prospects for the practical implementation of the STEAM concept in the system of mathematics education but also significantly modernizes it based on stimulating students' curiosity, interest, and active cognitive activity, forms their subject position, initiative and independence in the acquisition of knowledge; it directs their interest in mastering the skills of finding non-standard solutions to problems, actively acting in new situations, an original departure from stereotypes during actions, and cooperation. Undoubtedly, a modern teacher should be trained to work in a new digital society and face high expectations regarding teachers' competencies relating to STEAM education. Further research will examine the practical implementation of STEAM education in primary schools based on personal IT devices.

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