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ICT and current trends as a path to STEM education: implementation and prospects

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Abstract. The aim of the study is to build a model for the introduction of STEM education in institutions of general secondary education, to demonstrate the experience of using ICT in STEM education. Research objectives: to determine the role and place of information and communication technologies in the model of introduction of STEM education in general secondary education institutions for the formation of key competencies; to find innovative solutions to create conditions that will promote the interest of student youth in the choice of STEM professions. Object of research: the model of the introduction of STEM education in institutions of general secondary education Subject of research: information and communication technologies in the model of introduction of STEM education in institutions of general secondary education as a component of the school educational environment. Analysis of scientific publications makes it possible to determine the role and place of ICT in the model of introduction of STEM education in general secondary education institutions. The presented experience of the systemic implementation of STEM education in general secondary education institutions allows the formation of professional competencies of teachers in the field of STEM education and can be useful in their professional activities. The study shows that the systemic implementation of STEM technologies in the educational process increases the effectiveness of training, the level of motivation of participants in the educational process and the quality of knowledge in the subjects of the natural science cycle, and also contributes to the formation of key competencies of students.

Keywords: STEM, STEM education, ICT, STEM education implementation model, digital services, augmented reality, virtual reality, key competencies

1. Introduction

STEM is a popular trend of education that encompasses the natural Sciences, Technology, technical creativity (Engineering) and Mathematics. This is a direction in education, in which the curriculum enhances the science component in combination with innovative technologies [12].

The key characteristics of STEM education's educational activities consist of the following features: integration of science, technology, engineering and mathematics; organization of educational activities based on the system of learning progression; providing contextual learning;

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innovation-based learning; organization of activities focused on designing and solving problems; use of authentic and formative assessment [5].

The tasks of STEM education are: formation of skills for solving complex practical problems, critical thinking, creative qualities and cognitive flexibility, organizational and communication skills, ability to assess problems and make decisions, readiness for conscious choice and mastery of future profession, financial literacy, holistic scientific worldview, values landmarks, general cultural, technological, communicative and social competencies, mathematical and natural literacy; comprehensive development of personality by identifying its inclinations and abilities; mastering the means of cognitive and practical activities; upbringing of a person who strives for lifelong education; formation of skills of practical and creative application of the acquired knowledge.

The main advantages of STEM education:

- the opportunity to develop ingenuity and creativity, which leads to new ideas and innovations;
- ensuring the sustainability of learning in a safe environment;
- encouragement of research and experimentation;
- encouraging students of all ability levels to work together in a team environment;
- encouraging the application of knowledge and skills that can be used in the real world;
- encouragement to use technic and innovative technologies;
- formation of problem-solving skills;
- encouragement to adapt to different scenarios [19].

Working with STEM is often called the work of the future as the sector continues to grow.

According to the 2018 US News and World Report, students study STEM fields twice as often as their parents, and 52 percent of parents surveyed believe that the number of STEM jobs in the United States will increase significantly in the coming years. Two out of five Americans say that the shortage of STEM workers is at a "crisis level" in the United States, and there is a need for more people to take on such roles. The distribution of demand for specialists in the fields of STEM, according to the Bureau of Labor Statistics of the United States in 2018 is shown in figure 1.

Science and industry are experiencing an acute shortage of IT specialists, programmers, engineers, specialists in high-tech production of bio- and nano-technologies.

State STEM education programs have been adopted in Australia, China, Great Britain, Israel, Korea, Singapore, and the United States to meet such requests.

Strengthening the role of STEM education is one of the priorities of modernization of education, an integral part of public policy to raise the level competitiveness of the national economy and human development capital, one of the main factors of innovation in education, that meets the demands of the economy and the needs of society [21].

2. Related work

A brief overview of the history of the STEM and STEAM is presented in [4]. This article traces a history of STEM and STEAM. It also provides an assessment of the risks inherent in current trends of STEAM roll-out in schools, from the lack of resources for professional development.

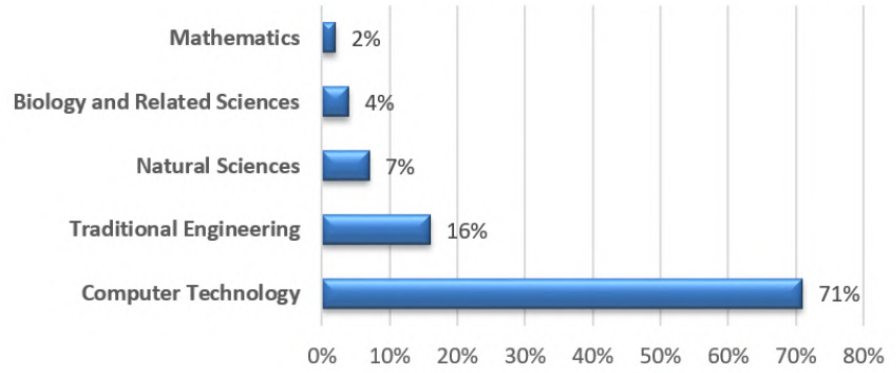

Figure 1: The distribution of demand for specialists in the fields of STEM, according to the Bureau of Labor Statistics of the United States in 2018.

Review the implementation of STEM Education models in the early 21st century is presented in the work [50].

The aim of the study by Gencer et al. [8] is to explore integrated STEM models at theoretical level based on the literature examination about integrated program approaches.

The study of Li et al. [17] probes into the localization of STEM education based on the present situation in China. In the educational model of "STEM education + creator", this study finds out the model of integrating STEM education into the talent cultivation process by means of creator space.

Kramarenko, Pylypenko and Zaselskiy [15], Midak et al. [22], Semerikov, Mintii and Mintii [38], Shapovalov et al. [41, 42, 43], Shapovalov, Shapovalov and Zaselskiy [44], Shyshkina [46], Slipukhina et al. [47] define the conceptual and categorical apparatus on various aspects of STEM education, cover the introduction of STEM technologies in educational institutions.

Analysis of models of integration of formal and non-formal STEM education in Ukraine is offered by Polikhun et al. [35]. The authors reveal the features of the educational STEM environment and offer methodological approaches to the organization of STEM projects.

Sharko [45] considers the methodical problem of teaching students STEM disciplines.

Morze, Gladun and Dziuba [28] analyzes modern views on STEM education and features of its introduction into the educational process, the impact on student motivation; demonstrated the need to prepare students for the skills of the twenty-first century through the introduction of STEM education, starting from primary school. The key and subject competencies that can be formed in children while learning the basics of robotics are described.

Theoretical and practical aspects of informatization of education, in particular the use of information technology as one of the areas of implementation of STEM education, studied by Fedorenko et al. [7], Hlushak, Proshkin and Lytvyn [10], Morze, Kuzminska and Protsenko [26], Morze et al. [27], Morze and Kucherovska [29], Morze and Strutynska [30, 31], Ramsky and Rezina [36], Semerikov et al. [39, 40], Spirin et al. [48, 49].

Erasmus+ project "STEM in Education" aims to encourage and inspire teachers of STEM – science, technology, engineering and mathematics – to teach using supporting Information and communications technology (ICT) [13].

Erasmus+ project entitled "Inclusive STEM Education to Enhance the capacity to aspire and imagine future careers" (I SEE) designs innovative approaches and teaching modules to foster students' capacities to imagine the future and aspire to STEM careers. The goal is not only to develop professional skills but also to foster students' identities as capable persons and citizens in a global, fragile and changing world [11].

The STEMkey Erasmus+ project "Teaching Standard STEM Topics with a Key Approach to Competence" develops training modules that are used in higher education programs for future STEM teachers, which transforms the learning abilities of future STEM teachers [32].

A large number of international scientific and practical conferences (Conference of Space Research Educators, STEM Annual Educational Conference, California STEAM Symposium, STEM Solutions Conference) confirms the relevance of STEM technologies in education and the interest of the scientific community in these innovative issues.

In Communal Higher Educational Establishment "Kherson Academy of Continuing Education" of Kherson Regional Council there is an extending experience in teachers' trainings in STEM education [16].

3. Problem setting

Education reforms in the field of science, technology, engineering and mathematics (STEM) are especially important for the competitiveness of Ukraine and other countries of the world.

In modern conditions of technology development, the issues of practical implementation of STEM approaches in education are relevant, in particular, the problem of the development of an information educational environment is one of the key ones.

The object of the research is the model of introduction of STEM education in institutions of general secondary education.

The subject of research is the information and communication technologies in the model of introduction of STEM education in institutions of general secondary education as a component of the school educational environment.

The purpose of the article is to build a model for the introduction of STEM education in institutions of general secondary education, to demonstrate the experience of using ICT in STEM education.

Research tasks:

- to analyze the main features and benefits of STEM education;
- to build a model for the introduction of STEM education in institutions of general secondary education;
- to determine the role and place of information and communication technologies in the model of introduction of STEM education in institutions of general secondary education for the formation of key competencies;
- to find innovative solutions to create conditions that will promote the interest of student youth in the choice of STEM professions;
- to demonstrate the experience of using ICT in STEM education in the practice of modern educational institutions, to summarize the obtained data and provide conclusions.

4. Model for the introduction of STEM education in institutions of general secondary education

The main conditions for the development of STEM education in secondary school are:

- development of values to achieve a common goal;
- team and leaders;
- STEM education model;
- STEM education development plan;
- learning and gaining new experience;
- expanding the circle of like-minded people and presenting the results.

The model for the Introduction of STEM Education in Institutions of General Secondary Education is presented in in figure 2.

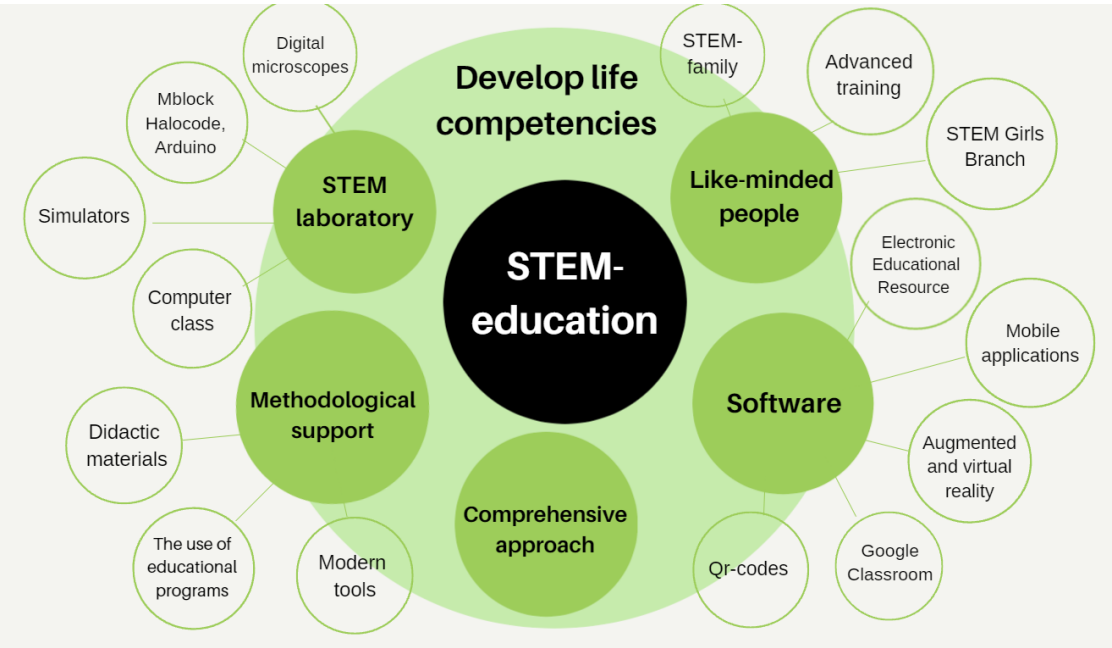

Figure 2: The model for the introduction of STEM education in institutions of general secondary education.

For the systematic implementation of STEM education in the institution it is necessary to: study the approaches and features of modern STEM education; introduce a policy of transformation of the institution with STEM; develop a strategy and implementation plan; determine resource provision and indicators.

The purpose of introducing STEM into the educational process: the formation of key competencies of students.

One of the most important components of the model for the introduction of STEM education in general education institutions of secondary education is the formation of a circle of like-minded

people among the administration, teachers, students and their parents, including through joining the STEM Girls communities, the formation of a STEM family, professional development of teachers (participation in webinars, trainings, contests, olympiads).

Information and communication technologies act in STEM education both as a subject of study and as a means of teaching. Therefore, the creation of a unified information and educational environment that ensures the management of the educational process, the exchange of ideas and thoughts, and joint work on projects is a prerequisite for the implementation of STEM in an educational institution.

Such an environment includes:

- STEM laboratories with appropriate equipment (computers, tablets, electron microscopes, 3D printers, robotic constructors and platforms, etc.);
- software (distance learning systems, mobile applications, augmented and virtual reality applications, e-learning resources, cloud environments, etc.);
- methodological support (methods, forms, teaching aids: textbooks, manuals, didactic materials, etc.).

Changes should take place in all areas of activity of the educational institution: creation of infrastructure; content and assessment of student achievement; teacher training; ensuring continuous monitoring [24].

5. Practic ICT and current trends in education

In the conditions dictated by modernity, it is necessary to "keep an eye on the pulse" of new technologies. The development of society, science and technology puts the education system in front of the need to use new tools, forms and methods of teaching. The modern world dictates new rules that require students: critical thinking, communication, creativity and teamwork. Departure from old projects in the form of printouts to improvements, modern multimedia projects, ready-made products that students do themselves.

Students in the classroom should be able to implement the idea with further refinement and improvement. Proceed from the framework of standard and established concepts and show creativity. Teachers need to prepare children not just for monitoring, not for performance, but for a successful future.

The test for many was distance learning, which forced them to quickly adapt to work in the digital world. Teachers also faced the issue of distance work on an individual trajectory, finding tools to become distant assistants to students, support the learning process and increase motivation to work.

Information and communication technologies have radically transformed the educational space, qualitatively changed the environment, opened new opportunities and became a basic system forming factor in the development of education. Smartphones are simply indispensable assistants in learning. And it's not just the use of e-classrooms through applications (such as Classroom, Universe, Matific), but also a lot of creative opportunities. It's no secret that the use of Qr-codes, augmented and virtual reality is now becoming popular. At the time of available technologies, it is not difficult to master and use them. Qr-code has firmly taken its place in

education. The practice of use is also in new textbooks, notebooks, including the publishing house "Ranok", which provide electronic support and place access to electronic simulators near the test papers (the student has several attempts and the opportunity to download or send the result to the teacher).

Augmented reality technology promises to be no less common in education. It is becoming very popular nowadays, and we are showing more and more interest in it. Encyclopedias, fairy tales, and educational literature already contain "hidden worlds". Mobile applications are happy with the variety [20]. Augmented Reality (AR) technologies are able to project digital information (images, videos, text, graphics) outside the screens of devices and combine virtual objects with the real environment [37]. Virtual Reality (VR) with the help of a 360° image transports a person to an artificial world, where the environment is completely changed [1]. You can get acquainted with augmented reality with just a smartphone, but to dive into the virtual space you will need a special helmet or goggles [33].

These immersive teaching methods can potentially become a key tool in education and revolutionize the learning of both schoolchildren and students. Teachers can use virtual and augmented reality for students to interact with different objects in three-dimensional space [34].

Importantly, the introduction of elements of STEM education helps to form the following competencies: information, lifelong learning, initiative and entrepreneurship, social and civic, mathematical, information-digital and basic competencies in science and technology.

Unfortunately, some teachers are still apprehensive about adopting STEM approaches in education to their own arsenal. There are certain fears, "myths" and stereotypes. It is necessary to start attracting new educational trends with the "education" of the leadership in this matter, the involvement of activists. Get acquainted with the experience of implementation practitioners, analyze and choose your own implementation model.

6. Experience of STEM implementation in school

The path to STEM education at Rakivskiy institution of complete secondary education began with a combination of information technology, mathematics and art. Thanks to the knowledge and skills acquired through self-education and refresher courses, teachers introduce students to new trends in education: qr-code, cloud services, e-testing, learn to create e-textbooks and deepen their knowledge in STEM.

To deepen their skills, engage students in IT, and prepare for success, they have been trained and instructed in the Cisco Sandbox. The Network Academy not only gives a start to successful IT specialists, but also prepares conscious users, for whom, in our opinion, the future of STEM education.

The model of realization of STEM education became the own "formula of success", which helps to encourage students to independent and creative activity, provides attraction of "atypical" forms of work.

Modern tools: online tests, online Olympiads ("Na Urok", "Vseosvita", interactive school "Ranok"), Google applications, Microsoft Education opportunities, platforms "Matific", "My Class" and others help to motivate, raise interest in students, consolidate time in class and are

excellent helpers for teachers in preparing for class. Implementation practice includes not only the use of modern educational learning platforms during classes, but also the use of: mobile applications, augmented and virtual reality, makering and design.

The use of educational programs, opportunities for virtual learning space, classes in the sandbox of the Cisco Network Academy (IoT and Cybersecurity course) enhances the prestige of rural schools, allows to take into account the eco-component, financial literacy and to use a gamified approach to learning.

Work on the implementation of ICT in Rakivskiy institution of complete secondary education began in 2018 with a pilot project of using the Electronic Educational Resource "MyClass" [23]. Rakivskyi institution is one of the 100 schools in Ukraine that have started implementing this resource. The resource has in reserve most of the school subjects, designed not only for work in the classroom, but also at home, monitoring, activity tracking and an interesting system of TOPs. The percentage of students involved on the platform exceeds 60%. Students actively work on the platform, compete with each other, organize competitions between classes, in addition to grades, they also have the opportunity to receive awards ("MyClass" diplomas for first places in the TOPs). It is nice that parents and teachers are also interested in the resource. As a result, the leading 3rd place among users-institutions of the Kherson region.

A year later, the school's mathematics teachers began to actively use platforms such as Geogebra (for students in grades 7–11) and Matific (for students in grades 5–6, a digital math platform developed by education experts) to help implement practical application of knowledge in an interesting and cognitive form (figure 3).

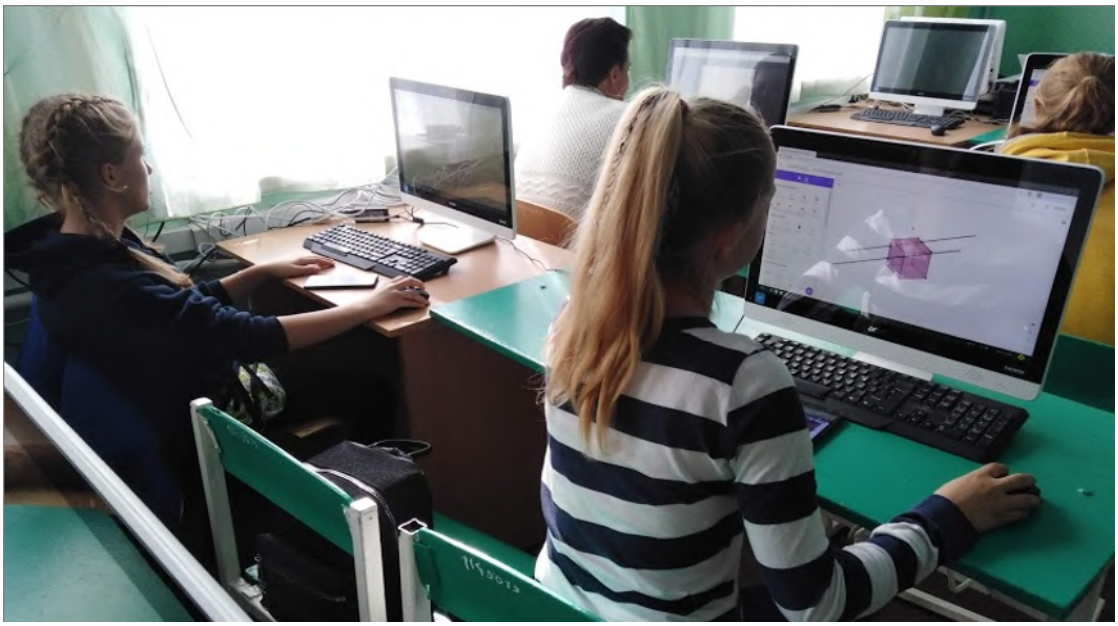

Figure 3: Using the GeoGebra environment to build models in geometry lessons.

GeoGebra is more than just a free dynamic geometric environment [6, 14]. The use of this tool makes complex drawings interesting and clear, "dry" mathematical processes – turns into

almost scientific work. Especially children like working with 3D scenes, the ability to "explore" objects in full, for example, working with applications in geometry lessons, when studying geometric bodies and constructing their cross sections. A rather complex topic becomes more accessible, it saves time for understanding and helps in application, acquisition of skills. The processes are no longer boring, and children are given the opportunity to put into practice the acquired knowledge.

The Matific training platform, recommended by the Ministry of Education and Science of Ukraine, provides for three ways of use: assignment of tasks and tracking of successes; individual topics; use of planned tasks. The system allows you to work not only with interesting, interactive tasks, but also to move your own learning trajectory, gives the opportunity to compete in the "Arena" with classmates from around the world in mathematical dexterity. It has a good system of motivation, so students not only work on lessons, do homework (15–20 minutes), but also conquer bonus missions, find time for additional work, which brings success that is very pleasing.

Matific uses game principles to encourage students to learn through discovery, and has tools for teachers, including worksheets, lesson plans, and real-time reporting. The program is available not only online but also offline. The system works in a browser and can also be downloaded as a mobile application (separate versions for teacher and student). It is possible to update the database to receive tasks and send results. Children like this form of activity, they are actively involved in the opportunity to work with the platform (in lessons and homework). The institution uses a platform for students of 2nd, 3rd, 5th and 6th grades. Matific provides an exciting opportunity to learn mathematical concepts that previously frightened and "disobeyed". It's fun, rewarding and open to all students (figure 4).

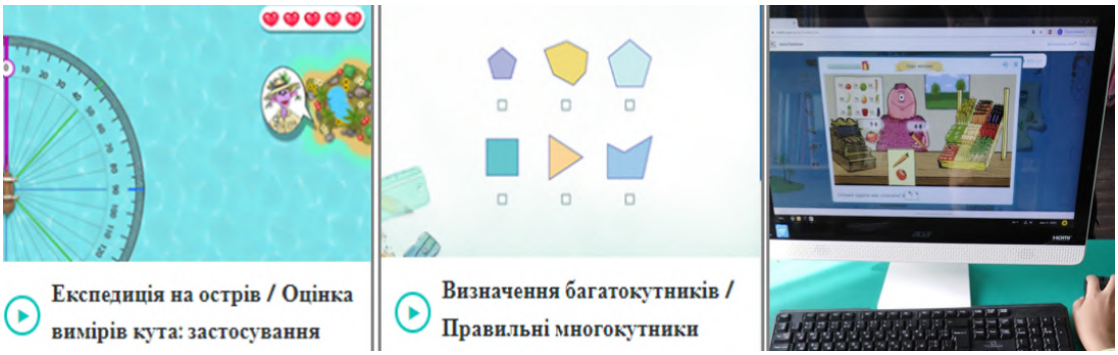

Figure 4: Using the Matific environment in Math lessons.

In addition to mastering learning platforms, the possibilities of QR codes are used: setting up access to students' electronic classrooms, for registration for quests, courses, etc., placement of schedules, applications, instructions and assessment of tasks. Such an organization is convenient and practical for both students and teachers (figure 5).

An additional motivation is the attractiveness of color and shape and the use of link abbreviations (which make it possible to monitor the work with codes). Students have quick access to learning materials and do not spend time searching and entering long links.

Figure 5: Using the QR codes in learning materials.

The use of Google Classroom allows you to organize activities in offices, set up joint activities [3], and is a tool for extracurricular activities, such as web investments. Google Classroom can combine several tools in one activity. For example, the Da Vinci Footprints website provides an opportunity to learn about machines of a well-known kind, offer augmented reality research (augmented reality supplement for Da Vinci Machines AR), travel the Internet, and present a real test of the invention, the Challenge of Creation [18].

The Google Classroom provides a wide range of related tools and extensions that automate routine operations, help diversify, and support the learning process.

An important aspect of the implementation of STEM education is the continuous professional development of teachers. Thus, teachers mastered the course on the secrets of distance learning "NonStop Education" 2.0 and Pitch "Immersion" in STEM at the Kherson Academy of Continuing Education. Workshops on the use of web tools in distance and blended learning and a course on immersive technologies were also useful.

Augmented and virtual reality applications play an important role in education. Augmented reality makes it possible to interact with the subject, to explore the properties that are useful not only in the study of mathematics (spatial figures), but also in the study of biology (cell structure, the structure of the human body).

Quiver – 3D Coloring App allows you to "revive" the child's colored coloring pages. The database contains images of plant and animal cells, maps, images of sea creatures, volcanoes that can be used in educational training. The appendix also contains materials useful for mathematicians: Platonic solids and materials for the study of magic numbers [2]. Quiver – 3D Coloring App is used in lessons I Explore the World (New Ukrainian School) and in extracurricular activities (figure 6).

A digital microscope is used to carry out research in STEM projects. The eyepiece through which the object is observed has been replaced by a digital camera. Objects of natural origin are used for research; objects man-made; objects are studied, compared and their properties are distinguished. The studied objects are displayed on a personal computer monitor or on a

Figure 6: Using augmented reality applications.

projection screen, which allows you to perform research in group work, developing skills of teamwork. Digital microscopes can be used at different stages and types of lessons. Students have increased motivation and cognitive activity. Photos and videos taken during the work are used for editing videos, creating educational projects in computer science lessons (figure 7).

Figure 7: Using a digital microscope in STEM projects.

Cisco sandbox classes are conducted under the guidance of an instructor. The Cisco Networking Academy provides access to computer science courses for teachers and students. Thanks to the capabilities provided by Cisco, students can work without special equipment.

The All-Ukrainian action “STEM Spring 2020” provides access to courses of different levels of difficulty: from a beginner who works with ready-made devices, to a user who is able to model physical space, program IoT work and is interested in competitions. Packet Tracer simulator

can be downloaded from the website. Students learn to model smart devices, program, create models of houses, rooms, etc.

Involvement in All-Ukrainian activities, in particular the marathon "Girls power tech" and the master class "ANYONE CAN CODE", which gives an opportunity not only to study interestingly, acquire useful skills, but also to receive awards of success, plays an important role in strengthening students' motivation for STEM technologies (stylish certificates, digital badges, valuable gifts).

Students are involved in learning the basics of programming through the use of wireless single-board computer Makeblock HaloCode, which the institution received as a result of winning the ideas of Hackathon 2019. Makeblock HaloCode is a single-board computer with built-in Wi-Fi for programming (includes a wide range of electronic modules). HaloCode offers a variety of features for working with AI & IoT applications with a few mouse clicks; it makes learning programming easy, fun and interesting. HaloCode allows you to use IoT applications and create simple, home devices. Provides access to the microphone module and support for Microsoft Cognitive Services. Sensors allow the use of HaloCode for the implementation of STEM projects [9].

Since 2020s, the direction of robotics has developed. Students use Makeblock and Arduino technologies in integrated stem projects, studying physical laws, programming, mathematics [25].

The use of the above-mentioned tools is good in combination, most of them are not limited to a specific subject or cycle of lessons. The success of STEM education lies in a comprehensive approach. However, ICTs are an important catalyst for the effective implementation of STEM education.

Analysis of the results of the implementation of STEM technologies for 3 years allows to identify an increase in performance and motivation to learn. The use of ICT helped to involve students in active work and mastering the subjects of the natural-mathematical cycle. Thanks to the method of blended learning, the "flipped classroom", which began to be implemented from the 201-8-2019 school year, the students of the institution were ready to work under quarantine restrictions. Educational platforms, remote classes such as google classroom and webinar rooms were common-place. The only obstacles were limited access to quality internet coverage and difficult technical conditions in some families due to financial constraints. Indicators show that the use of ICT in the classroom helps to increase the level of academic achievement in distance and blended learning. For example, we offer monitoring of educational activities in mathematics (table 1, figure 8).

The result of active work with STEM directly is the victory in the competitions "Na Urok", "Vseosvita", "Kangaroo", the diploma of the most active STEM Girls Branch 2020.

As part of the cooperation, the official status of the STEM Girls Branch was confirmed, and a Cooperation Agreement was signed with the Center for the Development of Corporate Social Responsibility – STEM Girls Community to strengthen and develop educational and scientific activities, including for further development and implementation of STEM education in Ukraine; Cisco Academy opened in the institution; the strategic plan of the Rakivskiy institution for the next years is created.

An important condition for the implementation of STEM education is the presence of a team. The activity of a team of like-minded people allows you to find funding, develop and develop. To

Table 1
Monitoring the quality of mathematics studies in the institution.

Level	2017–2018	2018–2019	2019–2020	2020–2021
Initial	15%	15%	14%	14%
Average	62%	57%	49%	46%
Sufficient	23%	23%	35%	36%
High	0%	5%	3%	5%
Quality of knowledge	23%	28%	38%	41%

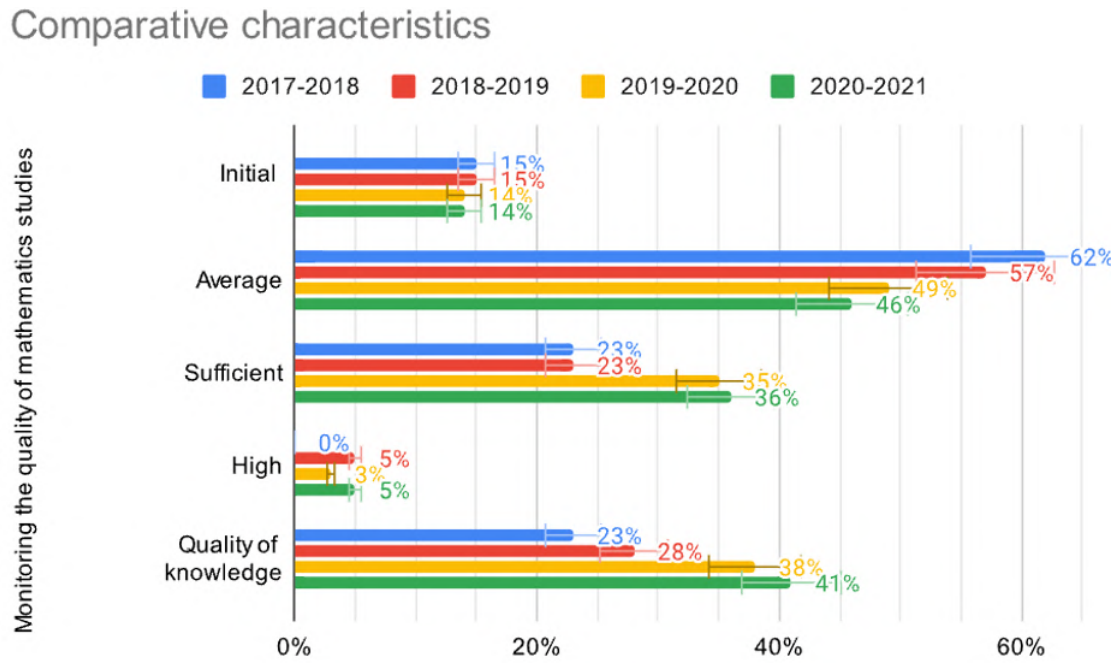

Figure 8: Monitoring the quality of mathematics studies in the institution.

spread the experience, it is necessary to constantly cover the work on the site of the institution, to keep a blog so that the community monitors the success of the institution. It is necessary to promote STEM education, make it attractive for students and parents, overcome stereotypes and attract as large an audience as possible. Therefore, the institution: created its own YouTube channel; the page of the STEM family of the institution was published on Facebook; published the page of the STEM Girls Branch in social networks Facebook, Instagram (rakivkastream) and Tik-Tok (@girls_stem).

7. Conclusions and outlook

To prepare a successful graduate, it is necessary to develop life competencies, and the main conditions for their development are the formation of reading, mathematics and competence in

the natural sciences. We consider it important to form a STEM family, which unites a community of teachers, children and their parents, helps to implement the idea of holding STEM weekend, STEM camps during the holidays, which includes involving all participants in the educational process in active STEM activities. Disclosure of the benefits of STEM and the destruction of gender stereotypes can enhance career guidance for choosing STEM professions.

For the effective implementation of STEM education it is necessary: development of scientific and methodological support and introduction of modern teaching aids; training and advanced training of scientific and pedagogical workers; expansion of the network of regional STEM centers; conducting scientific and applied research; analysis of the dynamics of STEM education development, identification of problems and forecasting of further tendencies of STEM education directions implementation [21].

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