*Educational Technology Quarterly*, Vol. **2021**, Iss. 1, pp. 118-139 https://doi.org/10.55056/etq.24

# Use of digital tools as a component of STEM education ecosystem

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**Abstract.** The authors investigate the theoretical foundations of the concept of ecosystem, interdisciplinary approaches and features of integrated STEM education in the educational process, analyzed the components of the educational ecosystem and proved that they all directly affect the quality of STEM subjects. The authors conducted a survey to identify ways to develop components of the ecosystem of STEM education, which involved 105 respondents, students of pedagogical specialties of Borys Grinchenko Kyiv University and teachers of secondary schools in different regions of Ukraine. The analysis showed that the successful implementation of STEM education, involving all components of the ecosystem, involves the development of science education, in particular, the introduction of inquiry-based learning and the use of digital technologies in the educational process. Process skills are described, which are formed using inquiry-based learning, examples of tasks for the formation of basic and integrated skills of the scientific process are presented. Based on the research, the role of digital tools in the development of science education is demonstrated and groups of digital tools are identified that are necessary for ecosystem development and will help increase the efficiency of the educational process, make STEM learning interesting and productive; examples of digital resources that support students' learning in various integrated STEM environments are given and their role in the development of the STEM education ecosystem is described. Digital tools can be used to increase students' positive motivation, expand their experience and accelerate learning, they help to study STEM subjects and encourage students to explore scientific ideas in new ways.

**Keywords:** ecosystem, STEM education, STEM classes, digital technologies, digital tools, skills in organizing scientific processes, science education

## 1. Introduction

Today, education programs emphasize the importance of providing students with a thorough education in science, technology, engineering, and mathematics (STEM). STEM education has been of great interest to educators and researchers in recent years [33]. The introduction of STEM education leads to the search for alternative approaches and teaching methods that can meet the challenges of Industry 4.0. In addition, teachers view STEM education as a learning strategy, an innovative approach to learning, learning technology, assessment, teaching aids, teaching materials and textbooks [16].

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According to the National Teachers' Association, STEM education is an interdisciplinary approach in the educational process that integrates academic concepts with real-world lessons in which students apply their knowledge of science, technology, engineering and mathematics to specific situations [42]. It also shows that the focus on STEM education is a key area of world education during the Industrial Revolution 4.0.

The New Ukrainian School (NUS) Concept [13] and the Law of Ukraine On Education [30] identify 10 key competencies, among which the development of competencies related to STEM education is of particular importance: mathematical literacy, competencies in science and technology, information and digital competence, the ability to learn throughout life and entrepreneurship. In addition, the concept of development of natural and mathematical education (STEM education) in Ukraine [28], the implementation of which is planned for the period up to 2027, states that in order to actively involve students in research and development, it is necessary to introduce new methods and forms of organization of the educational process.

The State Standard of Basic Secondary Education in Ukraine emphasizes that the requirements for compulsory learning outcomes are determined on the basis of the competence approach [10]. One of the key competencies defined in the standard are competencies "in the field of natural sciences, engineering and technology, which involve the formation of a scientific worldview; ability and willingness to apply an appropriate set of scientific knowledge and methodologies to explain the world of nature; gaining experience in studying nature and formulating evidentiary conclusions based on the information obtained; understanding the changes caused by human activity; responsibility for the consequences of such activities" – these are the competencies, the formation of which involves STEM education.

The Guidelines for the Development of STEM Education in General Secondary and Extracurricular Institutions in the 2021/2022 academic year state that "development of the national economy, ensuring the competitiveness of our state is possible through effective interaction of economy, science, education, human capital development, attracting innovation in all spheres of society. An urgent problem for science and practice, given the current educational trends, is the formation of competencies, worldviews and values, effective learning using a transdisciplinary approach to learning, based on the practical application of scientific, mathematical, technical and engineering knowledge and skills for further their use in professional activities" [35].

Given the above, it is advisable to consider more deeply the development of the ecosystem of STEM education in the context of developing skills in organizing the scientific process in the implementation of science education and the use of digital tools as components of the ecosystem. Analysis of recent research and publications.

## 2. Literature review

The development of STEM education involves the formation of science education. The works of various authors are devoted to the study of the formation of science education. Milenina [36] analyzes the diachrony and potential of science education in the global dimension. Halchenko [21] notes that "the concept of science education emphasizes the prospects of knowledge production to prepare people adapted to living conditions in a society of innovative technologies and social standards, which are becoming more dynamic. Modern theory of science education

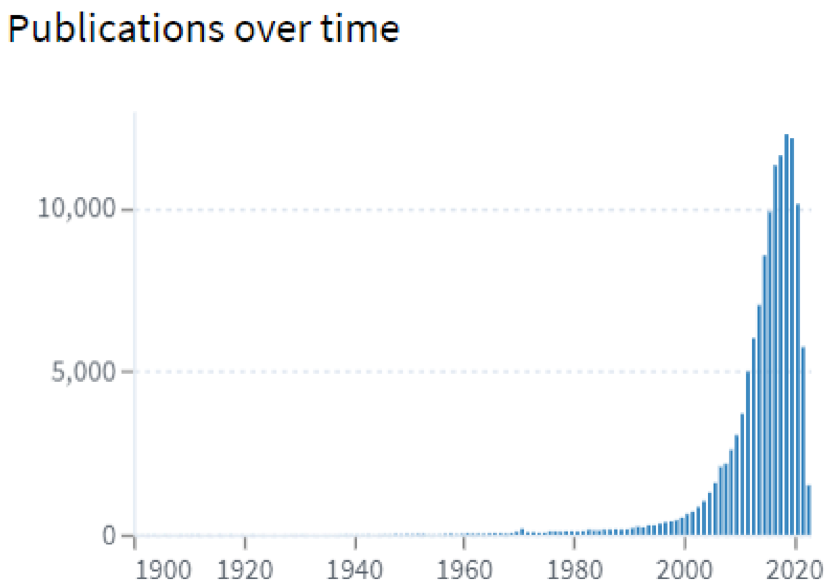


**Figure 1:** The growing number of scientific publications on STEM education in recent years.

affects all areas of educational and pedagogical practices, on their participants, attracting to the world of real and informal scientific knowledge" [21]. Substantiation of the need for science education in secondary school in the digital transformation of education is described in a study by Hrynevych, Morze and Boiko [22], which widely presents an overview of innovative pedagogical technologies that can be effectively used to spread scientific thinking to the wider list of subjects and the formation of STEM education.

In the research of many scholars, STEM education is seen as a promising approach that involves the use of an integrated curriculum that provides opportunities for "more relevant, less fragmented and more stimulating experience for students" [18, p. 186]. The problems of the real world are not fragmented in the individual disciplines taught in schools, and to address these challenges people need skills that cover these disciplines as a whole [9].

Over the last year, a significant number of different studies have been published (figure 1) on STEM education. This emphasizes the urgency of the problem of developing different methodological approaches to its implementation in the educational process of educational institutions.

Various aspects of t he use of technologies to support the implementation of STEM/STEAM education are considered by Borrego and Henderson [5], Bybee [6], Corlu, Capraro and Capraro [8], Dovgyi et al. [11], English [14], Kelley and Knowles [25], Kim et al. [27], Kramarenko, Pylypenko and Zaselskiy [29], Margot and Kettler [31], Mayo [32], Morze and Strutynska [39], Ong, Smith and Ko [44], Plaksenkova et al. [48], Pylypenko [49], Semerikov, Mintii and Mintii [53], Stryzhak et al. [55], Uttal and Cohen [58], Valko and Osadchyi [59], Xie, Fang and Shauman [63], Zeidler [65].

The development of local educational ecosystems STEM as broad educational networks is considered by Balslev et al. [3]. Researchers believe that local stakeholders can contribute to education by addressing key educational issues, and point to the role of school leaders in implementing the STEM ecosystem on the ground. Researchers at the University of Michigan are developing a STEM-ME framework to understand what is needed to develop mentoring in the implementation of STEM ecosystems [37]. A more detailed analysis of recent research and publications is discussed in the section 3.

*The aim of the article* is to determine the role of digital tools for building the ecosystem of STEM education and the conditions of its development.

## 3. Theoretical foundations of research

STEM is an educational approach that combines different sciences, technologies, engineering and mathematical thinking. An important concept related to STEM education is interdisciplinarity. Interdisciplinarity in education is considered as a pedagogical innovation [60]. The key pedagogical problem in the development of STEM oriented curricula is the technology of integration of components, which, on the one hand, are close disciplines, and on the other – independent established ontologies:

- *Science* as a way of knowing that helps to understand the world around us;
- *Technology* as a way to improve a world that is sensitive to social change;
- *Engineering* as a way to create and improve devices to solve real problems;
- *Mathematics* as a way to describe the world "analysis of the world and real problems with numbers" [34].

Such an integrated approach is natural and in fact in demand when a certain real problem is solved (for example, when organizing problem-based learning according to a chain of questions "What is it? How to deal with it? How and what to improve? How to present it clearly?" and others). Thus, there is a combination of scientific method, technology, design and mathematics in the basis of the development of educational STEM program. It is important that the result of integration may be the introduction of a separate subject STEM / Science or certain changes in the curriculum of each of the STEM subjects based on the introduction of innovations, strengthening the practical component in solving real problems.

Scholars distinguish between several types of interdisciplinary approach, depending on the nature of the links between disciplines (table 1).

Despite the potential benefits and increased focus on integrated STEM education, the implementation of this learning strategy faces several challenges identified by various researchers. First of all, the introduction of an integrated STEM approach in the educational system, which has a very well-established, discipline-based structure, requires a deep restructuring of the curriculum and lessons [40]. Moreover, integrated STEM education often requires additional teaching materials and educational resources and tools for students, such as construction tools (eg saws, gauges and hammers), electronic devices (eg computers, design programs, robotics kits and calculators) and other materials used in design (eg wood, foam, glue, cardboard or construction paper) [54]. Thus, creating a school culture and environment that supports an integrated STEM approach to teaching and learning can be costly and time consuming [40]. This requires the creation of an ecosystem to meet the educational needs of participants in the educational

**Table 1**
Types of interdisciplinary approach.

| Type | Description |
|---|---|
| *interdisciplinarity* | related to the study of research topics within many disciplines, as well as the transfer of methods from one discipline to another. The research topic integrates different disciplinary approaches and methods |
| *multidisciplinary* | compares several disciplines that focus on one problem, but does not combine them; multidisciplinarity refers to the study of a research topic within one discipline, support for other disciplines, combining different aspects. At the same time, the elements of disciplines retain their original essence. This contributes to the expansion of knowledge, information and methods |
| *cross-disciplinary* | the approach is related to the study of the research topic at the intersection of many disciplines, as well as the general features of the disciplines |
| *transdisciplinary* | goes beyond individual disciplines, focuses on a specific problem and the acquisition of relevant knowledge [23], which are related to all disciplines, between and beyond, in order to understand the modern world under the imperative of unity of knowledge |

process in the implementation of STEM [38]. In addition, for the effective implementation of STEM education, teachers must have a deep knowledge of scientific, technological, engineering and mathematical content they teach, and they must have specialized knowledge of how to teach students STEM content, and have special pedagogical knowledge and skills. However, many teachers report that they do not feel ready to use STEM programs with their students in the classroom [12]. Moreover, research by El-Deghaidy and Mansour [12] has shown that teachers do not sufficiently understand the importance of T (technology) in STEM and that they may not have a sufficient understanding of the basics of science and technology and the interaction between the two disciplines. Teachers' beliefs and attitudes towards teaching and learning, as well as their resistance or lack of motivation to change their beliefs and practices, can create another problem for the implementation of integrated STEM education [2]. In addition to the problems of finding resources and insufficient teacher knowledge, another problem for the implementation of integrated STEM education is the lack of consensus on how to implement integrated teaching and learning STEM [56].

One of the main approaches to the implementation of STEM is science education. Despite teachers' understanding of the importance of modern educational trends, the formation of basic competencies of teachers in science education is an important task for creating and maintaining a full-fledged STEM ecosystem [22].

The educational ecosystem is an environment that allows students to immerse themselves in different points to engage in learning. The term "learning ecosystem" was used as a way to describe the interaction of different components in the learning environment. For example, Chang and Guetl [7] note that individuals who study in the ecosystem can form groups and interact spontaneously in the same way as organisms within the biological ecosystem. How different stakeholders perform and adapt can contribute to or hinder the success of the educational ecosystem.

The National Research Council defines the learning ecosystem as "the dynamic interaction between individual students, the diverse learning environment, and the community and culture in which they are embedded" [41, p. 5]. The elements of the learning ecosystem include people; networks of people; designed and natural conditions; resources and difficult to define aspects such as history, culture and politics.

According to Traphagen and Traill [57], "the STEM learning ecosystem includes schools, community institutions such as extracurricular and summer programs, research centers and museums, as well as non-formal learning at home and in a variety of environments, which together provide a wide range of learning opportunities for young people" [57].

The STEM education ecosystems provide a cross-sectoral learning architecture, offering all young people access to rich STEM learning environments so that they can develop important skills and participate in science, technology, engineering and mathematics. Strong STEM educational ecosystems have dynamic collaboration between schools, extracurricular institutions and projects, STEM expert institutions (such as museums, research centers, universities and STEM professional associations), the private sector, NGOs, youth and families [62].

In the digital age, STEM ecosystems can be physical or virtual. Learning outside the classroom can be improved through the use of technology through video [43] and virtual laboratories.

"Inanimate" components are also part of educational ecosystems and include the physical environment and learning tools such as media and technology. Although the definition of the learning ecosystem seems to vary depending on the focus of stakeholders, many, if not most, use the term to focus on the role of technology in learning. However, in our opinion, the emphasis should be on, as suggested by Gu, Crook and Spector [20]. In addition, 21CLEO Research Team [1] emphasize the importance of such a factor in the learning ecosystem as accessibility. Different components of the educational ecosystem are considered: one reflects all its participants, and the other – the infrastructure (figure 2).

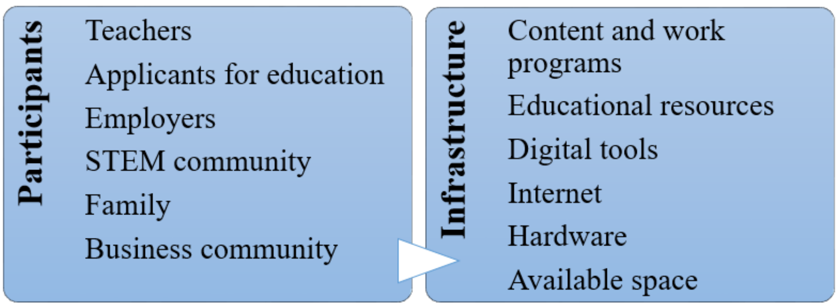


**Figure 2:** Components of the ecosystem of STEM education.

Like the natural ecosystem, the educational ecosystem has no center, but responds as a whole when any of its components change. However, if you need to get a complete picture, you can change the focus in the analysis of each element of the educational ecosystem, as is often done by researchers of the natural ecosystem. We agree with many researchers that it is necessary to understand the concept of the educational ecosystem as a system that is not controlled by one component, but as a series of complex relationships between many stakeholders, if we focus on its participants. The analysis of the educational ecosystem is a direct reflection of the relationships of a complex system. At the same time, the process of creating its model involves a compromise between simplicity and accuracy, and the real difficulties are hidden [1].

However, it is advisable to analyze how each component of the educational ecosystem is affected by other parts. Consider the example of the ecosystem of STEM education, what role in its development in society have its individual components, including digital technology.

The use of digital technologies in STEM education gives students an attractive and interesting way to interact with science, as well as expands their access to practical science education. Interactive virtual labs with gamification elements, such as exciting 3D universes, virtual and augmented reality, mobile applications, are the most commonly used digital tools that support STEM education. The use of digital technologies for STEM learning can improve student learning outcomes [26].

It is difficult to involve modern students in the study of science. Modern students are so accustomed to a high level of interactivity and games that they are easily "disconnected" from learning when teachers use traditional methods. And due to high costs and lack of resources, many schools are unable to provide their students with adequate access to science labs. As a result, students may not have the opportunity to study practical sciences, which is an integral part of science education [64].

## 4. Research methodology

To determine the ways of developing the components of the ecosystem of STEM education, their impact on other components in the study used a set of empirical (questionnaires of teachers of secondary and higher education students of pedagogical specialties) methods, as well as analysis of results. 105 respondents took part in the survey, including students of the Borys Grinchenko Kyiv University in pedagogical specialties and teachers of secondary schools in different regions of Ukraine.

## 5. Research results

The idea that STEM involvement and learning takes place only in integrated subjects in school classes or specialized programs is wrong. Research clearly demonstrates that students' interest, motivation, interests, understanding, and skills development develop in different environments, periods, and in different social roles. Many communities use the "STEM ecosystem" approach to identify the components of the STEM implementation process, the best approaches for its implementation, requirements and timeframes, enrich and empower participants, and expand participation in STEM projects.

The STEM education ecosystem consists of places, ideas, institutions and people available to support learning and involvement in the educational process [4] and tools that can be attributed to the necessary conditions for its development in the digital transformation of education.

Each component of the STEM education ecosystem directly affects the quality of STEM subject study. Like natural ecosystems, educational ecosystems evolve over time. How the educational ecosystem has evolved – who has participated, contributed to development, or benefited in the past – shapes the perception and participation of its participants today. Therefore, an important factor in the formation of the ecosystem of STEM education is the study of the current state of development of its components.

Any sustainable ecosystem is characterized by a certain functional structure, stability, diversity and local adaptation. For the effective functioning of the STEM education ecosystem, it is advisable to work with other STEM providers to learn how to strengthen and supplement each of the components, which will combine different approaches to integrated learning.

Consider some components of the ecosystem of STEM education in accordance with the analysis of the results of the study.

Components related to *formal education* are aimed at providing professional support to teachers in the field of STEM, developing educational programs and resources, selecting forms and methods for implementing STEM education approaches, providing opportunities to participate in STEM projects that help students analyze and solve real problems at the level of school, district, city, etc. The survey conducted in the process indicates the needs and willingness of teachers to implement STEM, but they depend on the form of ownership of the educational institution – public or private, and educational policy for the implementation of integrated learning. In particular, the percentage of respondents who indicated that STEM is implemented in their schools is higher in private schools than in public ones (figure 3). This indicates a direct link between the development of this area and the different levels of material support of the educational process, the speed of innovation in public and private educational institutions and different definitions of educational policy by individual educational institutions.

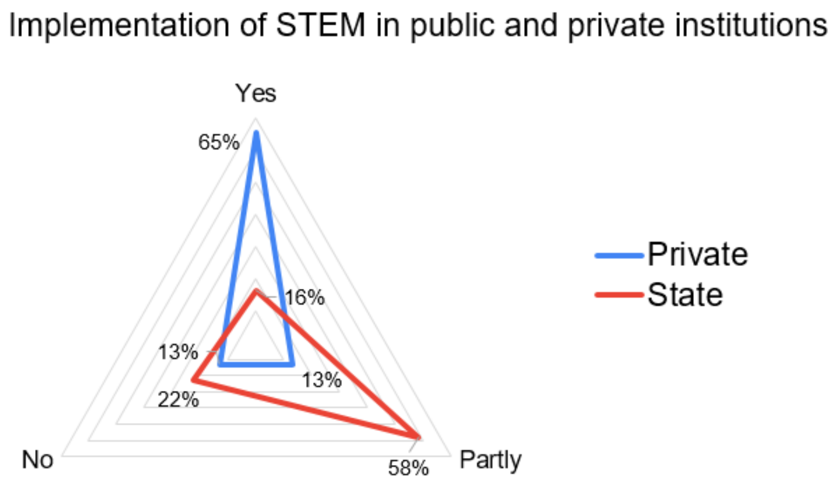


**Figure 3:** Percentage of respondents who indicated that STEM (private and public schools) is implemented in their schools.

66% of all respondents indicated that STEM lessons are possible in their schools, if schools have appropriate equipment and support, 28.9% say that the introduction of STEM is possible as a mandatory component of the curriculum (figure 4).

The most important reasons that slow down the implementation of STEM in schools, respondents identified: the installation of specialized STEM laboratories – 70%, teacher training on STEM implementation – 60%, training of teachers on the use of digital resources and tools for

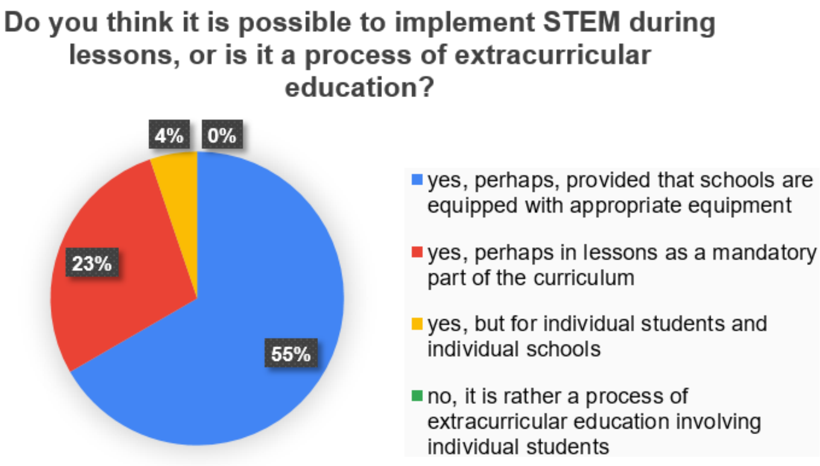


**Figure 4:** The results of the survey on the possibility of implementing STEM in lessons.

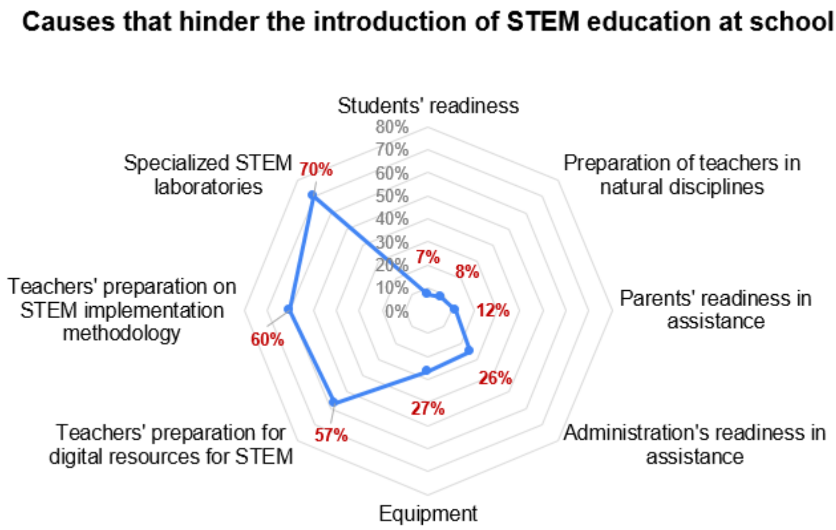


**Figure 5:** The result of the survey on the reasons that hinder the implementation of STEM education in schools.

STEM – 57% (figure 5).

The *parents'* role is very important in shaping the STEM educational ecosystem as well. 31% of respondents identified the willingness of parents to assist in the implementation of STEM. Studies show that the family has one of the greatest influences on the interest and persistence of young people in STEM education [17]. However, when it comes to involving family members in the success of young people in learning the basics of STEM in informal institutions, the results of the survey indicate a gap from the practical implementation in practice of helping parents in this education.

Creating *communities* as an environment for sharing practices and communication is a natural process for improving the functioning of the ecosystem. STEM communities are no exception. Their activities are based on the analysis and construction of curricula, coordination of instructions, promotion of professional development of teachers and participation in various decisions that are fundamental to the development of the educational ecosystem STEM. In Ukraine, teachers use the communities of Facebook (Department of STEM education of the Institute of education content modernization, "Quality of education"), where you can read educational news, exchange experiences, useful materials, participate in discussions and more.

The *business community* in the STEM education ecosystem also plays an important role: businessmen provide their own experience, help with real-life challenges, charitable support, access to STEM at the local industry level, participate in evaluating and supporting innovative projects and startups. The business community can involve students in real production processes, use digital tools to organize project activities, and so on. In particular, various events are organized in Ukraine to support innovative ideas. So, every year since 2017, there is a GET Business Festival, which brings together more than 3,000 entrepreneurs and professionals to share ideas, partnerships and improve the business climate in Ukraine, where those interested can share their own strategies. Students are actively involved in such communities.

One of the important steps for the successful implementation of STEM education with the involvement of all components of the ecosystem is the development of science education, which is based on the ability and skills of students to conduct research and form STEM competencies in students. This is confirmed by the result of a survey on the importance of innovative methods and pedagogical technologies that should be used in STEM lessons. In particular, the coefficient of importance is the highest for research and cognitive learning and the method of projects that are the basis of science education (figure 6).

| | Coefficient of importance |
|---|---|
| Inquiry-based learning | 0,74 |
| Project-based learning | 0,61 |
| Problem-based learning | 0,55 |
| Making | 0,44 |
| Collaborative learning | 0,42 |
| Flipped classroom | 0,42 |
| Blended learning | 0,42 |
| Formative assessment | 0,36 |
| Storytelling | 0,32 |
| Microlearning | 0,31 |

**Figure 6:** Survey results on the importance of innovative methods and pedagogical technologies in STEM education.

*Inquiry-based learning* requires research, which involves the development of important skills, which are divided into two groups: skills of organizing scientific processes and manipulative skills.

Manipulative skills include moving or using an object to achieve a goal or accomplish a task. These in the context of the STEM approach include [15]:

- use of research equipment;
- correct and safe maintenance of research equipment;
- proper cleaning of research equipment; correct and thorough processing of the sample.

Science process skills contribute to the formation of the habit of analyzing materials and phenomena whose properties need to be investigated and used safely. Their formation can lead to an understanding of new scientific ideas and concepts, they are common to research in many scientific disciplines and reflect the behaviour of scientists and researchers. Skills in organizing scientific processes are skills that scientists use to study and explore the world. They are a means of creating content and a means of defining concepts [52].

According to the materials of the AAAS project "Science: A Process Approach", the skills of organizing scientific processes are grouped into two types (figure 7) – basic (table 2) and integrated (table 3). Basic (simpler) provides a basis for learning integrated (more complex) skills [45].

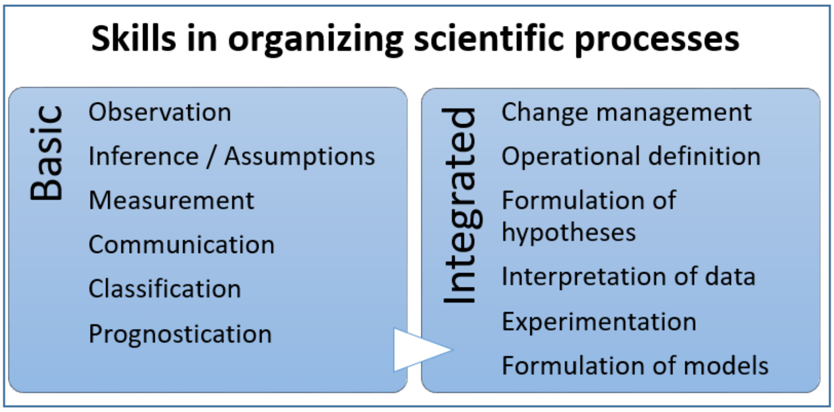


**Figure 7:** Skills in organizing scientific processes.

The described approach in the implementation of the ecosystem of STEM education involves the use of digital environments and tools.

Digital technologies can provide access to information that is often unobvious: the reflection "inside" of seed germination processes, the study of storms around the globe, the ability to conduct experiments on other planets, and so on. They can also provide children and adults with models on how to ask questions about the world we live in, and they can give adults instructions on how to help children experiment, ask questions and formulate assumptions that can be tested, and explain phenomena. based on data they collect through their own experiments and the observations of others [47].

STEM teaching and learning can be improved by using digital technologies to:

- providing models of real interaction for teachers, parents and children;
- connecting teachers to the educational community (for example, providing access to professional development opportunities that support the content and skills of STEM used for initial learning);

**Table 2**
Basic skills in organizing scientific processes.

| Skill | Description | Example |
|---|---|---|
| Observing | Using the senses to gather information about an object or event | What is the trajectory of the fall of a leaf from a tree? Description of the structure of the parachute |
| Inferring | Creating a "reasonable guess" about an object or event based on previously collected data or information. The process of thinking, as a result of which from one or more judgments a new judgment is derived, which contains new knowledge | Assumptions that falling objects are affected by certain forces |
| Measuring | Use standard and non-standard measurements or estimates to describe the size of an object or event | What material is used to make parachutes? Is the shape of the parachute important? Measure materials to create a prototype |
| Communicating | Use words or graphics to describe an action, object, or event | Description of the change in the time of parachute landing depending on its structure in writing or using a schedule |
| Classifying | Group or organize objects or events into categories based on properties or criteria | Placement of all models of paper parachutes with a certain size of the dome of the main parachute, the length of the slings, in one group |
| Predicting | Presentation of the outcome of a future event based on visible / obvious arguments or previous observations | Prediction of parachute landing time depending on the structure of the parachute based on the schedule |

- providing rapid access to teacher training resources, such as textbooks and adapted student activities, using a variety of methods;
- demonstration to children and adults of phenomena and visual and auditory information to which they would not have access;
- involve children in tasks using technologies that encourage sharing, collaboration and discussion, such as playing digital games in pairs;
- providing individual learning opportunities that reflect the level of previous knowledge or experience [46].

Properly selected digital tools to support the educational ecosystem allow you to make the STEM learning process as motivated and effective as possible, while ignoring them leads to irritation and waste of extra resources (energy, energy and time) of all participants in the educational process.

When choosing digital tools, teachers should adhere to certain criteria (table 4) and determine the reason for using the appropriate digital tool [47].

The choice of digital tool depends on the teacher, the content of education on the curriculum and classroom infrastructure [51].

Digital tools and services that help teachers solve learning problems in the context of the

**Table 3**
Integrated skills in organization of scientific processes.

| Skill | Description | Example |
|---|---|---|
| Controlling variables | Identification of variables that may affect the outcome of the experiment; keeping the basic factors unchanged and replacing only the independent variable | Awareness from previous experience of the fact that the parachute launch height and the weight of the parachutist must be controlled and left unchanged during the experiment to see exactly how the structure of the parachute will affect the landing time |
| Defining operationally | Define how to measure a variable, an object, or its properties, such as size, volume, duration, number, expansion in space, and so on | Note that the landing time will be measured in seconds |
| Formulating a hypothesis | Making a probable assumption of the result of the experiment. Guess a position that is temporarily considered possibly true until the truth is established. The correct hypothesis should be based on specific data, include independent and dependent variables, can be tested by experiment | The larger the area of the dome of the main parachute, the longer the parachute will land. If we make (...), then we get (...), or (...) |
| Data interpretation | Organization of data and conclusions based on them | Record the landing experiment data in a table and formulate a conclusion that establishes the relationship between the data obtained according to the variables |
| Experimenting | Ability to conduct an experiment, including asking a question or identifying a problem, hypothesizing, identifying and controlling variables, operationally identifying those variables, conducting a "pure" experiment, and interpreting its results | The whole process of organizing an experiment on the influence of the structure of the parachute on the time of landing |
| Formulating models | Creating a mental or physical model of a process or event | The parachute model lands according to the aerodynamic properties of a design |

implementation of blended and distance learning, including the educational ecosystem STEM, include:

- Tools for creating electronic content
  - Longreads
  - Creating and editing images
  - Visualization
  - Creating presentations
  - Creating interactive content
  - Screen capture
  - Video creation
  - Creating collages

**Table 4**
Criteria for selecting digital tools.

| Criteria | Explanation |
|---|---|
| Relevance | The material has a strong connection to the curriculum or topics for which teachers use it |
| Navigation | Easy to use when students use a new tool |
| Settings | Full flexibility to change content and settings helps teachers meet students' needs |
| Interactivity | Deeply engaged students "come to life" and become more motivated |
| Accessibility | Many materials can help teachers reach students with special learning needs. |

  - Creating comics
  - Creating cartoons
  - Creating word clouds
  - Interactive books and interactive worksheets
- Tools for various purposes
  - Organization of webinars
  - Organization of communication through messengers
  - Management of educational group work
  - Organization of joint work with documents
  - Creating mind maps
  - Virtual digital boards
  - Organization of research and cognitive training
- Learning management systems

For inquiry-based learning, which has the highest importance according to the teacher survey, there are many tools that support inquiry-based learning that teachers can use effectively to engage all students in interaction [19]. The use of selected tools (figure 8) will allow students to participate in a wide range of learning tasks that are guided by queries and questions. The selection of tools is based on the stages of the inquiry approach used in the Go-Lab environment [24].

The results of the survey show that teachers are most interested in using STEM lessons in the use of virtual, mixed and augmented reality, virtual laboratories, 3D printers, robotic kits and tools for modeling objects and processes and creating animation (figure 9).

According to the results of the survey, virtual, mixed and augmented reality and virtual laboratories received the greatest interest from teachers.

Virtual reality is a world created by technical means, which is transmitted to a person through his sensations: sight, hearing, touch and others. Virtual reality mimics both influences and reactions to influences. To create a convincing set of sensations of reality, a computer synthesis of properties and reactions of virtual reality is carried out in real time. The fundamental difference between virtual reality (VR) and augmented reality (AR) is that virtual constructs a new artificial world, and augmented reality only adds some artificial elements to the perception

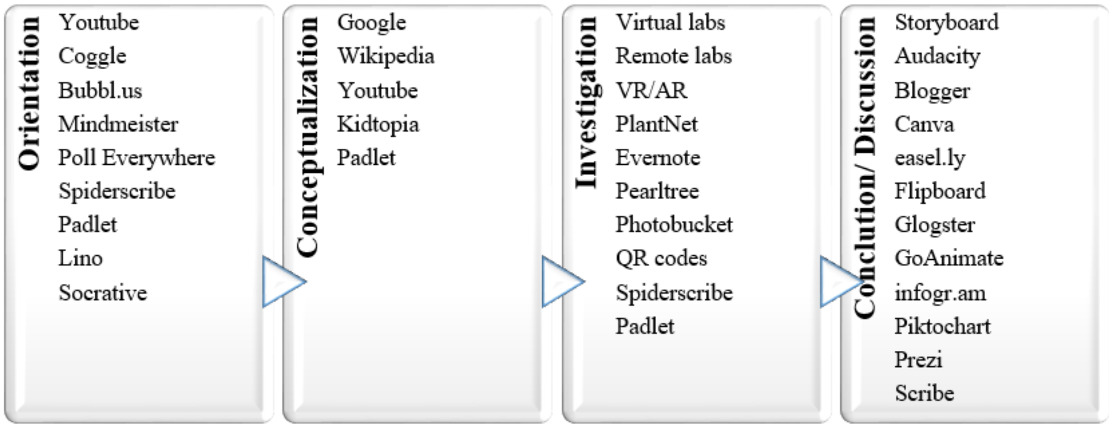


**Figure 8:** Tools for research and cognitive learning.

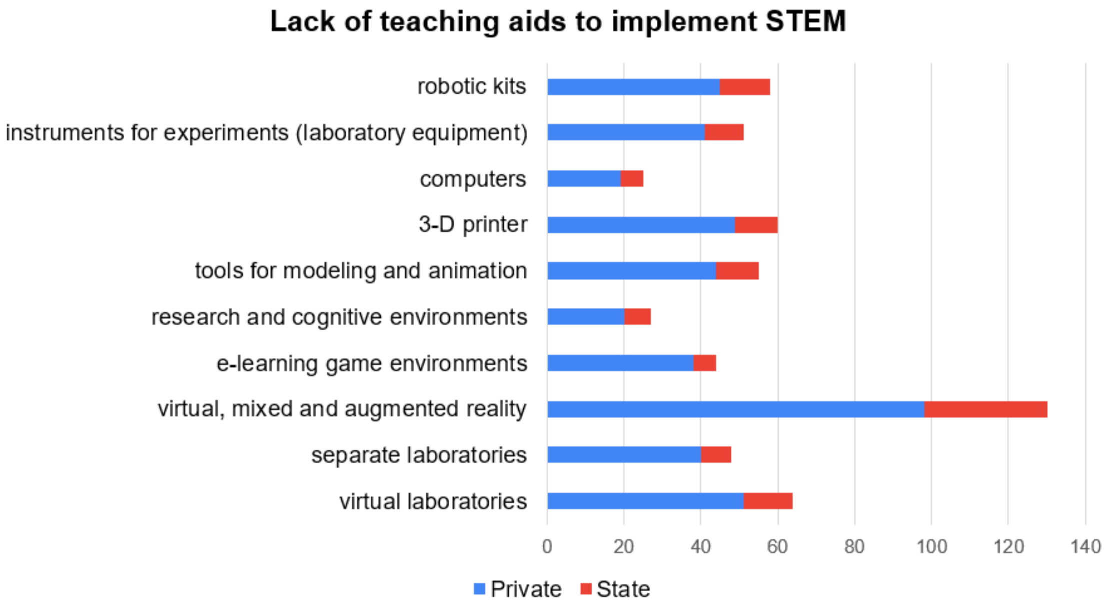


**Figure 9:** The result of a survey on the use of teaching aids in conducting STEM lessons.

of the real world. The peculiarity of mixed reality is that here virtual content is not just added to the real environment, as in the case of AR, and the user has a direct interaction with it.

The basis of learning with the use of virtual reality are immersive technologies – virtual augmentation of reality, which allows better perception and understanding of the surrounding reality, i.e. they immerse a person in the created event environment. The use of such technologies is not so common in education, although there are already examples of STEM centers with specialized equipment for such activities [38]. The following virtual reality headsets (helmets) can be distinguished among computer VRs: HTC Vive, Oculus Quest 2. Mobile VRs include:

Gear VR, Google Cardboard.

Educational content using virtual reality is divided into three types: Video 360°, platforms and platforms (Rumii, EngageVR, Anyland, NeosVR, High Fidelity or Bigscreen), interactive programs (Apollo 11 VR, The VR Museum of Fine Art, InMind-2, Minecraft Education, 3D Organon Anatomy) [61].

AR applications that can be used in STEM lessons include: encyclopedia with augmented reality IEXPLORE, "Organic compounds. ATLAS GUIDE", "LiCo.STEM", "Animals 4D", "Anatomy 4D", "Planets 4D", "Elements 4D", Spacecraft 3D, Star Walk 2, Amazing Space Journey, Atom Visualizer, Electricity AR, Da Vinci Machines AR, LandscapAR, CleverBooks Geography, CleverBooks Geometry, Skyscrapers AR, Bridges AR, Quiver – 3DColoring App, AR Flashcards – Animal Alphabet, My Cardiac Coach, etc.

Virtual laboratories, in which teachers have shown interest, are modern tools for conducting educational experiments, which is an important component of science education. Practical and laboratory classes are an integral part of any science curriculum, as they provide practical application of theories studied by students, as well as opportunities for the development of practical skills. Although most studies have shown that laboratory activities have a positive effect on students [50], teachers continue to find innovative ways to provide laboratory activities to students. Examples of resources for conducting experiments in virtual laboratories:

- Yenka for demonstration of simulations in mathematics, science, technology, ICT and computing;
- PhET Interactive Simulations for Science and Math;
- a resource with multidisciplinary content and open source technology tools to help teachers provide learning using CK-12 Simulations;
- WOLFRAM Demonstrations Project;
- Gizmos – library of math & science virtual labs and simulations;
- Stellarium Web, an online planetarium running in web browser based on the open source Stellarium Web Engine project;
- Ptable – interactive periodic table showing names, electrons and oxidation states. It visualizes trends, three-dimensional orbitals, isotopes and mixed compounds.

Let's focus in more detail on the tool that contains a database of virtual laboratories and allows you to implement an inquiry approach. In addition to a unique and wide range of remote and virtual laboratories, the Go-Lab educational portal offers applications that help create a learning and research environment (ILS). The Go-Lab project offers access to scientific databases, tools and resources that support students' exploratory learning activities. Teachers can make full use of the educational portal, share experiences, participate in discussions and create a quality educational product. For this category Support Online are presented: user manuals, video tutorials, tutorials and tips, community forum, online course, forum. There are only three steps you need to take to create a query-based learning space:

1. Find online labs to support query-based learning with the Go-Lab repository (http://www.golabz.eu).
2. Create a unique environment just for your students with a variety of files, links and applications (http://www.graasp.eu).
3. Share resources with students (link created by Graasp).

## 6. Conclusions

Today, attention is being paid around the world to providing students with a thorough education in science, technology, engineering and mathematics as modern society becomes digital and technology is rapidly changing. The need to form an ecosystem of STEM education in the face of changing labor markets, the risks posed by the world's fourth industrial revolution, and determining its impact on the educational process in today's realities is an important task facing education. In these conditions, synergy, joint efforts of public and private educational institutions (formal and non-formal), business and communities, which can take place in particular in the design and development of educational ecosystems, are important for ensuring the new state standard of education in Ukraine, successful implementation of integrated learning technologies. state, regional and local levels.

To solve this problem, an ecosystem must be created, the participants of which can contribute to education by solving key educational problems.

The STEM education ecosystem consists of "living" and "inanimate" parts, each of which needs analysis and development. In the context of limited funding for education, first of all it is necessary to work on improving the "living" component – ie to train educators, teachers, parents and students; to demonstrate to each of the stakeholders the importance of this direction for the future not only of education but also of each member of the community. It is very important to intensify business in order to more actively involve and assist not only in the development of "inanimate" components of the ecosystem, but also in connecting to the process of demonstrating best practices, successful individual and collective projects of innovation processes.

Modern conditions of society development, analysis of the labor market and developed sources demonstrate the need to use modern digital tools, select and create online environments that will help develop the necessary competencies not only to achieve educational goals but also improve learning overall.

The use of digital tools in STEM education enables students to experiment or explore phenomena beyond physical limitations. Virtual labs and simulations allow students to manipulate data, study variables, and observe their effects to understand the relationships between variables — which is very important for science education. Innovative technologies, such as augmented and virtual reality, can provide contextual learning and immersion.

Not many teachers use different digital tools in science education. Most digital tools are in English, and teachers do not feel confident enough to use them in their daily practice. Teachers need in-service training courses to provide them with resources and digital tools that support STEM education and engage young students in STEM experiences that may be the subject of future research.

*Prospects for further research* include analysis of the infrastructure of the STEM education ecosystem, development of a teacher training program, and determining the importance of using innovative methods in STEM education.

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