Innovative Educational Technologies, Tools and Methods for E-learning
Scientific Editor Eugenia Smyrnova-Trybulska
"E-learning", 12, Katowice–Cieszyn 2020, pp. 242–256
DOI: 10.34916/el.2020.12.21

STEM AND STEAM IN CONTEMPORARY EDUCATION: CHALLENGES, CONTEMPORARY TRENDS AND TRANSFORMATION. A DISCUSSION PAPER

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Abstract: *This article, research review, focuses on STEM and STEAM in contemporary education as research literature review and viewed by experts from different countries: Austria, Poland, Russia, Spain and Ukraine. The article aims to provide opinions, views and reflections by an international team of experts from 6 universities from West, Central and East Europe on important topics: A. Robotics and STEM Education: Challenges, Contemporary Trends and Transformation; B. Microlearning – Effective Methods of E-Learning. The paper includes the theoretical background of the topics discussed, research literature review, analysis of national and international experience, examples of practical achievements and a description of contemporary trends as well as reflections and conclusions.*

Keywords: STEM, STEAM, microlearning, robotics in contemporary education, challenges, trends, transformation.

INTRODUCTION

"Skills in Science, Technology, Engineering and Mathematics (STEM) are taking on more and more importance as a component of basic literacy in today's knowledge

economy. To ensure Europe's growth, we will need one million additional researchers by 2020" (European Schoolnet http://www.eun.org/focus-areas/stem).
The theme of the 11th Annual international scientific conference "Theoretical and Practical Aspects of Distance Learning" was „E-learning and STEM Education". The debate, which was held in October 2019 within the framework of DLCC2019 conference, focuses on STEM and STEAM in contemporary education as viewed by experts from different countries: Austria, Bulgaria, Poland, Russia, Spain and Ukraine. The article aims to provide opinions, views and reflections on important topics relating to Robotics and STEM Education: Challenges, Contemporary Trends and Transformation; Microlearning – Effective Methods of E-Learning, as expressed by experts from several universities, located in Western, Central and Eastern Europe. The paper includes the theoretical background of the discussed topics, an analysis of national and international experience, examples of practical achievements and description of contemporary trends as well as reflections and conclusions.

1. BACKGROUND OF STUDY AREAS

Active contemporary learning and teaching methods which could be used and could improve effectiveness in STEM education include: Problem–based learning; Project–based learning; Inquiry–based learning; Flipped Classroom; Digital Storytelling; Gamification (Smyrnova-Trybulska, 2019: 3–7)
Kommers (2019) in his research identified three main questions about Problem-Based Learning, in particular, in STEM education:

1. "From your current good practices, does the choice for PBL (ProblemBased Learning) as a framework for gaming, storytelling and simulations look as an appropriate one?
2. What do you see as the most important steps to be undertaken before PBL can be integrated in courses throughout your organization?
3. What additional elements would you like to be articulated sharper in the years to come?" (Kommers, 2019: 36).

Research devoted to interaction between tool and talk: how do instruction and tools support consensus building in collaborative inquiry-learning environments described in (Gijlers, Saab, Van Joolingen, De Jong, Van Hout-Wolters, 2009). In his own research (Schäfer, 2019) presents inquiry-based learning in mathematics as an idealized process on the one hand, and in actual implementation on the other. This was done "(…) against the backdrop of cultural-historical activity theory according to Roth and Radford (2011), which more precisely defines the theory for mathematics learning based on Leontiev (1978)" (Schäfer, 2019: 217).
Morze, Smyrnova-Trybulska and Gladun (2018) in their own study, conduct a comprehensive analysis of selected aspects of IBL in STEM-education. In particular, the authors analyse advantages and some aspects STEM education, contemporary trends in modern professions and present several examples of good practice (Morze, Smyrnova-Trybulska, Gladun, 2018: 361).
Höffler, Köhler, Parchmann (2019) stressed in their research that "At present, scientists not only are expected to be creative, resourceful, and inventive regarding their

research questions and to understand their field and research methods, but also need to determine how to teach, how to catalog, how to fill out proposal forms, and much more", devoted scientists of the future and an analysis of talented students' interests. Among STEM challenges, there is "(…) discussion around robotics and stem education could concerns, in particular key competences, selected legal regulations, good examples of the use of robotics in various schools in various countries, popularization, dissemination" (European Schoolnet, 2018: 1).

2. ROBOTICS AND STEM IN CONTEMPORARY EDUCATION – CHALLENGES, CONTEMPORARY TRENDS AND TRANSFORMATION

Experts from different countries discussed and reflected on rules and trends of development and effective delivery of robotics and STEM education.

Professor Theo Hug from University of Innsbruck noted that as for robotics in education, there are many hopes and technological promises regarding future developments. However, many of the descriptions on this subject that are available today are abridged descriptions corresponding with unrealistic expectations and reduced or misleading perspectives. This begins with widespread ways of talking about human-like characteristics of robots and claims of artificial intelligence (AI) where talking about artificial stupidity (AS) would be more appropriate. And it ends as far as future perspectives are related to exclusivity of innovation pathways suggested by global education industries. In many cases, educational potentials of digital media are squandered and pedagogically questionable developments are promoted. What we need, is critical analysis of the work of algorithms in our societies generally and especially in educational contexts rather than non-transparent claims that robots can act as intelligent teachers, empathic companions or autonomous parties enabling innovative learning cultures.

Professor Nataliia Morze from Borys Grinchenko Kyiv University, Ukraine answered this question and presented her point of view concerning the role and perspective of development of STEM and STEAM in contemporary education, using Ukraine as an example.

In order to meet the needs of our technological society and develop the desire and ability to engage the population in science and technology, STEM education should be implemented in elementary school. This is especially true for countries that aim to overcome the STEM gap, having a large number of job vacancies due to a lack of skilled workers. Unfortunately, Ukraine is one of those countries.

STEM training brings together an interdisciplinary approach and project-based approach, the basis of which is the integration of natural sciences into technology, engineering and mathematics. It is very important for primary and secondary school students to learn science, technology, engineering, and mathematics in an integrated way, as these areas are closely interconnected in practice and in life and close to the changes that are taking place in society. Now, the human sciences (from the word Art) are actively added to the listed science bases, and so they talk about STEAM education. STEAM education facilitates development of critical thinking skills and assists in solving issues that are necessary to overcome the difficulties faced by children in their lives.

1. The implementation of the STEAM approach in primary school creates a background for the development of students' interest in natural and technical disciplines. STEAM education through practical classes shows children the use of scientific and technical knowledge in real life. For the last three years, we at the University have been conducting an experiment with several schools to teach junior students the basics of STEAM (Smyrnova-Trybulska, Morze, Zuziak Gladun, 2016); Morze & Gladun, 2016). We have prepared an educational concept for teaching STEAM students, manuals and didactic materials for teachers. Based on our methodology, elementary school students design, build and develop products for the modern industry at every STEAM lesson. The students carry out a specific project, as a result of which they create their own prototype of a real product, explore its properties, put forward hypotheses for its improvement, discuss the problems that arise.

STEAM lessons are characterized by active communication and student teamwork. The discussion process contributes to free atmosphere conducive to discussion and expression. Students are not afraid to express their opinions, they learn to speak and present their views. Most of the time, children do not sit at their desks, but test and develop their projects. They keep in touch with the teacher and their teammates. STEAM lessons are fun and dynamic, which prevents children from being bored. Children do not notice how time is spent in class, and they do not become tired at all. Such lessons provide children with positive motivation to learn. When busy constructing machines, bridges, structures, they are increasingly interested in science and technology. When children are actively involved in the process, they remember the lesson well, master cognitive research methods, formulate hypotheses, and test them. Students acquire skills in science education and corresponding STEAM competencies. Now we are planning to check the positive changes in the formation of the following important *skills*: "Critical thinking, Reading comprehension, Active listening, Speaking, Complex problem solving, exercising judgment and decision making, Writing, Monitoring, Active learning, Time management, Coordination, Systems analysis, Mathematics, Social perceptiveness, Systems evaluation Instructing, Science, Learning strategies" (Jang, 2016: 290(7)).

Knowledge: "English language, Mathematics, Computers and electronics, Engineering and technology, Administration and management, Customer and personal service, Education and training" (Jang, 2016: 290).

Work activities: "Obtaining information, Taking decisions and solving issues, Interacting with computers, Communicating with supervisors, peers, or subordinates, Updating and using relevant knowledge, Reviewing data or information, Identifying objects, actions, and events, Processing information, Documenting/recording information, Organizing, scheduling , and prioritizing work, Thinking creatively, Establishing and maintaining interpersonal relationships, Evaluating information to determine compliance with standards, Interpreting the meaning of information for others, Monitoring processes, materials, or surroundings, Communicating with persons outside organization, Assessing the quantifiable characteristics of products, events, or information,

Judging the qualities of things, services, or people, Training and teaching others, Scheduling work and activities, Preparing objectives and strategies, Coordinating the work and activities of others, Provide consultation and advice to others, Developing and building teams, Inspecting equipment, structures, or material, Coaching and developing others, Guiding, directing, and motivating subordinates" (Jang, 2016: 291(8)).
STEAM-education consists of the following main stages: question or problem, discussion, hypothesis, design, construction, testing and improvement, conclusions, presentation of results. These steps are the basis of a systematic design approach. In turn, coexistence or the combined use of different opportunities is the basis of creativity and innovation. Therefore, the simultaneous study and application of science, technology and the arts can contribute to numerous new innovative projects.
It is also important to invite modern, developing industries into the core components of STEM education. One such area is robotics. After all, robotics is a universal educational tool that is acceptable for all ages – from elementary students to university students and academics. Robotics is an applied science that studies the project design, development, construction, operation and the use of robots (Morze, Strutynska, Umryk, 2018).
The use of educational robotics allows for identifying the students‘ technical talents in the early stages and to develop them and help forming STEAM competences as a whole. Therefore, the problem of training robotics specialists , and in particular, the training of future teachers of STEAM-education, and in particular, robotics, becomes extremely important.
Robotics training gives students the opportunities to solve real life problems that require knowledge of STEM subjects, including:

- Mathematics (spatial concepts, geometry – to understand the ways of movement of robots);
- Physics (electronics, principles of operation of sensors, which is the basis of robots);
- Technology and Design (design of devices, parts of robots, their construction),
- ICT (programming of robotic systems).

Robotics training provides pupils and students with practical experience in understanding the technological components of operating automated systems; adapting to constant changes when managing complex systems; the use of previously acquired knowledge in real situations. Robotics attracts the attention of scientists as a means of empowering pupils and students, and in the process of learning robotics, young people can take an active position as co-constructors, rather than as passive recipients of knowledge or consumers of technology. When it comes to robotics in the context of its use in the educational process, they are talking about a new direction in education – „educational robotics".
Professor Xabier Basogain from University of the Basque Country, Spain answered the question: Can you indicate any of the activities that your research group performs for in the STEAM area? and presented his position and an interesting experience. "Our group develops different activities to promote STEAM in education. For

example, the most recent has been a summer course entitled „Integrating STEAM Education in the Schools of Euskadi“.
The example, the most recent has been a summer course entitled „Integrating STEAM Education in the Schools of Euskadi“ (University of the Basque Country)
For example, the most recent has been a summer course entitled „Integrating STEAM Education in the Schools of Euskadi“. The course is aimed at primary, secondary and university professors in the context of the summer courses of the University of the Basque Country (Course "Integrating STEAM Education in the Schools of Euskadi". https://www.uik.eus/en/incorporando-educacion-steam-en-las-escuelas-de-euskadi).
"I would like to highlight four sections to give an overview of the course:

1. What is STEAM?

STEAM education has been created as a unifying curricular paradigm in which students are trained in four different disciplines, in addition to the arts: science, technology, engineering and mathematics, in an interdisciplinary and integrated manner. First developed in the United States of America (USA), now attempts are being made to implement STEAM education in several countries, both in the public and private education systems.
The course presents a description of the current state of STEAM, an analysis of the main obstacles in the development of STEAM in the classrooms, and proposes methodological alternatives and curricular disciplines that help the incorporation of STEAM Education in Euskadi Schools.

2. Methodologies

Our proposal is born from a techno-pedagogical vision; therefore, we consider it crucial to have the ability to design didactic proposals that include the STEAM competence along with other curricular competencies and in an integrated way. The proposal to include STEAM in our classrooms is based on the methodological change that includes working on solving real problems, inquiring as a means to acquire knowledge, and integrating active methodologies and competencies.
One of the ways that can be explored is the inclusion of makerspaces in regulated training environments: collaborative, flexible and innovative makerspaces that are inevitably accompanied by active methodologies for education.
Addressing a STEAM project requires considering many questions and reflections such as: Where do we start as teachers? How to launch a STEAM project? What must be considered? What STEAM proposals exist? STEAM: How much, where and how? Design of educational ecosystems. STEAM and the school curriculum.

3. Curricular disciplines

This summer course identifies the following main obstacles to the implementation of STEAM in school systems: 1) the curriculum in mathematics is obsolete and, therefore, physics, chemistry and biology are studied with obsolete tools and perspectives; 2) the students are not educated in solving complex problems that require higher level mental processes, which involve higher level cognitive modules, known as System-1; 3) Students still use paper and pencil to solve problems, while complex problems require for their resolution an iterative process of experimentation and discovery. This iteration process in turn requires computational micro-worlds or ecosystems for its implementation and manipulation.

Our proposal is called Computational STEAM, which consists of a set of curricular strategies to address these three fundamental obstacles to successfully incorporating STEAM into the classroom. These strategies are designed to:

- Allow interdisciplinary integration of STEAM areas.
- New curriculum: Discrete Calculus, Differential Vector Geometry, Computational Cybernetics, and Probabilistic Computing
- Educate students in areas of problem-solving methods appropriate to their age.
- Address the high demand areas of modern society.
- Develop in students the great potential of System-1.
- Integrate the computational ecosystem model as a world that the student can explore and iterate solutions for problems called Type-B.

The course analyzes the type of problems taught in Mathematics and Science in primary and secondary education in Organisation for Economic Co-operation and Development (OECD) countries called Type-A problems, and presents other types of problems, called Type-B problems, which prepare the students to perform better in today‘s modern society.

4. Microworlds and computational Ecosystems

We use the *Scratch* and *Snap* programming graphical environments to iteratively experiment with Type-B problem-solving processes, processes that must be implemented in a computing environment.

We present computational examples of areas of modern mathematics appropriate for their integration into primary and secondary school classrooms (see Fig. 2).

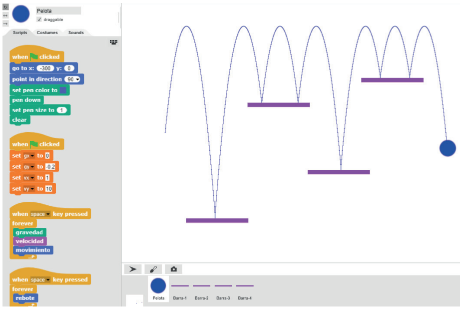
Online Course. This course was held last July in Bilbao with more than 30 participants. And then we created an online course version with the title "STEAM Education in the Schools of Euskadi: First Steps" (Online Course "STEAM Education in the Schools of Euskadi: First Steps". https://www.uik.eus/en/educacion-steam-en-las-escuelas-de-euskadi-primeros-pasos). The aim of the course is to introduce the concept of STEAM Education in the community of teachers of Euskadi.

The course is aimed mainly at teachers of primary and secondary education in Euskadi, regardless of the specialization or course that they impart. In addition, the course is designed for all future teachers of primary and secondary education, and in general for students of education-related degrees.

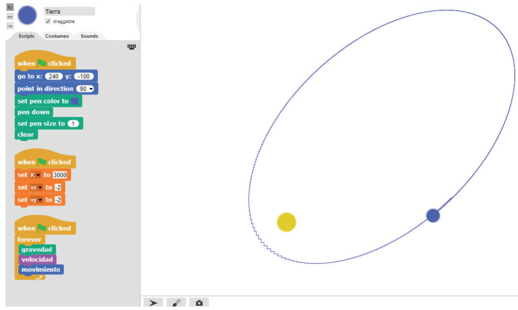
The course is held on the online course's platform of the Summer Courses Foundation of the University of the Basque Country / Euskal Herriko Unibertsitatea (UPV / EHU). It is a learning platform based on Moodle.

The participant must complete a set of tasks related to the contents of the course, including works, multiple-choice questionnaires, and participate in the module forums.

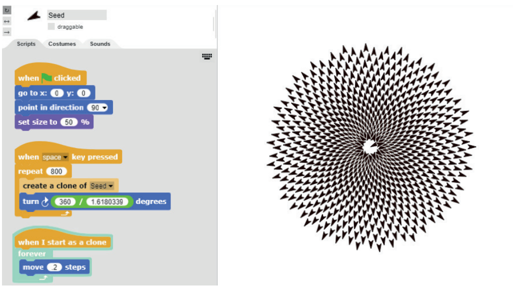
The course guide is structured in the following sections: Learning Competences and Objectives, Contents, Methodology and Work Plan, Evaluation Activities, Calendar and Bibliography.



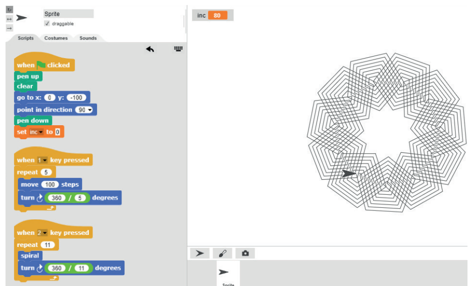
Example 1. Bounce of a Ball



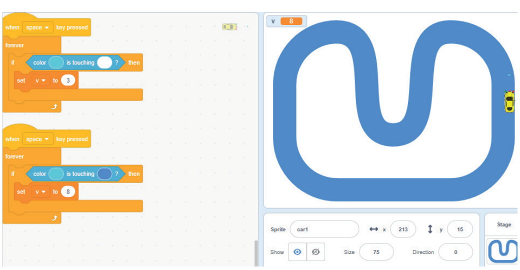
Example 2. Law of universal gravitation



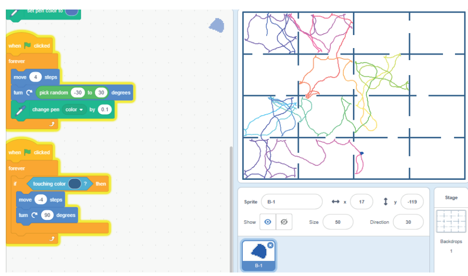
Example 3. Golden Ratio
and Fibonacci numbers



Example 4. Polygon Spiral Sides



Example 5. Driverless car



Example 6. Butterflies Study

F i g u r e 2. Computational ecosystems of modern areas of mathematics appropriate for integration in primary and secondary school classrooms

S o u r c e: Online Course "STEAM Education in the Schools of Euskadi: First Steps". https://www.uik.eus/en/educacion-steam-en-las-escuelas-de-euskadi-primeros-pasos.
Example 1 and Example 2: https://snap.berkeley.edu/collection?user=steam-euskadi&collection=SP-D1;
Example 3 and Example 4: https://snap.berkeley.edu/collection?user=steam-euskadi&collection=SP-D2;
Example and Example 6 https://scratch.mit.edu/studios/20686472/.

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Professor Theo Hug continues discussion. If we want to foster educational processes in the first place and not predominantly instrumental learning and behavioral modification towards unquestioned goals, then we have to think beyond the promotion of coding skills and computational thinking – then we rather have to focus on future oriented co-creative practices and data ethics, on educational benefits for all learners, communities and milieus, on viable forms of interaction with various sorts of non-human agents in educational contexts, and on the relevance of media-cultural contexts for processes of building up and organizing knowledge as well as for transformative learning and education.

Moreover, we have to explore effects as well as opportunities and limitations of practices and discourses in educational robotics concerning its three basic meanings, namely educational robotics (1) as technology education focusing on coding skills and digital fluency in robotics and mechatronics, (2) as an umbrella term for instructional learning formats and practices aiming at the utilization of robots, AI and machine learning in learning and training contexts generally, (3) as moral training for chatbots and social humanoid robots aiming at moral machines that behave and decide like humans. In doing so, we can sound out and create opportunities for responsible innovation pathways beyond financial interests of global education industries or power-political interests. Accordingly, educational robotics can be much more than "an innovative method of increasing the attractiveness of science education and scientific careers in young people's opinion" (Lepuschitz et al., 2019: p. v). There are many innovation pathways in education if any.

According to Professor Krzysztof Gurba, Pedagogical University of Krakow, since STEM represents science, technology, engineering and mathematics and STEAM represents STEM plus the Arts the difference seams technical and moderate. But this A in STEAM is important not only literally, as it adds a humanizing element to the teaching of students, but also methodologically, as it is necessary to supplement the quantitative methods for testing theories and hypotheses, with qualitative methods characteristic for arts, which allow the construction of hypotheses and the reconstruction of theories.

This complemented approach also gives a chance for a kind of "pull back", a longer distance enabling a wider view, a broader context and background, the so-called big picture and, as a result, learning to look at research in an extended way. While quantitative methods are a model for science, STEAM can additionally present achievements resulting from the use of a wide range of qualitative methods.

This broader perspective of the exact knowledge taught in schools and universities, expanded to include humanities, language arts, dance, drama, music, visual arts, design and new media, also coincides with the expansion of new educational technologies. The result consists in obtaining new contexts for strengthening science education with a humanistic element, for example in the form of various applications of immersive virtual environments, where peer-to-peer contact between learners becomes more direct, despite the lack of face-to-face contact.

Professor Tatiana Noskova from Herzen State Pedagogical University of Russia stressed that "In 2019, a digital platform for personalised learning was created in Russia with the participation of Sberbank and the Agency for Strategic Initiatives. Based on the presentations of this platform, it can be concluded that it is positioned as a set of conditions for solving numerous "traditional" problems of school education – low educational motivation, divide between knowledge and practical activities, overload of teachers and school administration with routine work, lack of parents' awareness and participation of the educational process. The digital platform with the help of artificial intelligence systems has the ability to automate most of the routine operations traditionally performed by a teacher (checking works, replicating materials, searching for new resources, etc.), thereby freeing up teachers' time for interaction with students according to their interests and needs. In addition, it provides modular design of programs and diversified work of children in the classroom and at home (Noskova & Yakovleva, 2020). Undoubtedly, the ideas of personalisation of education, embedded in the design of this platform, make it possible to set and solve not only primarily the tasks of teaching, but also the tasks of upbringing and personal development. Therefore, the ideas of STEM and STEAM education with the help of this platform get a new embodiment.

In summary, it is important to stress that the most important competences include: mathematical competence and competence in science, technology, and engineering; digital competence (Recommendation of the European Parliament And of the Council of 18 December 2006 on key competences for lifelong learning (2006/962/EC)). A lot of formal documents includes and stresses importance of engaging in STEM education, for example "In order to motivate more young people to engage in science, technology, engineering and mathematics (STEM) related careers, initiatives across Europe started to link science education more closely with the arts and other subjects, using inquiry-based pedagogy, and engaging with a wide range of societal actors and industries. While the definition of those competences has not changed much over the years, the support of competence development in STEM becomes increasingly relevant and should be reflected (…)" (Council Recommendation of 22 May 2018 on key competences for lifelong learning, p. C 189/3). Regulations in this respect exist in other countries too. For example, Spanish legislation is based on several main documents. The European Committee of the Regions is calling for measures to promote science, technology, engineering and mathematics (STEM) education in Europe, especially among girls and women. With an opinion prepared by Csaba Borboly (RO/EPP), President of Harghita County Council, the EU's assembly of local and regional representatives calls on the European Commission and the Member States to support STEM-re-

lated initiatives at local and regional level, to ensure necessary investment and to tackle shortages in this field in the planning of cohesion policy (EU STEM Coalition, 2019).
In the Spanish Basic Education Curriculum the different key competences that the student must achieve are described, and among them is the mathematical competence and basic competences in science and technology (LOMCE, 2013). Mathematical competence is described as applying mathematical knowledge to interpret, describe, explain and give answers to problems related to the needs of life, using modes of thought, representation and tools typical of the area (Decreto 236/2015, 2016).
The autonomous communities of Spain have developed different plans to develop STEM / STEAM. For example, STEMadrid is the Plan designed by the Community of Madrid to promote the study of STEM disciplines among students from Madrid. (STEMadrid, 2019). In the Basque Country the Basque Government Department of Education encourages and supports STEAM Education through the STEAM Euskadi Education Strategy (STEAM Euskadi, 2019).
Based on the analyzed sources and the authors' experience, one can distinguish the following main *challenges* in STEM education:

- Using the innovative methods and pedagogical approach adequate to the STEM, STEAM education.
- Teacher skills on STEM should be increasing and permanently developed (LLL)
- Gaps: Fundamental skills gap, Post-secondary education gap, Demographic gap, Geographic gap, Belief gap (Guijosa, 2018)

An analysis of experts' opinions allows you to distinguish the following trends in STEM education and transformations:

- Increasing rule of informal and extracurricular STEM education
- "Shift from 'learning to code' to 'coding to learn'
- Growing demand for 'bilingual' engineers (computer science + expertise)" (5 STEM education trends for 2020)
- Using methods and tools for effectiveness and successful networking and collaboration on STEM (in global scale)
- The promotion and dissemination of experience-based STEM learning in classrooms and workplaces.
- Personalized STEM learning (e.g. using AI, AR)

CONCLUSIONS

The mathematical competence as well as competence in science, technology, and engineering; digital competence included in the 8 key competences are, recommended by European Commission (EC) (Recommendations EC, 2006). Young people and students should be prepared in the fields of STEM education for successful functioning in digital society as well as for careers in contemporary and future professions which require adequate competences. Important and effective modes for popularization and dissemination of STEM education include formal regulations as well as extra curriculum education and activities, festivals, workshops, training, competitions, Olympiads etc.

We agree with the authors that potential pathways for overcoming challenges could include "Attracting more students and teachers to STEM education through a global approach from primary education to continuing professional development"…, "Breaking the barriers between subjects with pragmatic initiatives (teacher training sessions, publishing contents, sharing best practices, etc.) to improve the quality of STEM education by building on each country's strengths", "Evaluating and integrating curriculum and pedagogical innovations" (European Schoolnet, 2018: 23)

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