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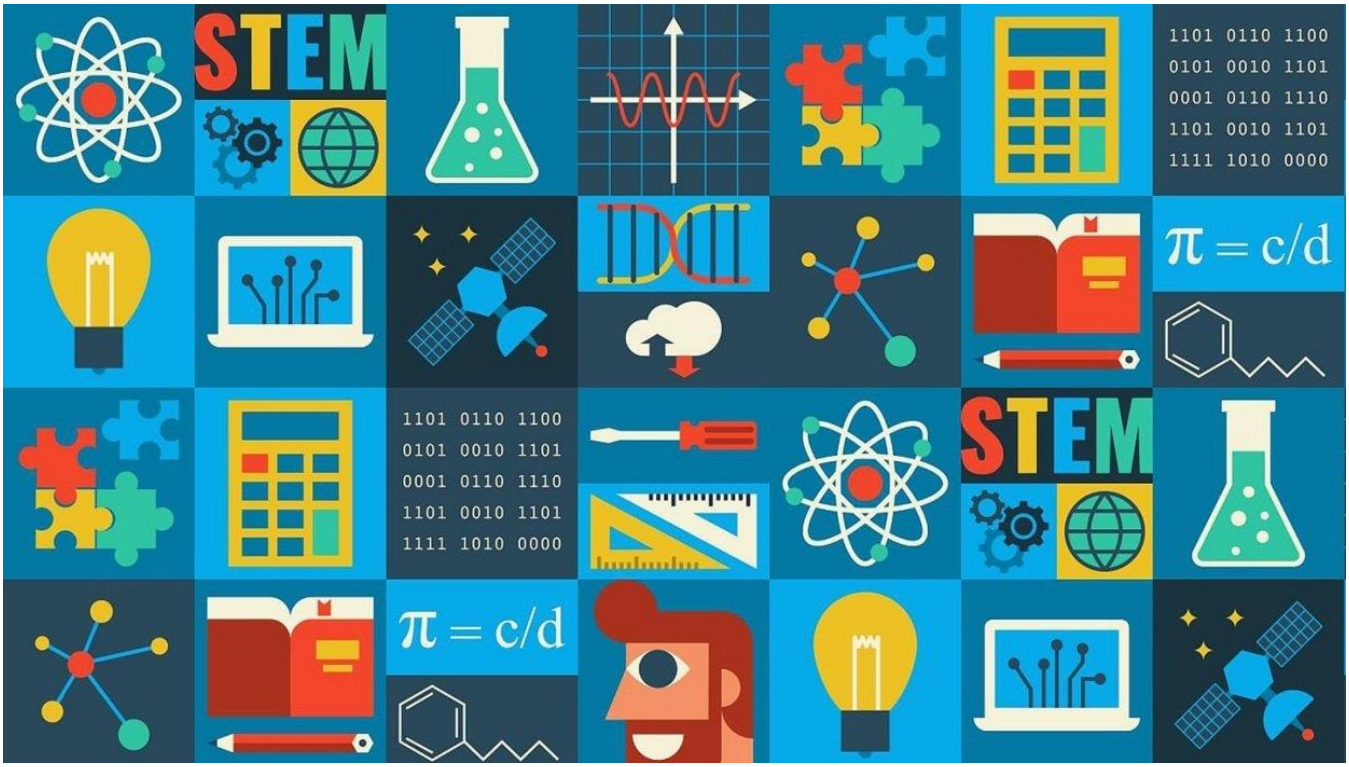

of Best Practices in STEM Education

Finland, Ireland, Sweden, Turkey, Russia, Kazakhstan

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Atlas of Best Practices in STEM Education (Finland, Ireland, Sweden, Turkey, Russia, Kazakhstan).

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Contents

1. Preface
2. Introduction……6
3. STEM Education in Finland……9
4. STEM Education in Ireland……23
5. STEM Education in Sweden……43
6. STEM Education in Turkey……58
7. STEM Education in The Russian Federation……72
8. STEM Education in Kazakhstan……94
9. References……116

Preface

Why does STEM Education matter?

Science, technology, engineering and mathematics (STEM) education has received increasing attention in recent years. Several studies indicate that a holistic understanding of STEM, through the integration of STEM disciplines, may foster students' understanding, motivation and well-being. STEM capital refers to STEM-related qualifications, skills, knowledge, interest and social contacts is also seen an important component of STEM education. As summarized below, rationales for why STEM or STEM education matters vary. Drawing on Labaree's study [1], we may classify them in three categories: the economic argument, the democratic equality argument and the social mobility argument.

The economic argument: Much of a country's economic prosperity, competitiveness and political leadership can be attributed to scientific and technological discoveries. A supply of qualified and productive member of society in STEM can develop and maintain innovative enterprise and nurture human capital for a sustainable economic growth [2,3]. Besides, from a social efficiency perspective, STEM skills are increasingly required by a range of sectors [4]. Nonetheless, there has been a shortage of graduates in STEM fields in some countries, heads of state and government across the globe have stressed the need to boost the number of people in STEM-related careers substantially [4,5]. Concerns about STEM education crisis vary across countries, yet main argument holds that not enough young people are inspired about pursuing an advanced degree in STEM fields. To overcome these problems, boost economic competitiveness through innovation, prepare and inspire the STEM workforce for the future, and fulfil structurally necessary market roles, several educators and stakeholders have motivated to develop innovative programs and policies to improve the quality of STEM education in formal, informal and non-formal settings [6]. In this perspective, STEM education is mainly perceived as a public good in service to private sector.

The democratic equality argument: The citizens make their decisions based on their knowledge, beliefs, social values, worldviews, as well as based on the understanding about STEM and natures of S-T-E-M. The participation of public in discussion, policy debates and decision-making about STEM-related issues is essential to maintain a healthy democracy. Accordingly, STEM education should ensure that every citizen has the opportunity to master essential STEM concepts and practices, and become STEM

literate. This in return may lead to appropriate democratic control over the directions of research, environment, social welfare, national security, and economic policies. Thus, STEM-literate public will have a stronger support and sense of ownership of the STEM enterprise and be better equipped to participate in civil society as jurors, voters, and consumers [7]. In this perspective, STEM education is mainly perceived as public goods designed to prepare public for more active and participant citizens.

The social mobility argument: By considering an increasingly volatile, uncertain, complex and ambiguous world, a holistic approach, which includes knowledge, skills, character and meta-learning competencies is needed to support the development of a 'whole person' [8]. In this context, cognitive as well as affective aspects and STEM capital play critical roles in individual's success, connectedness, well-being and future prospects [9]. A kind of STEM education, which provides opportunities to individuals to explore their passion, curiosity, make evidence-informed decision about themselves and their families, compete with social position, and prepares them for successful social competition for the desired societal roles are therefore crucial. In this perspective, STEM education is mainly perceived as a private good for personal consumption.

by Prof. Dr. Gultekin Cakmakci
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Introduction

STEM education is considered as "…an interdisciplinary approach to learning where academic concepts are coupled with real-world lessons as students apply Science, Technology, Engineering, and Mathematics in contexts that make connections between school, community, work, and the global enterprise enabling the development of STEM literacy and with it the ability to compete in the new economy [10].

STEM qualifications and skills are necessary for current and future workforce all over the world. STEM-subjects are the basis for staff training of the scientific-technological elite for the innovative development of the countries. Skills in STEM are becoming an increasingly important part of basic literacy in today's knowledge economy. To keep Europe and the whole world growing, educational systems need more than one million additional researchers by 2020. Yet science education can no longer be viewed as elite training for future scientists or engineers; only science-aware citizens can make informed decisions and engage in dialogue on science-driven societal issues.

Identification of best practices in STEM strategies implementation at national and regional levels is one of the main goals of the Erasmus+ KA2 (Capacity building in the field of higher education) project "Integrated approach to STEM teacher training" (2019-2021). The project itself is intended to enhance teacher training programs by introducing a new integrated curriculum thus producing a generation of new STEM teachers' cohort able to kindle interest to STEM subjects and to increase the number of HS graduates selecting STEM careers.

The aim of the Atlas of Best Practices in STEM Education is to collect best practices and initiatives based on reports on STEM policies and best practices at respective national and regional level given by EU partners (Finland, Ireland, Sweden, Turkey), the Russian Federation and Kazakhstan participants of the project shaped into an atlas.

Thus, the first chapter of the atlas begins with Finland best STEM practices. The main role is given to Finnish education ecosystem reform. The goal of this reform was to improve learning outcomes, take into account future competencies, renew pedagogy through experimentation, and turn to learn into an inspirational process throughout life. On the assumption of Finnish education ecosystem characteristics, the following initiatives and collaborative projects as LUMA, F2k, PaikkaOppi, Summamutikka etc. were described.

The second chapter is represented by Ireland best STEM practices. In Ireland after consultation with experts one of the ways of obtaining highly skilled workforce was recognized the way of STEM education. This has required a clear understanding of STEM education for the Irish context. The embedding of this understanding across the education system will help transform the STEM education experience of learners from early years through to post-primary. Based on Irish STEM Education Policy Statement and Implementation Plan the following initiatives and projects were developed and described: EPI-STEM, ATSSTEM, ENERGE, Maths4All.ie, 3DIPHE, Open Schools for Open Societies etc.

The third chapter is represented by Sweden with its best STEM practices. Instead of Sweden's national secondary and tertiary education policy, Sweden partners turned to passages relating to Sweden from Do Well Science - Manuals to Innovative Pedagogy in STEM Content (Erasmus + Project to Improve Secondary School Student Achievement in Science). In order to implement the main goals of this policy such projects as CETIS, NRCF, NCM, NATDID, KRC etc. were developed and then described in the atlas. The STEM PD Project is also an especially attractive STEM-activity that was paid attention in this chapter.

The fourth chapter describes Turkey's best STEM practices. This chapter includes public and private initiatives in the field. Initiatives led by, TUBITAK (the Scientific and Technological Research Council of Turkey), The Ministry of National Education (MoNE), STEM Labs at universities and science centers and non-profit initiatives such as The Turkish Technology Team Foundation are among them. The previously mentioned STEM PD Project is also implemented in Turkey.

The fifth chapter is devoted to the "Need for STEM" trend in Russian educational policy and practices. This trend is defined by the following strategic concepts, executive orders and national programs/projects: Executive Order on the Scientific and Technological Development Strategy of the Russian Federation; Priority National Project "Affordable Supplementary Education and Extracurricular Activities" (2016-2021); National Project "Education" (2019-2024). The main STEM-related goals and initiatives are Federal Project "Modern School"; Federal Project "Success of Every Child"; Federal Project "Digital Educational Environment". Judging from these initiatives, there is a lot of authentic STEM practices in Russia such as NTI STEM-related education projects and practices, STEM-related "Sirius" education practices, STEM Centers of the All-Russian Festival of Science 0+, Skolkovo MAKERspace STEM Education Center for schoolchildren etc., that are thoroughly described in this atlas.

The sixth chapter reveals the development of STEM education in Kazakhstan. This initiative is confirmed by the designated transition to the updated content of school education in the context of STEM within the framework of the State Program for the Development of Education and Science for 2016-2019. The projects like NIS, RFMSh, MIRAS International School etc. are true representatives of the national policy line.

The content of this atlas will be used to develop and implement master's programs in the field of STEM education and, therefore, to develop new HR in the field of STEM in the countries participating in Erasmus+ KA2 (Capacity building in the field of higher education) project “Integrated approach to STEM teacher training” (2019-2021). The atlas will be used as a piece of T&L resources for the future STEM teachers and the students of the mentioned above master’s degree program.

STEM EDUCATION IN FINLAND

Context

Since the 1970s, the education system has been reformed in Finland. It became decentralized, as each school or educational institution received autonomy to improve its education. The reform focused on three aspects:

- new approaches in pedagogy
- new learning environments
- digitalization of education

The goal of the reform was to improve learning outcomes, take into account future competencies, renew pedagogy through experimentation, and turn to learn into an inspirational process throughout life. Nowadays, STEM education technologies are included in all areas of Finland's school curriculum. STEM technology is not an additional set of standards in a problem-oriented approach to the creation of educational materials and their combination with educational standards for the formation of new competencies of the 21st century. The STEM approach can contribute to the development of student curiosity and creativity. Building a problem-oriented material is not as difficult as it might seem since the topics for projects can be environmental issues, food production, energy and other topics that are relevant around the world.

Characteristics of the Finnish education ecosystem [11–13]:

- cooperation in the field of educational policy strategies
- strict education quality demands
- educational partners work closely
- cooperation with social services and health care
- equity in education
- education is free (books, food, healthcare)
- well-organized specialized training and counseling
- school social assistance group as part of the ecosystem
- quality through decentralization
- leadership, management and quality work at the school level
- teachers are responsible for the local curriculum and assessment

The secret of the national policy is the importance of education for the development of the country, as well as for the adoption of unorthodox educational methodologies (such as STEM) designed for the present and future of the younger generation.

The STEM approach requires students to self-identify a problem, conduct research, develop a solution, test and evaluate the solution, and report the results. These competencies overlap with global scientific and technological competencies. This allows students to develop the skills of creativity, research, cooperation and communication that they need in order to realize global problems and prospects and become part of the solution to existing and future problems.

Teaching in Finland is considered one of the best professions. Teachers are on a par with doctors and lawyers, so there is a lot of competition to work in the education system. Even a master's degree in research is one of the teaching requirements. This means that teachers have five to seven and a half years of preparation before they lead a class. Future STEM teachers not only learn teaching methods but also spend a year at the university, learning how to teach this approach. They are taught how to participate in joint project teams and create such teams. Natural disciplines at all levels of instruction are taught through STEM technologies. Teachers are given a lot of freedom to try innovative approaches, such as developing an “outdoor math curriculum,” or joining forces with others to implement a team-based teaching method.

Thus, Finnish schoolchildren demonstrate a rapid increase in horizons and an integrative approach to knowledge, as evidenced by their consistently high results in the PISA (The Program for International Student Assessment) test. There is also a craft curriculum in Finland. In 2004, it was decided to include technology in the curriculum for crafts.

Education in Finland uses a pedagogical model of dialogue. This means that “the Finnish teacher is a kind of a guide in the classroom, and not as an authority model as in other systems. This requires more of the students, ponders their answers and triggers a dialogue between them under the guidance of the teacher. Argumentation and exchange of ideas are encouraged." This same aspect will help the student to develop with greater confidence in their learning. Even in education in Finland, teachers “can choose their teaching methods, textbooks and other materials,” says the Finnish General Directorate for Education.

Thus, students in schools learn in a more autonomous and equitable space, where it is important that all students study at the same time as others and given that the school

is an example in which they receive a less rigid education. Finnish students are “more concerned with understanding the phenomena”, along with the fact that one of the most characteristic features of these phenomena is that they are very organized and disciplined.

STEM-Related National Policies and Initiatives

The country’s national curriculum urges teachers to teach science through integrated and inquiry approaches [14]. Project-based science learning (PBSL) is one of the approaches that could motivate and engage students in learning science by actively involving them in the knowledge construction process [15–17]. Therefore, learning science through projects has the potential to increase students’ interest in learning science.

The distinctive feature of project-based learning is problem orientation, that is, the idea that a problem or question serves to drive learning activities. The second feature of PBL, constructing a concrete artefact, is what distinguishes project-based learning from problem-based learning. Helle, Tynjälä and Olkinuora [18] add three other features to PBL. The first, learner control of the learning process, which leaves scope for decisions regarding the pacing, sequencing and actual content of learning. The second, the contextualisation of learning is evident in student projects. The value of authentic or simulated learning contexts has been argued for both cognitive reasons and by the situated learning camp. The third, characteristic of the project method is its potential for using and creating multiple forms of representation. In modern working life, most tasks require the combined use of interdisciplinary knowledge in different forms.

The core curriculum mainly defines the mission, values and structure of basic education. It also defines the objectives and content to be learned in each subject. The core curriculum is a national regulation prepared and issued by the Finnish National Board of Education and all municipalities are expected to prepare their own local curricula in compliance with the core curriculum. The local curriculum is expected to implement the national targets but is also expected to take into consideration the local contextual needs. However, the municipality and schools have considerable freedom to interpret the curriculum as they want [19]. The idea that students are active agents of their own learning forms the basis of the core curriculum’s conception of learning (FNBE, 2016). One aspect of the core curriculum that is worth noting in relation to this study is that of the Transversal Competences. The seven transversal competences

stated by the core curriculum are designed in order to prepare students for the changing world. Transversal competences represent the values and attitudes required for using the knowledge and skills from different fields for personal growth, study, work, and civic activity (FNBE, 2016). These competences are part of everyday teaching 36 and learning activities of the school. These competences also clearly align with the need for incorporating teaching methods like project-based learning in schools. The seven transversal competences stated by the core curriculum are Thinking and learning to learn (T1), Cultural competence, interaction and self-expression (T2), Taking care of oneself and managing daily life (T3), Multiliteracy (T4), ICT competence (T5), Working life competence and entrepreneurship (T6), Participation, involvement and building a sustainable future (T7).

Finnish students receive also periods of phenomenon-based learning, a type of inquiry-based learning [20]. A phenomenon is defined as something that exists and can be seen, felt, tasted, etc., especially something unusual or interesting. Examples of phenomena include scientific discoveries, trends in technology, and natural disasters. Learning about or witnessing phenomena sparks our curiosities. With PhenoBL, students interact around real-world issues to investigate a problem or explore a curiosity from multiple vantage points. Students study phenomena as complete entities in their real contexts along with related interdisciplinary information and skills. It is the process of exploring questions using evidence collected from research. The information that is gathered is studied with and against existing models and theories. The insight gained from their investigations lead students to new understandings. Finnish students use this hands-on approach to explore themes ranging from entrepreneurship to space exploration. During PhenoBL, students create. Finnish students explored design during their phenomenon-based learning week. After researching famous Finnish designers, students used Tinkercad, a 3D design program, to make their own creations.

Some Finnish seventh grade students researched the amount of water usage in their community and in their homes. They created graphs depicting this information along with facts and statistics to show the need for conservation. In addition to the research, students programmed LEGO robots to solve a set of missions that pertained to water—how we find, transport, use, or dispose of it. At the end of the project, groups presented their research, programmed robotics, and proposed water conservation solutions to a panel of judges. The project began with students' desire to explore real life phenomenon and create their own models, which led them to advocate for action. PhenoBL also promotes teacher collaboration. At Espoonlahti School in Finland,

teachers from different disciplines team up to develop and implement interdisciplinary phenomenon projects [21]. For example, art and physics classes collaborate to learn how to use lighting when photographing. Biology and cooking classes collaborate on projects to learn about marine life before preparing special seafood dishes.

To promote STEM technology in Finland, a national development program, LUMA, was launched to support the competence of children and youth in mathematics and science.

- LUMA national platform of STEM education [22]

LUMA Center Finland is a network of 13 LUMA regional centers in Finnish universities. The network provides a national and international collaborative ecosystem for the development of mathematics, science and technology education, providing activities and access resources across the country. The current LUMA ecosystem is a social innovation in which universities, schools, teachers, students, and industry work together to engage all children and young people from 3 to 19 years old in mathematics, science and technology, and support research-oriented teachers to study in throughout life. The LUMA Center in Finland encourages and develops both national and international cooperation between educational institutions from kindergarten to universities, the business sector, administration, science museums and centers, teacher associations and the media, as well as all other relevant organizations. Annually, 400,000 people (children, youth, parents, and teachers) take part in the activities of the center. LUMA centers are represented in various universities in Finland:

- Aalto University Junior
- Central Finland LUMA Centre (University of Jyväskylä)
- LUMA Centre Lapland (University of Lapland)
- LUMA Centre of Central Ostrobothnia (Kokkola University Campus Chydenius)
- LUMA Centre of Ostrobothnia (University of Vaasa)
- LUMA Centre of Southwestern Finland (University of Turku)
- LUMA Centre of the University of Eastern Finland
- LUMA Centre of the University of Oulu
- LUMA Centre Päijänne Tavastia (Lahti University Campus)
- LUMA Centre Saimaa (LUT University and Saimaa University of Applied Sciences)
- Skolresurs (Åbo Akademi University)
- Tampere LUMATE Centre (Tampere University and Tampere University of Applied Sciences)

– University of Helsinki Science Education Centre

The University of Helsinki coordinates the entire network. Each center has its coordinator and director, working part-time or full-time. Coordinators regularly conduct web conferences. LUMA National Days are held once a year. STEM research and innovation in STEM training are being expanded through the national online portal LUMA.fi, the LUMA newsletter, and LUMA TV. Over 10 years ago, the Tämä toimii! (It works!) school technology contest started in the technology industry in Finland. Since 2013, LUMA Center Finland has taken responsibility for organizing this competition. The main projects of the LUMA Center are described in more detail below.

STEM-related Collaborative Projects (Government-Business-University) and Best Practices of Non-Formal / Informal STEM Education

– Tampere LUMATE Centre (Juniversity) [23]

The LUMATE Center in Tampere was the first LUMA technology-oriented center in Finland (the additional “TE” in the name comes from the word “Technology”). The center was founded in the spring of 2011 by the joint efforts of Tampere Universities, the Bureau of Economic Information, the Tampere Chamber of Commerce, the Tampere Technology Society and the Federation of Finnish Technology Enterprises. The center operates on the campus of Tampere University of Technology. The LUMATE Center organizes science clubs for children (grades 1 through 8): Lego robotic clubs, electronic clubs, programming clubs, and science clubs. Most of these events take place in the evening at LUMATE's study room, located within the Tampere Technology School. Also, every two weeks LUMATE organizes an event called “Tiedepysäkki” (science station).

During the school holidays, LUMATE organizes science camps every summer and autumn. Camps are designed for children from preschool to grade 8. In addition to activities for schoolchildren, LUMATE organizes monthly Science Cafes in the Old Library building in the center of Tampere. These are public events designed for older students and adults. Science cafes provide a unique forum for exploring interesting STEM subjects for high school students and students, as well as for the general public. LUMATE invites experts to popularize mathematics and coordinates national tours with other LUMA centers.

Teaching and training for teachers and student advisors: LUMATE provides a variety of learning resources. The first of these is the “Bank of Experts”, from which teachers can

invite various specialists to conduct presentations in their schools. Each expert is a specialist in a certain field, and their visits can be organized in such a way that they correspond to the teacher's timetable, thereby improving students' understanding of the subject at hand. LUMATE also maintains a central "laboratory equipment bank".

Schools can be provided with special equipment to demonstrate scientific phenomena in the classroom. Most of this borrowed equipment is available in sufficient quantity to allow an entire class to participate in the experiments. The LUMATE web page also has a training material bank, which includes a collection of instructions for scientific experiments and various methods for presenting various scientific concepts and ideas.

Nowadays the LUMATE Center is called Juniversity. Juniversity offers a range of opportunities to explore and experience science and delivers hands-on learning experiences to children and youth from preschool to secondary school.

Tampere Universities community is actively engaged in numerous science enrichment and outreach activities. Juniversity was established in autumn 2019 to bring under one roof all the science enrichment and school outreach activities from across the University. Juniversity seeks to foster positive attitudes towards science among all learners and support the work of teachers. Besides offering after-school science clubs and camps, Juniversity welcomes school groups to visit the science classroom on the Hervanta campus and explore science with hands-on activities. The Juniversity team hosts expert lectures and has a variety of materials and resources available to support learning. The team engages in outreach activities to expand the national knowledge base as part of the higher education community's mission to deliver impact for society. Science education is provided to instil scientific curiosity and encourage science learning among children and young people.

Juniversity's activities already cover a broad range of content in mathematics, natural sciences, and engineering and technology, thanks to the long-term work carried out at the Tampere LUMATE centre. In the future the activities will be increasingly expanded to include other disciplines. The extensive range of activities offred by Juniversity is made possible by the 25 student teachers who run the science clubs and camps and host the visiting school groups.

- LUMARTS [24]

In 2012, Aalto University began building a special LUMA laboratory for schools. It was called LUMARTS. LUMARTS Laboratory is a learning and teaching environment that supports and develops science, technology, and art. LUMARTS laboratory was

developed in conjunction with Biofilia. Biofilia is the LUMARTS functional unit for biological arts, which also strives to maintain a positive STEAM image (STEM + ART) and offers unique educational alternatives in the fields of science, art, and technology.

School teachers can book time at LUMARTS and bring their students to experiment. The teacher is responsible for the group, and Aalto University offers an assistant to do the work in the laboratory. Study tours for pupils and students aged 10–20 years vary from one hour to a longer time. For high school students, LUMA Center Aalto offers lectures and courses, for example, lectures and courses in mathematics, chemistry, astronomy, and biology, taught by teachers and university professors. Lectures in the natural sciences are organized on average twice a month; students from several universities participate in them.

– StarT Finland [25]

StarT is the flagship program of LUMA Center Finland (Finnish platform STEM). Launched in 2016, the main goal of the program is to bring science, mathematics, and technology closer to children and youth through interdisciplinary project co-education. The program is implemented by LUMA Center Finland (a network of regional STEM training centers at Finnish universities) through "learning communities" with the support of cooperation partners, including the Finnish National Education Agency and science and technology companies such as IBM.

The StarT program is implemented at three levels: 1. Local-level: Kindergartens, elementary schools, high schools and after-school groups participating in StarT. 2. Regional level: StarT festivals organized throughout Finland by LUMA centers together with local partners (does not apply to foreign participants). 3. National / international level: LUMA Center in Finland organizes a StarT gala concert, which awards teams selected by the StarT jury, as well as foreign teams. In the 2016-2017 school year, the StarT program supported 400 learning communities from Finland and 350 learning communities from abroad with participants from 36 countries.

– BioPop [26]

The BioPop Center is a resource center for science education at the LUMA Center at the University of Helsinki. The main goal is to inspire and motivate children and adolescents in the field of biology, to support the study and enthusiasm of biology in children and adolescents, and to support all biology teachers in teaching and professional development. They organize school visits to the university, clubs, camps

and teacher training on the job, and produce electronic educational materials for the site and blog.

- F2k [27]

F2k's main goal is to foster understanding and interest in physics and technology among Finns. The center works as part of the training of physics teachers at the Faculty of Physics, University of Helsinki. F2k provides on-the-job teacher training by offering workshops and summer courses for physics teachers and classroom teachers. Science clubs and summer camps for children aged 8 to 14 years have been held since 2004.

For high school students, the F2k laboratory offers practical experiments in modern physics and an understanding of modern research in the field of physics. He also organizes outreach activities in collaboration with organizations whose goal is to make science more famous.

- PaikkaOppi [28]

PaikkaOppi is a free online learning environment for schools. It includes tools for mastering the basics of geographic knowledge and recommendations on how to use geographic knowledge in different disciplines.

- Summamutikka [29]

Summamutikka is a resource center for teaching and studying mathematics as part of the LUMA National Center and the Department of Mathematics and Statistics. Summamutikka offers ideas on how to teach mathematics based on project activities. He supports and develops the teaching and study of mathematics.

- Tutki-Kokeile-Kehitä [30]

Tutki-Kokeile-Kehitä is a competition aimed at inspiring children and young people in science and engineering activities. Providing participants with the opportunity to receive feedback on their research and get to know other like-minded people, this opens a world of endless possibilities.

- SciFest [31]

SciFest is an annual international festival that brings together thousands of students, high school students and teachers to discover new experiences and learn about science, technology, and the environment. SciFest is held every year during one spring weekend in Joensuu, Finland. The festival is free and open to all.

- The Innokas Network [32]

The Innokas Network helps schools organize their 21st Century skills training activities and participate in educational development. They support schools by organizing training, consultations, and events in different parts of Finland. The network was created by a group of practicing teachers. To date, the network has more than 600 schools throughout Finland, as well as international partner schools.

Innokas training is based on the Innovation School model developed in collaboration between Finnish schools and the Faculty of Education at the University of Helsinki. This network is involved in many projects that are discussed in other sections.

– Co4Lab [33]

The goal of the Co4Lab project is to research and develop knowledge-based teaching methods, collaborative design, collaborative learning, and collaborative regulation. The project aims to improve the quality of science, technology and craft education in primary and lower grades of secondary school by organizing a series of design experiments. School projects focus on the study of complex real-world phenomena, the integration of knowledge and competencies in subject areas, the invention, testing and design of various products, as well as the accumulation of knowledge about the teaching process.

The project creates guidelines, models, and resources for knowledge-based learning to support teachers and schools in developing and implementing STEM practices.

– Growing Mind [34]

The Innokas Network is a partner in the Growing Mind research project funded by the Academy of Finland. This project, operating in 2018-2022, is aimed at the development of school activities of the 21st century and its study in the framework of digitalization of society. The Growing Mind project aims to create funds for the renewal and development of schools, teacher development, and student learning at the personal, social and institutional levels. Project activities are carried out in collaboration between schools and academic research. The events support the goals of the new core curriculum, the skills of 21st-century students and the professional development of teachers.

– Uutta luova asiantuntijuus (ULA) [35]

Innokas Network is a partner in a teacher training project funded by the Finnish Ministry of Education and Culture - “New Creative Expertise - Combining Primary and Continuing Teacher Education” (ULA). The project aims to develop new structures and content, allowing to connect both the training of new teachers and the retraining of

teachers on the job. Interdisciplinary topics in teaching and teaching include knowledge of different languages, equal and democratic school, research work, collegial cooperation, student motivation, interaction, and digitalization, as well as cooperation between curricula.

– Finnable project [36]

In 2012-2015 Innokas network was responsible for the implementation of the Innovation School project, funded by Tekes. The project studied the school and its surrounding community as a complex of networks of learning environments. For the Innovation School, new methods of using technologies have been developed, including new ways to use digital technologies to support students. So, the Finnable project was created. FINNABLE 2020 contributes to the creation of new learning ecosystems that go beyond the traditional boundaries of where, when and with whom learning takes place.

This project conducts research and development of collaborative, technology-oriented learning environments for the 21st century - locally and internationally. FINNABLE 2020 is supported by contributions from research institutes, practitioners in schools, and industry partners. FINNABLE 2020 consists of four work packages: Boundless Classroom, Teacher's Toolkit, Exergames in Learning and Emergent Learning Technologies and Communities.

– Ekopaku [37]

Ekopaku acts as an environmental school. The car includes all equipment for nature research and training materials, as well as pre-designed training aids. Ecovan – an outdoor classroom (Aulikki Laine, Finnish Association of Schools of Nature and the Environment). In new curricula, memorable, experiential and phenomenon-based learning plays a very important role in teaching. One way to expand learning is through outdoor learning. Ecovan has everything you need for outdoor learning.

– ScratchJr [38]

ScratchJr is an introductory programming language that allows young children (5-7 years old) to create their own interactive stories and games. Children connect the graphic programming blocks so that the characters move, jump, dance and sing. Children can change characters in the color editor, add their voices and sounds, even embed their photos - and then use the programming blocks to spice up their characters. ScratchJr was inspired by the popular Scratch programming language

(scratch.mit.edu), which is used by millions of young people (ages 8 and older) around the world. ScratchJr is available as a free app for iPad and Android tablets.

– Arkki International Ltd [39]

In 1993, the Finnish National Education Agency created the basis for a curriculum on architectural education. It was then that the schools of fine art, music, and dance had a new partner - the school of architecture. The curriculum for architectural education is divided into early education, basic art, and advanced education. Early education is for children and parent groups for children from 4 to 6 years old, basic education is for children from 7 to 14 years old, and advanced education is for children from 14 to 19 years old.

Arkki uses a wide range of methods but focuses on 3D working methods. By creating miniature models, as well as on a 1: 1 scale, children can make discoveries on their own, rather than receive answers from adults. Teaching at Arkki is about art and the environment. One of the main goals of architectural education is to provide children with ways and opportunities to observe and evaluate their surroundings. In family groups, the goal is to help children begin to form interactive relationships with their environment.

Education improves their sense of space, shape, movement and materials, and structures. The student plays an active role in studies and training. Teaching is based on the special approach of each age group to the perception of the world and experiences.

– SuoMu [40]

SuoMu, the Finnish design training association, promotes the use of design education on a variety of learning platforms. SuoMu conducts seminars and lectures for schools and various cultural events. At SuoMu Design School events, you can enter the image of a designer and go through the entire design process with SuoMu assistants in various subjects. The Mutku project - “Design Education for Elementary Schools” was launched in 2012, and as a result, in 2014, a design manual for primary school teachers “Mutku” was published. A tour of SuoMu Design Ambassadors to elementary schools disseminates information on design and creative learning. In the fall of 2015, a pilot project began with teachers of an elementary school in Helsinki, which aims to update teaching practices throughout the curriculum.

– ITEEA [41]

ITEEA's mission is to expand technological and engineering capabilities for all people, as well as to educate and promote the professionalism of those involved in these activities. ITEEA is committed to meeting the professional needs and interests of its members, as well as improving public understanding of technology, innovation, design and engineering, and their contribution to human life.

STEM-Teacher Training Programs and Courses

The Finnish National Board of Education emphasized the following core values for the development of teaching profession competences [42]:

- life-long learning
- knowledge and research-based orientation
- effectiveness
- anticipation of future needs and competences in education

The teaching profession is a learning profession, and teachers are expected to develop their work and profession throughout their careers. Finnish teacher education is based on a strong research orientation. This reflective and critical knowledge creation approach is also important for in-service training. In Finland, there is a strong movement from individual in-service training days towards more long-lasting development projects and programs that could be more sustainable in their effects. FNBE outlined that staff training must integrate the latest research, knowledge from education evaluations, new knowledge creation, and competence development.

Most universities have education centers for teachers' in-service training. It is important that research-based and research-informed orientation of pre-service teacher education continues, and teachers can learn the most up-to-date and advanced knowledge of their subject matters as well as pedagogy through in-service training. University centers' in-service training provide more projects and longer development processes than short courses. The aim is that teachers critically reflect on their own work and create small design-based action research projects through which they learn new competences and also share new ideas with their colleagues.

LUMA Centre Finland also promotes effective continuous professional development for STEM teachers. the University of Helsinki launched a Massive Open Online Course, MOOC (in Finnish) that aims to provide support and ideas for teachers to find and utilize a suitable nearby business as learning environments. In addition, the course provides tips for planning and implementing a good visit and for creating a learning material.

The current LUMA ecosystem is a social innovation in which universities, schools, teachers, students, guardians, and industry collaboratively engage children and young people from ages 3 to 19 in math, science, and technology and support research-oriented teachers at all levels for lifelong learning [43]. The core value of this collaboration is shared expertise.

The LUMA Center Finland encourages all collaborating partners to share their ideas, experiences, and practices freely, in the spirit of open education. The center supports communality among children, youth, and teachers. Their natural interaction with the scientific community in the universities and industry is fostered, and their voice is a part of the design process of the LUMA activities.

The LUMA Center supports teachers' lifelong learning through a continuum model [44] that includes the following components: (1) pre-service training, (2) an induction stage, and (3) in-service training. LUMA activities have been integrated into the training of both elementary and subject teachers at Finnish universities. During their studies, preservice teachers are provided with authentic and regular experiences to interact with children and youth by leading different activities in the LUMA Center. Pre-service teachers also use the latest research information to actively produce teaching materials and ideas that benefit all teachers of STEM subjects in Finland.

STEM EDUCATION IN IRELAND

Context

In recent years, governments of developed countries around the world and in Ireland also [45] have paid special attention to improving the quality of education in science, technology, engineering and mathematics (STEM). STEM disciplines are extremely important for modern society. They expand our understanding of the world and are key in many important areas of activity [46]. Mathematics and natural science provide answers to fundamental questions of nature, and engineering allows you to turn these answers into technologies. Analysis of the current situation shows that the development of STEM disciplines will accelerate economic development, support innovation, and provide the foundation for future prosperity [47]. High-quality training of graduates of STEM disciplines will ensure the development of the knowledge economy. Ireland aims to be the center of technological innovation and the leader of highly intelligent industries. To do this, Ireland's strategy for research and development, science and technology is being created. This development plan provides qualitative changes in the field of STEM education to support the most talented individuals and leaders of educational institutions and methodological centers.

STEM Education Policy Statement and Implementation Plan for Schools

In Ireland after consultation with experts, one of the ways of obtaining a highly skilled workforce was recognized through STEM education. This approach required a clear understanding of STEM education for the Irish context. The embedding of this understanding across the education system will help transform the STEM education experience of learners from early years through to post-primary.

In November 2016 a Report on Science, Technology, Engineering and Mathematics (STEM) Education [48] was published. The agreed Terms of Reference (TOR) for the review were as follows:

- The preparation of teachers (Initial Teacher Education; ITE) at Primary and Post-Primary Level for STEM education.
- The best methods of supporting the current cohort of STEM Teachers within the system, with a particular focus on Continuing Professional Development (CPD) programmes.

– The introduction of new teaching and learning modalities that would enhance STEM education in our schools and for which there is a strong evidence base (e.g. inquiry-based learning and problem-based learning approaches; new assessment modalities).

– The use of technology to enhance learning (especially digital and/or on-line approaches).

– The promotion of STEM careers and the identification of methods to enhance the engagement of students in STEM subjects.

After analyzing the current situation, the authors of this report [49] suggested the following:

– Produce an integrated National STEM Education Policy Statement with input from, and relevance to, all stakeholders across the continuum of education in Ireland (primary, secondary and third level). This Policy Statement should include a detailed implementation plan with responsibilities and timelines clearly outlined.

- Introduce computer science (including coding) as a Leaving Certificate curriculum subject. This is critical to address the ICT skills deficit in Ireland.

- Establish the STEM 2020 Partnership – a fixed-duration, public-private (enterprise-exchequer) partnership to create a fund to support a prioritized set of agreed, specific initiatives consistent with the recommendations of this report. This would entail pooling of resources from enterprise partners, philanthropy and crowdsourcing with resource-matching by the exchequer (DES, DJEI, SFI) over a five-year period. A fund of €8M per annum for five years, equally subscribed from public and private interests, is envisaged.

- Establish STEM education research as a national research priority with multi-annual, sustained funding commitment through SFI. (The following recommendation would be an excellent means of achieving this).

- Establish a National STEM Education Research Centre, comprising a small number of regionally distributed nodes (based on the highly successful UK Science Centre model). This national centre would act not only as a centre of excellence for research and innovation in STEM education, it would also provide locations for delivery of CPD programs for teachers.

- Create an annual ‘Excellence in STEM Teaching’ award scheme to recognize those teachers who are pioneering innovations in STEM education and who are outstanding educators.

While this report has focused almost exclusively on the STEM disciplines and STEM Education in general, it is now well established that the intersection of these areas with the Arts (visual and performing) and Design offers great potential in terms of both cultural advancement and economic development opportunities. With this is in mind, it is important that any future strategy for STEM in Ireland takes account of the STE(A)M hybrid, where A represents the Arts and Design (including design thinking). It is proposed, therefore, that the Royal Irish Academy play a formal role in advancing the thinking on this topic in the Irish context with a view to influencing future policy decisions regarding STEM Education.

The STEM Education Report was followed by development of the STEM Education Policy Statement and Implementation Plan [50]. A series of STEM education consultations were undertaken between May and July 2017 to gather the views and opinions of key stakeholders to inform the Policy Statement on STEM Education [51]. Implementation of this approach will take place over several phases from 2017 till 2026.

Implementation Phase 1 (2017-2019) – Enhancing. Phase 1 sought to accelerate activity already underway in key areas. It also sought to build capacity across the system and develop new initiatives. Initiatives from schools themselves through clusters and partnerships would be particularly encouraged. Audit and evaluation of key methods that are crucial to achieving our ambition and developing the benchmarks of success would be undertaken. Phase 1 focused on establishing what is necessary to provide a quality STEM education experience. Key to this is the analysis of existing baseline data and the generation of new benchmarks to develop targets and indicators which are well-defined, realistic and time-bound.

Implementation Phase 2 (2020-2022) – Embedding. The focus of Phase 2 will be on deepening capacity building and supporting a coherent STEM environment. A structured approach, which incorporates monitoring and review, will allow actions to be revised and developed in line with identified needs.

Implementation Phase 3 (2023-2026) – Realising. Phase 3 will focus on realising the vision of providing the highest quality STEM education experience for learners. Actions in phase 3 will be informed by reviews of Phases 1 and 2, ongoing research and the changing educational and societal environment.

STEM Education Policy Statement [52] (2017-2026) focusses on the many strengths in STEM education while providing a roadmap to address the areas for development. In developing this Policy Statement, three key principles have been identified that will underpin all STEM education initiatives: STEM is about igniting learners' curiosity so they participate in solving real world problems and make informed career choices; STEM is interdisciplinary, enabling learners to build and apply knowledge, deepen their understanding and develop creative and critical thinking skills within authentic contexts; STEM education embodies creativity, art and design. The actions outlined for STEM education will build on a range of reforms and activities already underway such as curriculum reform and innovative teaching, learning and assessment. They are also informed by the STEM Education in the Irish School System Report, research and extensive consultation with stakeholders. Other influencing factors include parents' perceptions, expectations and the evolving STEM education eco-system.

Concepts and Projects

- EPI-STEM

The National Centre for Excellence in Mathematics and Science Teaching and Learning was established in September 2008 at the University of Limerick, initially supported by funding from the Higher Education Authority's Strategic Innovation Fund. In 2014 the University established a Chair in STEM Education and the Centre was renamed EPI*STEM – the National Centre for STEM Education. (tel.: +353 (61) 23 47 86, FAX: +353 (061) 23 47 99, e-mail: epistem@ul.ie) [53]. The Centre aims to improve STEM education through research into effective teaching, learning and professional development. The mission of EPI-STEM is to conduct an integrated program of research, teaching, and engagement that addresses national and international challenges in STEM education. This goal can be achieved by leveraging distinctive connections between STEM education academics and STEM discipline academics, and by forging connections with policy makers, practitioners, industries, and community groups that have a stake in STEM education.

The vision of EPI-STEM is to be recognized as the premier national centre for STEM education that positively influences STEM education policy and practice as well as public perceptions of STEM. EPI-STEM aspires to international recognition for high-quality, high-impact STEM education research that supports beneficial exchange of knowledge between researchers and the communities they serve and leads to enhanced teaching practices and improved educational outcomes for learners.

- Numeracy Across the Curriculum Project

In August 2019, EPISTEM launch the Numeracy Across the Curriculum [NAC] [54] project for schools in the Limerick region. It is a yearlong research and development project that develops strategies for teaching numeracy across the curriculum in both primary and secondary schools.

The NAC project is an excellent opportunity for schools across the Limerick region to establish fruitful and meaningful links with the university. This project seeks to develop teachers' understanding of numeracy, while also guiding teachers on how to recognize and embed numeracy opportunities within their subject area. In order to participate in the NAC project two teachers (of any subject) from each school must attend a summer school (3 days in August 2019) and 2 workshops (1 day in November 2019 and 1 day in May 2020) and engage in 2 action research cycles which involve the delivery of model lessons; classroom observations and supportive feedback from the EPI-STEM research team; and teacher and student interviews.

- Common European Numeracy Framework

With financial support of the European Union under the Erasmus+ scheme four countries - the Netherlands, Austria, Spain and Ireland – have initiated the first steps to come to a Common European Numeracy Framework (CENF) [55] and are going to work towards such a framework between 2019 and 2021. As result of this project a Common European Numeracy Framework (CENF) will be established and based on this framework a set of professional development modules for adult numeracy educators will be developed. The CENF will incorporate the latest insights into quality numeracy skills and competencies which are relevant for our technologize and numbers-drenched society.

- A Global Approach to the Gender Gap in Mathematical, Computing, and Natural Sciences: How to Measure It, How to Reduce It?

This project [56]started in January 2017, will last till January 2020 and consists of three tasks. Tasks 1 and 2 provide data on which to base conclusions, to direct actions to attract and retain women in science, and to develop and evaluate practical recommendations. Task 3 collects information on effective practices. The relevance of the study is due to the fact that although the description mathematical and natural sciences have long and honorable traditions of participation by highly creative women contributors but however, the percentages of women scientists remain shockingly low and there is a significant gender gap at all levels between women and men.

- Pre-service teachers' understanding of the concept of numeracy as a cross curricular subject in post-primary schools in Ireland

At present, internationally and in Ireland, there is a conscious effort being made to improve and raise the profile of the teaching and learning of numeracy. Teachers' perceptions and interpretations of the concept of numeracy relies greatly on their understanding of numeracy. If teachers have a deep understanding of the concept of numeracy, and an awareness of the essential role it plays in allowing an individual to fully engage in society, then the inclusion of the teaching and learning of numeracy will play a more significant role within their subject(s). This study began in September 2016. Its purpose is to assess current pre-service teachers' understanding of the concept of numeracy as a cross curricular subject and to identify the knowledge required by pre-service teachers to integrate numeracy into their lessons. This study will be carried out in three universities in Ireland till June 2020 with second year Professional Master's in education students.

- Primary and Post Primary teachers' insights into their teaching of algebra

Since January 2018 this research has focused on teachers' insights into their teaching of algebra, particularly during the transition from primary to post-primary school. Data generated in this research specifically investigates upper primary and lower post-primary school teachers' conceptual understanding of algebra. The study was qualitative in nature and involved two phases of semi-structured interviews with a cohort of upper primary and lower post-primary school teachers.

- What's the Point? Teachers Perspectives' on the Incentive of Bonus Points for Studying Higher Level Mathematics

In Ireland, a Bonus Points Initiative (BPI) was introduced in 2012 for mathematics. Through this initiative, any student who opts to study higher level mathematics receives an additional 25 university entrance points on condition that they pass the Leaving Certificate examination. The main aim of this study is to investigate the benefits and challenges associated with the BPI from the perspective of mathematics teachers. This project commenced in January 2018 and questionnaires were distributed in April 2018. 800 teachers across 400 post-primary schools were targeted and 266 teachers responded.

- WiSTEM2D Scholars Award Program [57]

This program is sponsored by Johnson & Johnson, providing bursaries and mentoring to female undergraduate students in any of the University of Limerick's STEM

disciplines. The goal is to fuel the research passion of the selected women and inspire career paths in their respective STEM fields.

- Career Mathways Project

The project [58] received funding under the SFI Discover scheme, SFI's Education and Public Engagement program which seeks to promote the awareness and engagement of the Irish public in STEM. According to SFI "...the mission of this programme is to catalyse, inspire and guide the best in STEM education and public engagement. This is done by supporting and developing the education and outreach STEM sector in Ireland by investing in developing and extending capacity in this area and also exploring and encouraging novel means of public engagement and communications."

Career Mathways aligns with the goals of the Discover Programme as it seeks to promote STEM, and in particular mathematics, among Transition Year students; their parents; their mathematics teachers as well as career guidance teachers. The initiative aims to highlight the mathematics underpinning a variety of careers, as a way of enhancing student engagement across all STEM subjects. The project engages with several well-known, high profile personalities (e.g., television presenters and sports commentators, a lawyer, a meteorologist) and other professionals, who all volunteered their own time to act as STEM Ambassadors. In their role as STEM Ambassadors these professionals recorded an interview with the Career Mathways research team in which they explored the different types of mathematics they use in their careers and highlighted how important is it to have a good understanding of mathematics and be proficient in the subject. These videos serve to make mathematics more visible and fascinating to students and it is hoped that it will help teachers when faced with the common question "Where will I use this again?" The videos were then used by the team of researchers to develop a suite of resources including detailed and innovative teaching and learning plans; student workbooks featuring authentic, real-world problems as well as a poster series sponsored by a national newspaper to highlight the value of mathematics in a variety of different professions.

- TiME (Time in Mathematics Education)

This project was funded by the Irish Research Council [59]. The introduction of the new Project Maths curriculum into post-primary schools in 2010 prompted a number of reports and studies to suggest that there is an insufficient amount of time allocated to teaching mathematics in Ireland (Department of Education and Skills, 2011; Cosgrove et al., 2012; Irish Maths Teachers Association, 2012; Jeffers et al., 2013; Beggy and O'Meara, 2014). However, none of these reports provided concrete evidence of the

exact amount of time allocated. Thus the main aim of this project was to investigate such issues surrounding the allocation of time for mathematics instruction.

- Chain Reaction

Chain Reaction [60] was a project focused on creating a sustainable approach to the use of scientific inquiry in the classroom using a cascading model to facilitate its impact. This project ran from 2013 to 2016 across 12 partner countries and located within UL is the Irish partner involved. The Chain Reaction model is cyclical in nature so each year the project recruited new teachers (10 each year) from different schools ensuring a large number of teachers and students were able to participate. The focus in Ireland was to create a professional learning community (PLC) involving teacher educators, in-service teachers, pre-service teachers, practicing scientists and policy makers with the aim of developing a living educational theory of what teachers believe inquiry to represent in their own classroom context. After teachers had engaged in interactive IBSE professional development, their students (in the 14-16 age group) worked together to research scientific scenarios. Their work was then summarized in a national "Express Yourself" conference held each year in UL where students presented posters related to their investigation and the experience of using an inquiry approach. All methodologies used were coherent with the revised science syllabus and the work was conducted as a community of practice that emphasized sharing ideas in a truly developmental process.

- Student Mathematical Preparedness for Third-Level STEM Degrees

The aim of this project was to explore students' mathematical preparedness for STEM education at tertiary level in the Irish context. The project took an innovative approach to the issue of student retention in STEM degrees by investigating the perceptions of three stakeholders – teachers, students and lecturers – on the mathematical preparedness of students for studying science and engineering at tertiary level. This project also examined the existence and perception of interdisciplinary STEM education in preparing students for the transition to tertiary level STEM learning.

- CASTeL

CASTeL is Ireland's largest research centre in Science, Technology, Engineering, and Mathematics (STEM) education (Dublin City University, Dublin 9, tel. +353 (0) 1 700 5862, castel@dcu.ie, eilish.mcloughlin@dcu.ie) [61]. CASTeL's mission is to support the development of STEM learners from an early age and thus enhance the scientific, mathematical and technological potential of Irish society. For nearly two decades,

CASTeL has made a significant contribution to STEM education both nationally and internationally. Through evidence-based research, CASTeL leads and advises on the design of innovative and effective curriculum, teaching and learning in STEM education from early childhood to graduate level. CASTeL is uniquely positioned to conduct interdisciplinary research because of its diverse backgrounds in STEM disciplines (mathematics, science, biology, chemistry, physics, engineering, digital learning, and technology). CASTeL brings together the research expertise of the Faculty of Science and Health Sciences and the DCU Institute of Education, which is a major provider of teacher education in Ireland. This allows CASTeL to be at the forefront of developing the knowledge and skills of future teachers to teach STEM subjects. In addition, CASTeL provides Continuing Professional Development (CPD) in STEM education, encompassing both consistency and breadth. CASTeL is known for its leading role in international STEM education initiatives. Many of these focus on inquiry-based learning, in which problem solving and experimentation are based on students' curiosity and observation, allowing them to make sense of the world through critical thinking and reflection.

- Assessment of Transversal Skills in STEM (ATSSTEM) [62]

ATSSTEM is a project of innovative policy experiments, which is carried out in 8 EU countries and includes a partner network of 12 educational institutions. ATSSTEM is committed to providing teachers and students with effective and necessary digital assessment approaches to develop the cross-cutting skills of second-level students in STEM (Science, Technology, Engineering and Mathematics). This model is being developed, implemented and evaluated as part of a large-scale classroom pilot project leading to policy recommendations at both national and European levels for further educational transformation. Teachers, researchers, and students participating in the project will help plan new pedagogical approaches and learning outcomes to influence systemic change that will enable them to succeed in achieving their educational goals. The project also aims to ensure that policymakers have a deployment strategy to create a creative learning environment appropriate to their national or regional context.

- ENERGE – Energizing Education to Reduce Greenhouse Gas Emissions

As the existing stock of high school buildings ages (it may take years from planning to completion of new schools / major renovations), there is a need for low-cost solutions that ensure long-term resource efficiency in schools and reduce greenhouse gas emissions (GHG). The EU directives on energy in construction and the climate

protection measures 2020 and 2030 confirm this need. ENERGE [63] is meeting this need with targeted physical interventions that combine the web platform and building sensors (e.g. electrical, thermal, etc.) with behavioral research and new educational approaches that enable schools to participate in reducing energy and greenhouse gas emissions. This holistic, adaptable and interdisciplinary approach will combine sociological, pedagogical and communication expertise with low-cost technology, ICT interventions and systems engineering. ENERGE will be showcased in schools in France, Germany, Luxembourg, Ireland, the Netherlands and the UK. ENERGE is committed to achieving a minimum 15% reduction in total energy consumption in 12 schools with demonstration sites during the project period and will engage and enable management, teachers, students and support staff (the entire school ecosystem) to reduce energy consumption through the development of a new website. platform tailored for various stakeholders in the school ecosystem. Long-term impacts will be consolidated through the development of additional and revised teaching materials to complement existing school curricula (for students aged 12-18, i.e. ENERGE will monitor the impact of project initiatives outside the school environment on the home environment of staff and students (24 homes) to monitor how school interventions can have a wider impact outside the school environment ENERGE committees will be set up in the demonstration schools to focus on the transnational participation of project schools, long-term impact studies, and empower the entire school community to participate and support energy efficiency and reducing greenhouse gas emissions.

- Let’s Talk about STEM

Let’s Talk about STEM is a pilot project [64], funded by Science Foundation Ireland, and led by DCU’s Institute of Education in conjunction with the Centre for the Advancement of STEM Teaching & Learning (CASTeL) in DCU. This project is a collaboration between researchers in psychology and science and technology education to implement a pilot program to tackle the under-representation of women in science and technology, focusing on the early involvement of girls in science. This project, based on twenty years of solid international research and initiatives, is a STEM education program for parents and teachers of young children that highlights the potential impact of language on children's science and motivation to learn. In particular, it emphasizes that girls consider themselves capable of using and researching science. The program invites parents, preschool educators, child class teachers and informal STEM educators to participate in workshops in which they examine evidence on the role of language in girls’ and boys' different motivations for science learning and their persistence.

- Maths4All.ie

Maths4All.ie [65], funded by SFI Discover, is a website designed for and with teachers. It contains activity plans, continuous professional development materials and video clips based on activities carried out in Irish primary and preschool classes. Plans are based on the draft specification of the forthcoming primary mathematics curriculum and Aistear and are suitable from preschool to third class. The website offers a video-based approach to continuous professional development and modules relating to mathematical tasks, talk and the use of play and picture books are available. Currently, work is under way to extend the activity plans on offer to include the senior classes of primary school. New professional development modules are also being developed in response to a survey of teachers' needs and preferred formats.

- 3DIPHE – Three Dimensions of Inquiry in Physics Education

This ERASMUS+ project [66] is focused on different levels of inquiry relevant for physics education: 1) Inquiry based learning for pupils; 2) Practitioners' inquiry for teachers; 3) Inquiry of coaching for partners; 4) Educational research design of 3DIPhE. The goals of the project are to establish professional learning groups (PLG) of teacher practitioners and train them to inquire their own practice of inquiry based learning (IBL). Regular PLGs' meetings provide a forum for discussion of inquiry problems, modes of inquiry, methods, evidence, and conclusions, and reflection on improvement of the IBL in classrooms. PLGs from different countries exchange their experience, discuss their problems and reflect on methods, evidence etc. Results of these processes are presented at national and international events. Good examples of IBL praxis are presented in a written, publicly available form. Based on the experience, courses on practitioner inquiry and coaching PLGs will be developed. Regular accompaniment and inquiry of all processes within the project will result in an extensive educational design research study.

- Open Schools for Open Societies

This project [67] supports a large number of European schools to implement Open Schooling approaches by a) developing a model that promote such a culture, b) offering guidelines and advice on issues such as staff development, redesigning time, and partnerships with relevant organizations (local industries, research organizations, parents associations and policy makers), and c) suggesting a range of possible implementation processes from small-scale prototypes through to setting up an "open school within a school" or even designing a new school while it is testing and assessing

them in more than 1,000 school environments in 12 European countries. The themes of the project activities developed and pursuit in participating schools that will take place will focus on areas of science linked with the Grand Societal Challenges as shaped by the EC, will be related to RRI and will link with regional and local issues of interest. The project is coordinated by Ellinogermaniki Agogi Scholi Panagea Savva (EA) and has 20 partner institutions. The project aims to describe and implement at scale a process that will facilitate the transformation of schools to innovative ecosystems, acting as shared sites of science learning for which leaders, teachers, students and the local community share responsibility, over which they share authority, and from which they all benefit through the increase of their communities' science capital and the development of responsible citizenship.

STEM activities

- Smart Futures

This is a selection of various educational activities for schoolchildren and students that allow them to understand the meaning of STEM education [68].

- SciFest

The SciFest programme consists of a series of one-day STEM fairs for second-level students. The aim of the programme is to encourage an interest in, and love of, the STEM subjects.

- Tech Week

It is a nationwide series of events, showcasing and celebrating Ireland's application on technology which provides a platform for students to learn, share ideas and create connections to enhance our future world.

- The Festival of Curiosity

It is Dublin's annual international festival of science, arts, design and technology with new digital, virtual and blended formats for people of all ages to explore and discover science, arts, design and technology in playful new ways.

- STEM in the Midlands

Accenture STEM professionals visited schools in the Midlands and presented STEM materials as well as explaining what Accenture has to offer. As a board member, one of the Accenture professionals is involved in the planning and direction of the organisation.

- CoderDojo

In 2016, Accenture set up its first CoderDojo coding club for a group of energetic young people, with a team of enthusiastic mentors from The Dock. Accenture continues to run the club for beginners to advanced learners, aged 7-17, through CoderDojo, in the Accenture offices in Dublin. CoderDojo offers a number of topics for children such as Scratch, Lightbot and Robotics, where they learned how to code, develop websites, create apps and games.

- Girls Only TY Week

This is a weeklong Transition Year work experience programme, for girls only, with the aim of encouraging them to think about choosing STEM subjects for Leaving Certificate and studying STEM career in College. 15 Female TY Students attended. After the week finished all girls who attended agreed that they would consider a career in STEM for the future and would now consider STEM subjects for the Leaving Certificate.

- CWIT and Teen Turn

Teen-Turn is a non-profit organization run completely by volunteers. This organization strives to give teenage girls from disadvantaged areas or schools the ability to explore technology and STEM and in turn choose to study these subjects at secondary school and university. Connecting Women in Technology (CWIT) is a network of technology companies working towards the common goal of attracting, retaining and promoting females in the technology sector. Teen Turn had connected with CWIT in the lead up to the first Technovation Challenge in Ireland (Jan – Apr 2018).

- Intel Ireland Balloon Rocket Launch

Intel Ireland reached out to 16 local primary schools with the aim of engaging third class students in an appropriately levelled science and engineering lesson, using inexpensive and widely available materials to demonstrate a scientific principle and the fundamentals of experimentation in an accessible and interesting way.

- Intel Ireland Mini-Scientist

Intel engaged with schools in the locality and also encouraged employee volunteers to encourage the competition in schools where they had an existing relationship. Schools are invited to complete an online registration form for entry (www.intel.ie/miniscientist), participating schools divide students into teams of 4 to work on projects relating to STEM and are then invited to host an exhibition of the

projects at the school, with Intel providing the adjudicators and prizes. Winning projects from each school progress to regional and then a national final.

- Introducing Students to Coding – Google CS First

A 6-week programme, led by volunteers from Google, to give 4th class students (ages 9-10) at an all-girls primary school (with disadvantaged school status) their first taste of learning how to code. Staff from the Google office volunteered 1 hour per week to go to the school and support the students through structured lessons on CS First - Google's free curriculum to teach coding with Scratch, a block-based programming language.

- Ericsson INFUSE

The Ericsson Athlone INvesting in FUture Software Engineers or INFUSE is a range of initiatives that focus on creating enthusiasm and interest around Science and Mathematics. The INFUSE program encourages interaction with the students at a young age in order to avoid the negative stereotypes of the career, especially for future female engineers.

- Fujitsu–Schools Business Partnership Programme

Since 2011, Fujitsu Ireland and St. Joseph's School, Rush have partnered together as part of Business in the Community Ireland's (BITCI) Schools' Business Partnership Programme. This programme aims to tackle the retention rate in post primary schools and gives young students an insight into the careers and options available in the STEM industry. Each year, four internships offer for students who have excelled throughout the programme. They come in for one week in the summer to work on meaningful tasks and projects across our business. In order to secure the internship, a class of 5th year students was equipped with a CV and Interview skills session in the school. These are life skills which will greatly benefit students in the long term. Then they were invited to Fujitsu for a site visit which includes a welcome speech from the Fujitsu CEO, a tour of the building and a careers speed networking session with Fujitsu employees. Following the site visit, students apply for the internship with the CV and cover letter which we helped them to create in the workshop. They are then called to interview, and four candidates are selected for the internships.

STEM Teacher training

The quality of teaching of STEM subjects in schools has a direct bearing on the quality of learner experience and achievement. Thus, any approach that aims to improve STEM education in Ireland schools must treat STEM teacher education as a key priority.

The importance of initial teacher education (ITE) in STEM lies in challenging and deepening student teachers 'beliefs about the learning process, in developing their understanding of the nature of the STEM subjects and familiarizing them with a range of teaching approaches. Teacher knowledge is usually viewed as having three strands: subject matter knowledge (SMK), pedagogical knowledge (PK) and pedagogical content knowledge (PCK) (Shulman, 1987). SMK concerns knowledge of content (e.g., knowledge of mathematical or scientific concepts, mathematical or scientific reasoning etc.). PK relates to knowledge of pedagogy and is generally subject independent (e.g. sociological or psychological aspects of education). PCK is the interplay between content and pedagogy, that is, the link between knowing something and facilitating others to learn it. It is expected that, as pre-service teachers progress through their preparatory programmes, these different forms of knowledge become more tightly interconnected.

There are two routes to registration as a primary school teacher in Ireland: the concurrent route, which involves completing an undergraduate degree course in primary ITE, and the consecutive route, which involves completing an undergraduate degree and a postgraduate programme of ITE.

In both entry routes, pre-service teachers are expected to engage in Foundation Studies, Professional Studies and School Placement (Teaching Council, 2011a). As part of professional studies, students begin to develop their PCK of all subjects of the Primary School Curriculum, including STEM subjects. Furthermore, the courses are directed towards pupils in classes from Junior Infants to Sixth class.

Essential Leaving Cert grades to qualify for ITE are a Grade C3 in Higher Level in Irish, Grade C3 Ordinary Level or D3 Higher Level in English and Grade D3 (either Ordinary or Higher Level) in Mathematics. The Teaching Council has provided advice to the DES on Leaving Cert grades for entry into ITE programmes. This advice is currently under consideration by the DES.

Similarly, there are two models for post-primary teacher registration. One is a concurrent model of a degree qualification in post-primary ITE, which combines the study of one or more approved curricular subjects along with teacher education studies.

The other is a consecutive approach of first completing an undergraduate degree, which enables the holder to teach at least one approved curricular subject, and then completing a postgraduate programme of ITE geared towards the post-primary age range.

At present, a student entering initial primary teacher education needs a minimum of a Grade D3 (at either Ordinary or Higher Level) in Leaving Certificate mathematics. However, the majority of entrants to primary ITE programmes exceed this grade, and only a small minority present with the minimum grade required in mathematics.

While a high level of content knowledge is necessary, it is not sufficient for the effective teaching of mathematics and, in particular, PCK is now recognised as a 'decisive' variable in student achievement in mathematics (Education Committee of the European Mathematical Society, 2012). In addition, one study has suggested that raising the minimum entry requirement in mathematics may not, in itself, yield a significant improvement of teaching (Corcoran, 2008). Nevertheless, the relatively low entry requirements for mathematics (primary teacher education) compared to the entry requirement grades needed for English, and Irish is, at the very least, problematic in the disciplinary prioritisation that it conveys to students. This balance needs to be redressed. Furthermore, greater support needs to be given to increasing discipline knowledge across STEM subjects at both primary and post-primary levels.

Because mathematics underpins all STEM subjects, there is a strong case for targeting improvements in mathematics teaching. Raising the entry levels (for primary teaching) in mathematics in a measured fashion would not only enhance the public and student perception of the importance of mathematics, but it would also ensure a higher baseline of subject knowledge upon which to build during ITE. In this context, it is most important to emphasise that pre-service teachers should be supported in achieving an agreed level of knowledge of mathematics as they undergo ITE.

Government-supported Initiatives have been put in place to address literacy and numeracy during teacher preparation, but the need to augment science education has not been addressed sufficiently, particularly at primary level. The development of specialist courses/modules in science subjects and science education during primary and post-primary ITE would serve to increase the content on offer to pre-service teachers (such courses/modules are already offered in some HEIs).

In general, the low level of knowledge and insight that pre-service teachers possess in the physical sciences is a matter of deep concern. Low percentages of students entering ITE courses have studied Physics or Chemistry for the Leaving Certificate,

while a high percentage of students have studied Biology (Murphy and Smith, 2012). Poor scientific content knowledge leads to a lack of confidence in teaching those subjects.

In Ireland, there has been a move in recent years towards the establishment of a general set of standards for teachers which includes the use of ICT in teaching and learning. Highlighting ICT as one of the key national priority areas and a significant aspect of student teachers 'developing professional skills, the Teaching Council lists ICT in Teaching and Learning as one of the mandatory elements of ITE (Teaching Council, 2011a). As ICT has the power to be transformative and lead to the design of new learning environments, its use needs to be embedded across course work in ITE.

School placement is an inherent component of all ITE programmes. While it usually takes place in either a primary or post-primary school (depending on the programme of study), some students of post-primary ITE programmes have a practicum in a senior primary setting. However, short placements with STEM-related industries during teacher preparation could also offer important experience and insights into the importance and practical applications of STEM. This would be an opportunity for industry to contribute to developing stronger STEM education in Ireland.

Continuing Professional Development

- STEM Teacher Internships [69]

This is a 12-week paid internship in a STEM role within industry (e.g. tech/pharma/finance) for pre-service primary and secondary level teachers. A pilot programme commenced in 2016 as a collaboration between DCU, Accenture and the 30% Club. Since then it has recruited over 20 companies to host STEM internships through the Connecting Women in Technology (CWIT), 30% Club and PharmaChemical Ireland networks. In 2019, 32 students completed internships across 19 host companies - bringing the total to 54 participating teachers to date. The pilot was created by DCU, 30% Club and Accenture as a practical way to address the low number of students, particularly girls, pursuing STEM subjects and careers, as consistently reported by Accenture's STEM reports. The participating teachers have since taken up teaching positions in schools and have incorporated these unique experiences in their subsequent teaching roles. They draw upon their experiences and transfer the knowledge and skills gained to their students and colleagues, to increase student interest and awareness of STEM roles and careers. The pilot programme was carried out with 5 students from DCU's BSc Science Education programme which qualifies

teachers of Physics, Chemistry and Mathematics at second level. The interns completed a 12-week paid internship at Accenture during the summer months. The programme was then extended to Intel and AIB in 2017 and has since been extended to other companies – with 9 companies hosting in 2018 and 19 companies hosting in 2019. The target for 2020 is to extend the programme to offer 50 internship positions in summer 2020. Research, including Accenture 'Girls in STEM' reports in 2013 and 2015 showed that teachers are one of the biggest influencers in young people's lives and they have a powerful multiplier effect. This led to the pilot of STEM Teacher Internship programme. Subsequent STEM report from Accenture in 2017 and What Now for STEM report in 2019 further highlights the need to make STEM subjects engaging for all students from an early age and that giving teachers a first-hand experience of working in STEM industry has the potential to change students opinion on future careers in STEM. The impact on the participating teacher has been transformative - in terms of increasing their understanding of STEM roles and careers in industry, addressing stereotypes, developing the key skills required to be successful in industry and the relevance of STEM subjects to real world applications. Positive feedback from companies is substantiated by the fact that all the companies who have hosted internships have offered to host again and increase the number of positions available in subsequent years. One of the key impacts of this programme is the development of education-industry relationships and closing the gap between STEM in schools and STEM in the workplace for students, teachers and parents.

- Professional development service for teachers [48]

The PDST is the country's largest single support service offering professional learning opportunities to teachers and school leaders in a range of pedagogical, curricular and educational areas. The PDST was established in September 2010 as a generic, integrated and cross-sectoral support service for schools. The establishment of the organisation was synonymous with the amalgamation and restructuring of a number of stand-alone services which now operate under the PDST providing their services to schools in the context of PDST's overall vision and mission. The work of the PDST contributes to school improvement by fostering reflective practice through the school self-evaluation process and through the ongoing development of teachers and school leaders through a range of CPD models. Amongst the priorities for the Department of Education and Skills (DES) for the coming years is the implementation of proposals to improve Literacy and Numeracy in both primary and post-primary schools. Other key priorities include supporting school leadership, school self-evaluation, assessment, ICT for teaching and learning, inclusion, health and wellbeing and post primary subjects

and programmes. These priorities inform the work of PDST and are addressed through the work of individual teams across the organization.

PDST Primary Workplan for 2019/2020

The PDST offers customized school support on application across all priority areas. This includes a model of sustained support for schools that are selected according to completion of an online application making a case for such support according to identified needs and plans for improvement. Sustained support involves various forms of deeper transformational modes of teacher professional learning aimed at building internal capacity and enabling schools to drive and embed change as independent communities of learners. Such modes include coaching, lesson study, in- school professional learning communities and the development of middle leadership cultures.

Primary STEM 2019/2020

Team Teaching for Inclusion in Mathematics, Lesson Study Shared Learning Day, Inquiry Based Approaches to Measures and STEM as Gaeilge, Number Sense Webinar, Play Based Approaches to Mathematics and Science Webinar [70].

- Maths Recovery

The PDST in conjunction with Maths Recovery Ireland providea CPD to selected DEIS schools in the Maths Recovery Programme. The Service Level Agreement between the PDST and MR Ireland for 2019 2020 stipulates that this will include the following: 8 days training for all Maths Recovery Associates; one Maths Recovery Teacher to be trained in 120 selected schools (on application); one class teacher to be trained in each of the 120 selected schools and also in schools already in the programme to a total of 400 schools (September 2019 to June 2020).

- Primary STEM Sustained School Support

Models of Sustained support for Primary STEM; Lesson Study; Communities of Practice; Coaching and Mentoring (September 2019 to June 2020).

- Primary STEM Summer Course

This new PDST Summer course aims to promote a classroom culture of curiosity and investigation in STEM. This course is designed to give teachers inspiring practical STEM activities. Teachers are facilitated to approach STEM in the primary classroom in an integrated manner. The range of relevant STEM curricular areas is addressed by stimulating and rich inquiry-based tasks. Making connections to the Arts curriculum,

integrating and combining creativity with a STEM theme, this course presents an interdisciplinary approach to presenting STEM subjects (July/August 2020).

- Digital Portfolios Pilot Project

This pilot study [71] aims to utilise a sustained support approach with 24 schools to explore how the usage of digital portfolios can support and enhance formative assessment practices in the primary school context. A collaborative cross-team approach is employed here, building capacity, whereby 4 advisors from the Digital Technologies team will upskill 4 advisors from the STEM team in this area and then the 8 PDST advisors will together provide support to the 24 schools involved in this initiative (3 schools per advisor). PDST draws from the success of the Post-Primary formative assessment through e-portfolio project (November 2019 - April 2020).

Once labs are online, faculty and students are freed from the equipment and scheduling constraints of the brick-and-mortar laboratory.

STEM EDUCATION IN SWEDEN

Context

STEM is the acronym for Science, Technology, Engineering, and Mathematics. It encompasses a vast array of subjects that fall into each of those terms. While it is almost impossible to list every discipline, some common STEM areas include aerospace engineering, astrophysics, astronomy, biochemistry, biomechanics, chemical engineering, chemistry, civil engineering, computer science, mathematical biology, nanotechnology, neurobiology, nuclear physics, physics, and robotics, among many, many others. Judging from the multitude of disciplines it is clear that STEM fields affect virtually every component of our everyday lives.

Today's students are tomorrow's leaders. Occupations in STEM-related careers are some of the fastest growing and best paid of the 21st century, and they often have the greatest potential for job growth. As you strive to keep up with the current and projected demand for STEM output, it is important that your country remains competitive in fields of science, technology, medicine, and all of the other STEM fields we have mentioned so far. The best way to ensure future success and longevity it is to make sure that your students are well versed in these subjects. Building a solid STEM foundation through a well-rounded curriculum is the best way to ensure that students are exposed to math, science, and technology throughout their educational career.

STEM-Related National Policies in Sweden

The curriculum for mainstream, preschool and school age (revised 2018) [72] has pages dedicated to Technology: Curriculum for mainstream, preschool, and school education (pdf) [73] (read more about: Swedish National Education Agency [74]).

Instead of Sweden's national secondary and tertiary education policy, we can turn to passages relating to Sweden from Do Well Science - Manuals to Innovative Pedagogy in STEM Content [75] (Erasmus + Project to Improve Secondary School Student Achievement in Science).

There is no specific policy in Sweden for the development of STEM education, but the diploma goals for a science program (gymnasium, high school) can be seen as a STEM policy: The science program is a program to prepare for higher education. With a diploma of completion of the program, students must have the knowledge necessary to obtain higher education, primarily in the field of natural sciences, mathematics and technology, as well as in other fields.

The STEM Professional Development Landscape in Sweden

- LiU leads projects in Eastern Europe [76].

Linköping University has been given the main responsibility for two large Erasmus projects in Eastern Europe. The goal is partly to develop a new master's program in mobile apps and game development; and a new curriculum for future teachers of mathematics, technology and science.

The two new projects extend between 2019 and 2022 and have each been awarded approximately SEK 10 million by the EU. LiU is the main responsible university in two different networks with 20 universities, of which twelve are in the "recipient countries" Russia, Azerbaijan and Kazakhstan.

The second project, *Integrated Approach to Stem Teacher Training (STEM),* in Kazakhstan and Russia aims to develop new syllabuses for future teachers in mathematics, technology and science. The current programs are old-fashioned, and interest in them from both pupils and future teachers is low. Many other countries are facing similar challenges for these subjects.

One of the things that need to be brought out is the connection between objects. How is mathematics related to physics and technology, for example? Now, the fields are separated far too strictly, and the pupils study them in isolation. They do not get to see how everything is related.

The "STEM centers" are also built in several locations, like the Fenomenmagasinet in Linkoping. It can spark the curiosity and interest of young people and teachers in mathematics and technology.

Participating universities in STEM:

- Linköping University, Sweden
- Hacettepe University, Turkey
- University of Limerick, Ireland
- University of Helsinki, Finland
- Southern Federal University (SFedU), Russia
- Immanuel Kant Baltic Federal University (IKBFU), Russia
- Belgorod State National Research University (BeISU), Russia
- L.N. Gumilyov Eurasian National University, Kazakhstan
- M. Auezov South Kazakhstan State University (SKSU), Kazakhstan
- Sarsen Amanzholov East Kazakhstan State University, Kazakhstan

ABOUT THE STEM PROJECT

Science, technology, engineering and mathematics (STEM) knowledge and skills are critical to sustainable economic development in the 21st century and are becoming an increasingly important part of basic literacy in today's knowledge economy according to the European Schoolnet. Advances in these areas underpin research across all scientific disciplines and drive innovation and job creation around the world. Science, technology, engineering and mathematics (STEM) knowledge and skills are critical to sustainable economic development in the 21st century and are becoming an increasingly important part of basic literacy in today's knowledge economy according to the European Schoolnet. Advances in these areas underpin research across all scientific disciplines and drive innovation and job creation around the world.

The main goal of the project is to improve the quality of training of STEM teachers at partner universities in accordance with the provisions of the Bologna Declaration and the needs of the knowledge economy.

Specific objectives of the project:

- Development of master's programs for the preparation of STEM teachers based on an integrated approach;
- Creation of regional STEM resource centers providing consulting and interaction services;
- STEM Ambassador Training;
- Teaching teachers new skills.

The project aims to meet the needs of partner countries for qualified STEM teachers by improving the quality of STEM education: Together with EU partners, a unique master’s program for teacher training will be developed based on an integrated approach. First, the teachers involved in the implementation of the new program, and then a wider range of teachers from the consortium members and regional universities and schools will be trained in modern teaching methods.

The results are achieved through the implementation of a 6-step program:

- PREPARATION "Best Principles and Practice"
- DEVELOPMENT "Developing a STEM Master's Program"
- DEVELOPMENT "Learning structure"
- QUALITY PLAN "Ensuring the quality of project implementation"
- DISSEMINATION AND DEVELOPMENT "Project visibility and sustainability"

- MANAGEMENT "Effective project management and coordination"

During the preparation phase, basic project policies and plans will be developed and an analysis of the basic needs of employers will be carried out. The main results will be obtained at the stage of project development. Training of trainers will follow a cascade model: first, a training program will be introduced for a small number of qualified trainers; trained trainers will then transfer the skills to a wider range of STEM stakeholders. All project results will be subject to internal and external evaluations. The project consortium consists of 10 universities from 4 EU countries and 6 universities from Russia and Kazakhstan. Associate Partners will actively participate in educational activities and dissemination of information.

Linköping University (LiU) is a large Swedish university specializing in medicine, education, engineering and economics. LiU manages teacher training programs for the entire Swedish school system, from preschool to adult education, as well as out-of-school teacher and pedagogy programs for people with special needs. The Faculty of Education has primary responsibility, but departments in all faculties of the university are involved in teacher training.

LiU has two national centers for STEM professional development: the National Center for Science and Technology Education (NATDID) and the National Center for School Technology Education CETIS. Both centers are appointed and funded by the Swedish government.

- National Centre for Science and Technology Education, Linköping University (NATDID) [77]

The aim of NATDID is to support school development in science and technology on the national level.

In order to fulfill this mission, NATDID will communicate research from current research in science and technology education, to those who work in schools. The goal is that teachers should be able to transform educational research into practice, thereby contributing to research-based teaching and learning in schools.

NATDID was founded after a decision from the Swedish government in 2014. Linköping University hosts the centre, which is located at Campus Norrköping, Sweden. The board of NATDID consists of delegates from different universities, as well as from the school context. A director leads the daily work of the centre, together with an assisting director and staff.

One aspect of communicating research concerns identification of available channels for communication. Digital arenas, websites as well as social media, are forums where both teachers and researchers are active. It is important to NATDID to exist where teachers and researchers are present. However, NATDID also believes in the importance of personal encounters: conferences, network meetings, workshops, and inspirational plenary talks, are some examples of how this could be arranged.

One important part of NATDID is establishing and managing networks for the target groups in school, in teacher education, and for relevant groups and organizations. This includes creating conditions for sustainable relationships and dialogue between the target groups.

NATDID has also been charged with coordinating the four Swedish resource centers in Biology, Physics, Chemistry and Technology, regarding issues of research communication:

- Chemistry Teachers Resource Center (KRC)
- National Resource Center for Biology and Biotechnology (Bioresource)
- National Resource Centre for Physics Education (NRCF)
- Center for Technology in Schools (CETIS)

Sweden has 4 resource centers for teachers, funded by Skolverket, the Swedish National Agency for Education, which each focus on a different area in the STEM field (Physics, Chemistry, Biology and Technology). The resource centers provide in-service teacher training, various teaching materials, newsletters, conferences and other relevant pedagogical resources.

Sweden also has a series of regional science centers which have been receiving government grants since 1997.

14 such science centers received state funding in 2009. The science centers are targeted at teachers, students and the wider community and are committed to spreading knowledge and stimulating interest in the STEM field.

There are special educational programs designed for teachers available at the center, attended by several thousand teachers across the country each year. Many of the centers also arrange outdoor visits and outreach activities to motivate new audiences and the wider public.

- CETIS – The Swedish National Resource Centre for School Technology Education, Linköping University [78]

The Swedish National Resource Centre for School Technology Education, CETIS, at Linköping University started in 1993. In 1996, the government made CETIS a national center. The main aim of the center is, in collaboration with teachers, teacher-trainers, and representatives for industry etc. to develop technology education in schools.

CETIS works with a broad array of activities. One of its larger commitments is to arrange regional or national conferences for teachers in Technology on a biannual basis. CETIS arrange network meetings for educators in teacher education concerned with Technology. Four times a year Centre publishes a newsletter and sends to all Swedish schools, free. Once a year it runs a two-day national research seminar for PhD-students in Technology education. The Centre has an active website (www.cetis.se) and can be found on Facebook (CETISliu). It provides teachers with support material and teaching support. Collaboration with the DfE and NAE is central to Centre, as well as industry, labour unions, company organizations, museums etc. It cooperates with other national centers as well as similar international hubs, since international overview and contacts are of great importance to it. Centres engage, and get engaged, in national competitions, EU applications, curricular activities, in-service training etc.

CETIS is situated at Linköping University, Campus Norrköping.

The ultimate aim is to inspire, support and help teachers develop good, general, technological education to all Swedish pupils and students. For this purpose, the wide term “Technological bildung” is often used which encapsulates most aspects of the pupil’s growth towards deeper technological knowledge, awareness, skills, competencies, and literacy. Centre's vision is to provide a body of knowledge that combines theory and practice, integrating technological knowledge, philosophy and science with the humanities, and the social and natural sciences.

The Swedish national curriculum for the Technology school subject has changed over the last six decades, and so has its motives. It has broadened from a male orientated industrial subject at lower secondary school to a compulsory subject for all pupils at all ages.

In the present curriculum for the compulsory school, technology is a core subject from year one to year nine (age groups 6-16). There are at least three good reasons for this. Each citizen living in a democracy must try to understand and evaluate technology and technical systems. Many of today's important social issues concern technological choices. By allowing the pupils themselves to play with, try out and develop different technical solutions they will become familiar with the technology that surrounds them in everyday life. Modern society is to a great degree dependent on the education of

scientists and technologists in more and more areas of work, who are discerning and aware of important issues.

Practical and investigative work is important, but the syllabus also emphasizes that the scientific and social aspects must be present in teaching, together with historical and international perspectives.

- The National Resource Centre for Physics Education (NRCF), Lund University and its operations [79,80].

NRCF is a national resource center with a mandate from the National Agency for Education. NRCF's purpose is to increase interest in science and technology, especially physics. Targeting teachers in preschool, primary school, high school and adult education will do this. Efforts should also be made to renew teaching and further train teachers. The National Resource Center for Physics shall operate on a national basis.

The NRCF's mission is to empower teachers to continue learning and help find inspiring physics teaching resources. This is achieved by conducting courses and training days independently and in collaboration with others and developing materials, as well as collecting, analyzing, evaluating and disseminating information from others.

The competence of the center's staff covers many different areas of physics and didactics, and they have experience in teaching at all levels. They have good contacts with researchers and teachers in all Swedish universities with physics education, with science teachers and with teachers from many schools throughout the country. They also have good international contacts in research and education.

The NRCF is based in Lund and has premises in the Faculty of Physics at Lund University. The Ministry of Education and the National Education Agency with additional support from the rector and the scientific and technical faculties of Lund University fund them.

NRCF is also active on various social media platforms where teaching and physics are discussed in different contexts.

In conjunction with National Resource Centers for Chemistry and Biology, the Center does NOT organize biennium for F-9 teachers. The Center participates in other events such as the School Forum, Mathematical Biennale, CETIS, Preschool Biennale and Physics Days of the Physical Society.

- National Center for Mathematics Education, Gothenburg University (NCM) [81]

NCM's task is to support the development of mathematics education in preschool, in the compulsory and voluntary school system. It was established by a government decision in January 1999. NCM is one of several resource centers for various school subjects established over the past 20 years.

The center is located at the University of Gothenburg, led by a director who, together with the center's employees, implements overall decisions.

NCM's staffs include people who have a background, or are active as teachers, teacher educators, researchers and mathematicians. They are responsible for and participate in various activities and projects such as

- publication of the journals Nämnaren and NOMA
- publication of literature for teacher education and teacher training
- participation in and arrangement of seminars, courses and conferences
- operation and development of several websites.

- Centre for School Biology and Biotechnology, Uppsala University [82]

The commission, given by the Ministry of Education and Uppsala University, is to support and inspire teachers in preschools, compulsory schools, and upper secondary schools and in adult education by

- supporting discussion and exchange of ideas between teachers
- work for raised competence at all levels of biology teaching
- giving advice for practical work in the laboratory
- promoting development of outdoor education
- supporting an integrating view of life science
- giving information about current development within the biological field
- supporting and promoting contacts between research, school and industry
- stimulating discussions about sustainable development and ethical questions.

Beginning during 2003, Centre distribute a magazine, Bi-lagan, in Swedish.

- Centre for School Chemistry Education, Stockholm University [83]

The Chemistry Teachers' Resource Center, KRC, is a national resource center and an initiative of the Ministry of Education and Stockholm University, operating since 1 July 1994. KRC has close contacts with the Swedish Chemical Society and business industry organizations.

KRC supports elementary and high school chemistry teachers to promote stimulating, engaging and relevant learning. Support for chemistry teachers includes, but is not limited to, preparing and advising on experiments and other teaching materials, advising on safety and chemistry issues, initiating and delivering continuing education for schoolteachers, and fostering contacts between the school and the chemical industry.

- The Swedish National Agency for Education (NAfE) [74]

The National Agency for Education is the central administrative authority for the public-school system, publicly organized preschool, school-age childcare and for adult education.

The Swedish National Agency for Education is tasked with ensuring that all children and students have access to the same high-quality standard of education and activities in secure environments. Our mission is to create the best conditions for the children's development and learning and to help improve the students' learning outcomes.

The agency prepares knowledge requirements, regulations, general recommendations and national tests. The agency is also responsible for official statistics in the area of education and it conducts national follow-ups and evaluations. The agency also oversees Sweden's participation in international education surveys.

The National Agency for Education also ensures that Swedish education maintains a good standard of quality. The agency achieves this with the help of national schools development programs and in-service training of the staff. It distributes grants and arranges head-teacher training programs.

The Swedish National Agency for Education (NAfE) has funded:

- 2013-2016 Science and Technology Project, approx. 15 M€
- 2012-2016 Raise Maths Project, approx. 270 M€
- 2007-2010 Raise the Teachers, approx. 360 M€
- 2011-2015 Raise the Teachers II, approx. 140 M€
- 2016-2018 Raise the Teachers II, approx. 120 M€
- Collegial Learning Project, Modules, (some STEM) XX M€

Added extra hours in school for Mathematics, change in curriculum 2013. Technology got 200 hours from 1^{t} to 9th grades in 2017.

STEM PD Net project [84]

CETIS and NATDID are two national centers affiliated with Linköping University. Together, they are involved in an EU project that concerns competence development in the STEM area (Science, Technology, Engineering, Mathematics). The name of the project is STEM PD Net.

It is a European project with 14 partners from 7 countries to develop a network for the exchange of experience and to strengthen the opportunities in the various countries for skills development in the STEM field. Linköping University is responsible for a so-called Intellectual Output that concerns policy activities and influence, with the aim of supporting the actors who want to get involved in competence development within STEM.

The aims of the STEM PD Net project are:

- Improving quality of STEM teacher Professional Development (PD) delivered in Europe on a large scale by:
- setting up research-based criteria for high-quality PD and enriching these with good-practice examples
- developing ready-to-use guidelines on how to feasibly measure the success of teacher PD in day-to-day settings as a mean of quality assurance
- developing a catalogue for PD providers showcasing good-practice examples on how to prepare teachers to deal with diversity
- collating a commented collection of STEM PD material allowing PD providers to easily find and select materials with a focus on their purpose, content, quality and potential.

Supporting STEM teaching through strengthening partnerships with and among PD practice by:

- setting up a European STEM PD centre network as a stable partnership among PD providers
- strengthening the national position of STEM PD centers and their potential for forming effective local partnerships through the involvement in the European network
- promoting a compendium of PD provider models so as to encourage ways forward to establish new specialized centers in STEM PD across Europe where they do not yet exist

– strengthening the voice of European PD centers through the development of a set of policy briefings and strengthened partnerships to communicate with policy makers.

Dealing with an increasingly complex reality in class is a development, which has accelerated in the last years and puts high demands on teachers. Thus, teachers need support through professional development (PD) activities to adopt new integrative methods. This need is particularly pronounced in STEM teaching (Science, Technology, Engineering and Mathematics), since STEM is a field in which all pupils, including migrants or those from disadvantaged backgrounds, should acquire appropriate skills in order to ensure their participation in work and life.

Nowadays, the need for high-quality STEM teacher PD and the promotion of approaches that allow teachers to deal with complex classroom realities has been recognized. This can also be seen in policy documents and reports such as the science education report (Science Education for Responsible Citizenship, European Commission 2015). It is also evidenced by the recent trend in Europe to establish PD centers to promote STEM teacher PD. However, these PD centers were not connected to each other and did not exchange experiences. Hence, the aim of the European Network of STEM Professional Development Centers (STEM PD Net) is to strengthening the position, work and knowledge base of STEM PD centers across Europe: through transnational exchange and mutual learning in a stable European PD center network, through linking research with practice, through developing ready-to-use guidelines and reference materials for STEM PD providers. This will also contribute to improving the quality and relevance of STEM teacher PD on a large scale.

That is the essence of our project STEM PD Net, funded by Erasmus+ KA2 (Key action for 'Cooperation for Innovation and the Exchange of Good Practices'). The project is coordinated at the International Centre for STEM Education (ICSE) of the University of Education Freiburg, Germany.

Network

To provide as many teachers as possible with relevant and high-quality professional development (PD) courses, in many countries national professional development centers have been set up in the past years. The European STEM Professional Development Centre Network grew out of the idea that these national centers should be connected internationally since they have similar aims and agendas, namely: investing in teacher professional development to substantially improve STEM

education as it happens day-to-day in schools. Despite different national circumstances, foci and structures the national PD Centres across Europe encounter similar concerns and challenges. International collaboration therefore is essential. The network ensures knowledge exchange in order to improve local practices in STEM professional development and strengthens the voice of practice when it comes to shaping STEM education in Europe.

The 2014 conference "Educating the educators – International approaches to scaling-up professional development in Maths and Science education" served as a platform to initiate the collaboration of PD Centres across Europe: in the course of the conference the first meeting of European Professional Development centres involved in math and science education took place. Hosts of the conference and the first PD Centre meeting were the European project MASCIL (mathematics and science for life!) coordinated at the University of Education Freiburg, and the DZLM (German Centre for Mathematics Teacher Education, funded by the Deutsche Telekom Foundation).

Owing to the resonance, the first meeting found, the University of Education Freiburg, as part of its initiatives within the MASCIL project, took a lead in facilitating further meetings. To date, five meetings of the European STEM Professional Development Centre Network took place: in December 2014 in Essen (Germany), in May 2015 in Vilnius (Lithuania), in December 2015 in Sofia (Bulgaria), in June 2016 in Hradec Králové (Czech Republic), in November 2016 in Freiburg (Germany) as part of the second Educating-the-Educators conference, in May 2017 in Gothenburg (Sweden) and in November 2017 in Madrid (Spain).

The next network meeting took place in Sofia (28/29 November 2018). This and future meetings will be hosted by a new Erasmus+ project (STEM PD Net) coordinated at the University of Freiburg's International Centre for STEM Education (ICSE) which serves to further promote the European collaboration of PD Centres and their activities to improve STEM education.

The European STEM Professional Development Centre Network has also grown substantially since 2014 and currently comprises around 30 members from 12 European countries, including university-based centers and such administered by Ministries of Education. The University of Education Freiburg, as part of its activities coordinated at the International Centre for STEM Education (ICSE), serves as the Network Coordinator.

National Centre for Mathematics Education, NCM – University of Gothenburg, Sweden [85]

University of Gothenburg (UGOT) is a large higher education institution in Sweden. One of many profile areas is knowledge formation and learning, where teacher education plays an important part. The university offers the broadest range of teacher education in Sweden in terms of available programs and subjects.

UGOT hosts the Swedish National Centre for Mathematics Education (NCM). The center is commissioned and financed by the Swedish government with the mission to coordinate, support, develop, carry out and follow up initiatives promoting Swedish mathematics education in pre-school, school and adult education. NCM is also specifically expected to stimulate and disseminate research in mathematics education in Sweden.

NCM produces well-founded materials for professional development (PD) and resources for teaching, made accessible through a teacher journal, books produced at the center, and a popular website for teachers. The center offers a rich collection of PD activities meeting teachers directly with workshops, conferences, and other shorter or longer programs, but also engaging in programs for facilitators who can lead PD activities at the local level.

NCM's network is wide and includes many teachers, municipalities, organizations, and authorities. Currently, NCM is for example developing PD dealing with ICT and mathematics education, special education in mathematics, and mathematics education for newly arrived immigrants.

STEM in Sweden universities

- KTH - Royal Institute of Technology (Swedish: Kungliga Tekniska högskolan), the Department of Learning in Engineering Sciences [86]

Learning in STEM. Learning in STEM (Science, Technology, Engineering and Mathematics) is one of four units at the Department of Learning, belonging to the School of Industrial Engineering and Management (ITM) at KTH. The unit consists of three research groups: Engineering Education in Society, Higher Education Organizational Studies (HEOS) and Learning in Technology and Science Education (TN-didactics). In addition to our research and development, the unit has KTH-overall assignments and competence in engineering education.

- Courses at Learning in STEM [87].

Learning in STEM (Science, Technology, Engineering and Mathematics) offers courses for teachers from P-12 education and higher education. The unit also offers courses for doctoral students.

- Courses for educators and teachers.

If you have a bachelor's degree but do not have subject knowledge, KTH offers specific purpose education within 'Teacher Lyft II', a continuing education course. Programming for teachers, with focus on technology or mathematics education (7.5 ECTS credits): In-service technology for teachers in school years 1-3 (7.5 ECTS credits); In-service technology for teachers in school years 4-6 (7.5 ECTS credits); Technology for Teachers, grade F-6 (7.5 ECTS credits).

- Courses in higher education.

Course offerings and course content are developed to follow SUHF's new recommendations for higher education. All courses can be included in the requirement of 15 credits of teaching at higher education for employment or promotion to staff at KTH.

- Courses in teaching and learning in higher education for KTH employees and doctoral students, Postgraduate and Doctoral courses at learning.

STEM degrees [88] are Science, Technology, Engineering, and Mathematics programs. They all require using research and reasoning to solve problems. And, they could lead to diverse career paths in growing fields. Within each category, you'll find many kinds of STEM graduate degrees. For example, engineering students could study civil, electrical, or computer engineering. Science students could study everything from biology to veterinary and animal sciences. You could pursue goals that range from building bridges to keeping IT systems safe. No matter what path you pursue, STEM careers are key to a brighter future.

Jönköping University becomes member of International Centre for STEM education 2018-12-04 [89]. The School of Education and Communication at Jönköping University has become an elected member of the International Centre for STEM Education (ICSE), a consortium of 14 European universities that are collaborating to carry out research in STEM education.

In summer of 2018, the School of Education at Jönköping University became an elected member of ICSE. The ultimate aim of ICSE is to help improve STEM education across Europe through practice-related research and its transfer into practice. STEM is a term

used to group together the academic disciplines of science, technology, engineering and mathematics.

Through membership in this prestigious consortium, the university has access to collaborations with some of the most successful international research institutes in STEM education research.

STEM EDUCATION IN TURKEY

Context

Innovation is very important for countries. It is an interactive and multidisciplinary process and tightly connected to life. In our time, there is a clear consensus among stakeholders on the importance of STEM education to the innovation.

STEM education has recently become an area of increasing interest in Turkey. For instance, recent policy documents [90] and science curricula [91,92] emphasize on interdisciplinarity in education. There are several STEM activities and STEM professional development programs.

- Science festivals, STEM education conferences and STEM enrichment programs [93]

The Turkish Supreme Council for Science and Technology (SCST) plays a critical role in setting the agenda and policies in STEM. The SCST suggests strategies on develoing a science culture, spirit of research and research skills among students. TUBITAK (the Scientific and Technological Research Council of Turkey) Science and Society Division [94] is responsible for coordinating the public engagement initiatives. TUBITAK gives funds to primary and secondary schools to run science fairs. Funding for each school is around US$1,000 and almost all applicant schools are successful. Although the funding is quite modest, the impact can be immense. In particular, it has enhanced collaboration among schools, universities and industry, and it has also created social inclusion in science education. TUBITAK Science and Society Division also has other funding (around US$20,000 per event) for organising large-scale science festivals. These science festivals have attracted children to participate in many hands-on science activities.

There are non-profit initiatives in this field. The Turkish Technology Team Foundation [95], STEM & Makers Fest/Expo [96] and Maker Faire [97] are among them. The Turkish Technology Team (T3) Foundation, founded by several entrepreneurs, supports educational projects and technology start-ups. They organise science engagement activities for primary and high school students and provide several support programs for university students and grants for young tech start-ups. The T3 Foundation aims to support 1001 Technology Teams and 1001 Technology Ventures by 2023.

- STEM PD Community of Practice (STEM CoP) [98]

STEM PD Community of Practice (STEM CoP), founded in 2019 as an outcome of the STEM PD Net project, is an independent body of network. STEM CoP aims to bring together researchers, practitioners and stakeholders from around the world to discuss issues related to STEM Education. STEM CoP develops STEM Curricula and run STEM PD programs in different countries. STEM CoP also publishes journals and books in STEM education [98]. STEM CoP organizes "International STEM Education Conference" and "International STEM Teachers Conference" [98] and its social media channels provide resources to teachers, initiating an online forum for teachers and lecturers.

National STEM policies and initiatives

- Science Centers

In Turkey, there are a wide variety of museums and science centers in different fields. Table 1 highlights main science museums, science centers, observatories, and planetariums in Turkey (see Table 1).

Table 1. Main science centers in Turkey [99]

Name	**Established**	**City**
Feza Gürsey Science Center	1993	Ankara
Deneme Science Center	1998	Istanbul
Bekirpaşa Municipality Science Center	2008	Kocaeli
Istanbul Museum of the History of Science and Technology in Islam	2008	Istanbul
Karşıyaka Municipality Science Museum	2009	Izmir
Gaziantep Planetarium and Science Center	2010	Gaziantep
Ödemiş Municipality Science Center	2011	Izmir
Eskişehir Science Experiment Center	2012	Eskişehir
Bursa Science and Technology Center	2012	Bursa
Karaman Municipality Science Center	2012	Karaman
Avcılar Science Center	2013	Istanbul
Sancaktepe Science Center, Observatory and Planetarium	2014	Istanbul
Konya Science Center	2014	Konya
Kocaeli Science Center	2014	Kocaeli
Elazığ Science Center	2015	Elazığ
Kayseri Science Center	2017	Kayseri
Üsküdar Science Center	2018	Istanbul
Hacettepe Science Center	2018	Ankara

- Ministry of National Education (MoNE), Turkey

Science and art centers [99]

Currently there are 182 Science and Art Centres in 81 cities with a population above 63,000 students [100]. These centers are designated for gifted and talented students. There is a huge demand for these centres; therefore, through an examination, primary school students (up to Grade 4) are placed in three fields (music; a 'general talent' field including science history, geography, etc.; and visual art) according to their talent. The nature of diagnostic tests for the selection of students has been criticised as has the fact that these centers are only for gifted and talented students. There have been public demands for science and art centers for all children no matter what interests and abilities they have.

These centers are run by the Ministry of Education and are free of charge for students who pass the entrance exam. These students can attend their centres until they graduate from high school. They take courses and extra-curricular activities and projects at the centre around 8 hours per week during school terms. They attend the center at weekends or weekdays based on their school timetable.

Scientix Project

Besides, General Directorate of Innovation and Educational Technologies participate in the Scientix Project as a national contact point. Scientix Project (The community for science education in Europe), which is conducted by European Schoolnet that is founded by European Commission, started in December 2009. The website "http:// www.scientix.eu/" of Scientix Project has been open to service since May 2010. Scientix is a community in which about 30 European countries participate for aiming the dissemination of good practices, projects and materials used in STEM education in Europe.

Scientix community is open to teachers, researchers, policy makers, families and anyone who is interested in STEM education. Scientix projects has been carried out as Scientix 2 between 2013 and March 2016. Third phase of the project named as Scientix 3 was started at April 2016.

The main goals of Scientix Project are:

- Informing all Europe about projects related to STEM education in Europe,
- Facilitating dissemination and sharing of materials and tools produced by STEM education projects,

- Creating a web-based platform where European national congresses, conferences, workshops or projects about STEM education could be announced to all Europe,
- Creating a web-based platform where teachers and academicians can share experiences and ideas on a European level,
- Presenting education materials suitable to inquiry-based education and adaptable to science and mathematics courses,
- Contributing to the training of STEM teachers by online and face-to-face trainings,
- Identifying students who are curious, skilled in questioning in primary and secondary schools and encouraging them Science, Technology, Engineering and Mathematics education departments of universities.

Ministry of National Education (MoNE), General Directorate of Innovation and Educational Technologies (YEĞİTEK) as Turkey National Contact Point in Scientix project, have performed some promotion activities (Scientix Science and Maths Conference, Scientix workshops, social media online promotions, online webinars, etc.). General Directorate of Innovation and Educational Technologies as Turkey National Contact Point continues to be a partner in Scientix 3 and represented at Ministries of Education STEM Working Group coordinated by European Schoolnet.

- STEM Labs at Universities and Science Centers

There are several STEM Labs at universities and science centers, which offer STEM teacher training programs and STEM enrichment programs for different age groups.

- Hacettepe University STEM & Maker Lab [101]

Hacettepe STEM & Maker Lab was established in 2009. Hacettepe STEM & Maker Lab has involved in several EC FP7 (e.g., S-TEAM, SAILS, MaScil) and Horizion 2020 (e.g. MOST) and Erasmus+ projects (STING, ENSITE, EMERGENT, STEM, ENSITE and INSTEM). Hacettepe STEM & Maker Lab has researchers with extensive experience in STEM curriculum development, in-service teacher training activities and public engagement of STEM. For instance, Prof. Dr. Gultekin Cakmakci, among others, has developed the new "Turkish Science Curriculum" and "Science Practices Curriculum", which have been implemented in Turkey since September 2017.

Hacettepe STEM & Maker Lab is a founding members and also consortium member of International Center for STEM Education (ICSE) (www.icse.eu/about-us/icse-consortium/). The lab has participated in the following EU projects:

- Project Title: Meaningful Open Schooling Connects Schools to Communities (MOST)
Funding Agency: European Commission- H2020-SwafS
Year: 2020-2023 (3 Years)

- Project Title: Strategies for Assessment in Inquiry Learning in Science (SAILS)
Funding Agency: European Commission- FP7 Project- Science in Society
Year: 2012-2016 (4 Years)

- Project Title: European STEM Professional Development Centre Network (STEM PD Net)
Funding Agency: European Commission- Erasmus +

- Project Title: Science Teacher Education Advanced Methods (S-TEAM)
Funding Agency: European Commission- FP7 Project- Science in Society
Year: 2009-2012 (3 Years)

- Project Title: Mathematics and science for life (MaScil)
Funding Agency: European Commission- FP7 Project- Science in Society
Year: 2013-2016 (4 Years)

- Project Title: Supporting mathematics and science teachers in addressing diversity and promoting fundamental values (MaSDiV)
Funding Agency: European Commission- Erasmus+
Year: 2017-2020 (3 Years)

- Project Title: Environmental socio-scientific issues in initial teacher education (ENSITE)
Funding Agency: European Commission- Erasmus+
Year: 2019-2022 (3 Years)

- Project Title: EMERGENT: Gender awareness and implementation strategies in STEM education
Funding Agency: European Commission- Erasmus+
Year: 2018-2021 (3 Years)

Project Title: Integrated Approach to STEM Teacher Training (STEM)
Funding Agency: European Commission- Erasmus+
Year: 2019-2021 (3 Years)

-Project Title: Innovative Networks for Science Technology Engineering & Mathematics education (INSTEM)
Funding Agency: European Commission- LLP
Year: 2013-2015 (3 Years)

- Project Title: STEM Teacher Training Innovation for Gender balance
Funding Agency: European Commission- Erasmus+
Year: 2015-2017 (3 Years)

Outcomes of these projects are available at:

http://www.hstem.hacettepe.edu.tr/tr/menu/yayinlar-5

http://www.hstem.hacettepe.edu.tr/en/menu/projects-10

- Middle East Technical University (METU). Center for Science Technology Engineering and Mathematics Education (BILTEMM) [102]

BILTEMM was recently established with the aim of advancing education in STEM fields. Through collaborative work of interdisciplinary community of faculty members, BILTEMM is committed to improving and enhancing opportunities for schools, educators, and students. The aims of BILTEMM include evaluating school curricula, developing new programs, advocating for diversity and access, and influencing relevant policy in education of STEM fields. BILTEMM activities target developing students' and teachers' 21st century skills and knowledge, enhancing their attitudes towards STEM fields, and contributing to the society by presenting solutions to the social and ecological problems through innovation in science, technology, engineering, and mathematics education.

- Workshops for Teachers. BILTEMM teacher workshops are aimed to help teachers in STEM-related skills. Everyone can follow the web site and social media accounts for upcoming events [103].
- Projects. The projects focus on developing new educational tools and curricula for learning in STEM fields, as well as developing and implementing professional development programs for teachers.
- Design-make-learn. Supported by METU Research Fund, Engineering Design Education Training for Teachers is conducted in collaboration between BILTEMM and METU Center for Wind Energy (RUZGEM).

- First step. Supported by the Science and Technological Research Council of Turkey (TUBITAK), this project aims at developing curriculum and materials to improve elementary students' math skills with real life applications.
- MAKEITREAL Erasmus+ aims at addressing underachievement in STEAM education through real product design and making practices.
- Amgen biotech experience project, conducted in collaboration between BILTEMM and TED University, aims to provide innovative professional development programs, materials, and equipment regarding molecular biology to middle school teachers.

- Istanbul Aydin University STEM Lab

Turkey's first STEM laboratory: Istanbul Aydın University STEM Laboratory [104] is the first STEM Laboratory in Turkey. Promoting STEM (Science, Technology, Engineering and Math) education was established in February 2015 with the cooperation of the US State Department and Istanbul Aydın University within the scope of the project among economically disadvantaged youth, especially among girls. Robotics, maker, coding and so on. trainings are carried out for teachers and students in the IAU STEM LAB. IAU STEM LAB is designed to be an example to schools in Turkey based on the integration of science, technology, engineering and mathematics. The schools are supported by the establishment of STEM Lab, STEM education to teachers and students.

STEM Labs are set up to schools, teachers and students and supported in STEM education. The trainings carried out in STEM LAB to date are as follows:1)Turkey's first STEM Teacher Certification Program (edited 25 times in 40 hours and about 500 teachers participated in the program); 2) K12 students are provided with STEM, maker, robotics and programming training; 3) STEM, maker, robotics and programming trainings are provided for gifted / talented students; 4) STEM, maker, robotics, programming trainings are provided for the schools and their teachers, where consultancy services are provided. (More than 1000 teachers have been given STEM education in STEM Lab and schools); 5) STEM teaching course, design, maker, robotics and programming trainings are provided for undergraduate students of Faculty of Education; 6) STEM Education project for Industry 4.0 in Vocational Technical High Schools accepted by TÜSİAD was carried out; 7) World STEM Festival project supported by TÜBİTAK was realized; 8) World STEM Education Conference, organized by IAU.

First STEM course in education faculties: STEM teaching course: One of the courses that will be taught for the integration of STEM disciplines is science, technology, engineering and mathematics (STEM). The course is offered as an elective course at the Faculty of Education of a Private University in the Spring Semester 2015-2016. The duration of the course is three hours, the credit is three and the ECTS is four. The duration of the course is planned to be 14 weeks. The course aims to provide students with basic knowledge and skills related to science-technology- engineering and mathematics (STEM) education at undergraduate level.

STEM projects of Istanbul Aydın University: "Promoting STEM education among economically disadvantaged youth, especially among girls" project / US Department of State / 2014-2016.

By İstanbul Aydın University' review of the literature and best practices on STEM and the obtained data, in order to promote the interest of disadvantaged students, especially girls about STEM, the project "Promoting STEM education among economically disadvantaged youth, especially among girls" was started and it was accepted in August 2014 and funded by the US Department of State.

- BAUSTEM Center at Bahçeşehir University, Istanbul [105]

BAUSTEM Center at Bahçeşehir University, Istanbul is a research and development center specializing in STEM teachers' education at the in-service level. Three faculty members, fellows and research assistants work at the center. As part of the externally funded Integrated Teaching Project (ITP) at BAUSTEM, several programs have been developed for the last three years for classroom, science and mathematics teachers. All programs emphasize equity, interdisciplinarity, rigor, and relevance in STEM learning and teaching. Over 5,000 teachers from Turkey, Caucasia, Southern Europe and Canada have benefitted from the hybrid (online and face-to-face) programs of Center.

- Muş Alparslan University STEM Education Application and Research Center [99]

Muş Alparslan University STEM Education Application and Research Center was established in 2019. The Director of the Center is Assoc. Prof. Dr. Bekir Yıldırım. Since its establishment, the center has actively provided several professional development programs for teachers and teacher candidates. Until now, over 500 teachers have been trained within the center.

– Yildiz Teknik University [106] STEM teacher education.

As part of this training, participants will be provided with theoretical and practical training in STEM education, which aims to provide analytical and design-oriented thinking skills, create solutions to everyday life problems using an interdisciplinary perspective, 21st century skills, STEM fields (science, technology , engineering and mathematics) from an interdisciplinary point of view. and they will make many applications related to this education. Upon completion of the training, participants who will have specialized knowledge and skills in STEM education, are aware of the use of this education in various disciplines and the use of the STEM approach in education, will be able to teach and apply STEM education, and will be able to provide STEM education.

Elementary school teachers, middle and high school teachers from all branches, teacher candidates, university students from all faculties, parents and anyone interested in STEM education can participate. There are no preconditions for participation. Successful trainees will be issued a STEM TRAINER EDUCATION certificate. With this certificate, STEM Education courses and courses can be taken in kindergartens, private schools and colleges, as well as private courses.

The Curriculum includes the following modules: STEM Education and Philosophy, Historical Development of STEM Education, Conceptual and Theoretical Foundations of STEM Education, Engineering Design Process & Application Examples, STEM Education Practices with materials from daily life, Sample STEM-based lesson plan review, STEM Education plan, scenario and activity presentations, STEM Education Applications with Building Sets, Measurement and Evaluation in STEM Education.

– Turkish STEM Alliance [107]

Turkish STEM Alliance was founded in 2015, it is an independent body of network for promoting public engagement with Science, Technology, Engineering and Mathematics (STEM). It unites STEM practitioners, researchers, policy makers and public to enhance the quality of STEM education and broaden participation in STEM. Turkish STEM Alliance consists of several different members from science centers, science museums, PD centers, NGOs, STEM centers, companies, research centers and public organizations.

– International STEM Education Summit / Mektebim Schools [108]

In this project, which was brought to Turkey with the vision of making Turkey one of the best practices' centers in STEM fields, our aim is to make Turkey a role model in

STEM education.

- International K12 curriculum. This project was prepared with a vision to determine competencies and standards of STEM education from pre-school to high school in Turkey, to increase the quality of STEM education, and to improve students learning processes. The STEM curriculum is prepared in accordance with international standards in cooperation with UNESCO to ensure that students are equipped to meet the future needs of Turkey.
- STEM teacher training *program.* The STEM Teacher Training program, which includes teaching and evaluating the international STEM curriculum developed in cooperation with UNESCO, consists of peer solidarity and learning platform, evaluation guides and tools.
- STEM student assessment and evaluation program. STEM student assessment and evaluation program has been developed to ensure that the benefits of international STEM education are measurable and in compliance with STEM requirements.

- GIS Project

Prof. Aziz Sancar GIS Camps [109], April and Zonguldak, representing the seven regions of Turkey, in May months, Mersin, Ankara, Ardahan, Istanbul, I STEIN in Ankara and Istanbul provinces (Science, Technology, Engineering, Mathematics) was held with the theme. 63 female students selected among the students participating in the activities and 13 guidance teachers assigned by the Ministry of National Education attended the TÜBİTAK Konya Science Camp on 11-12 June, 2016. The second day of the event was mostly spent with activities in the field of STEM. The day started with four different fast-paced workshops: "My Connection Establishment", "Cryptology", "Music of Fruits" and "The World of Living". Then, the states of matter were explained to the students with a science show. In the afternoon, a movie named "Mysteries of the Invisible World" was watched at the planetarium. After the screening, students participating in the "Design Your Car" activity raced the cars they designed, and besides the fastest first six cars, the three most beautiful cars were determined with the scores of the instructors. The second day ended with a visit to the Mevlana Museum. During the event, our students' interviews with students were given by Prof. Dr. Aziz Sancar's thank you message, and the introduction of Konya Science Center can be accessed at Bilimgenc.tubitak.gov.tr.

The first conference was held in Turkey Science and Technology Centers [110]. TUBITAK, the purpose of science and dissemination of technology and development in Turkey, bringing together stakeholders operating in the public and private sectors and stakeholders cooperating for the purpose to improve their relations with each other Konya Metropolitan Municipality and TUBITAK, Konya Science Center, May 17 to 18 in 2017 "Turkey Science and Technology Centers Conference" was carried out.

Deputy Minister of Science, Industry and Technology Assoc. Dr. Hasan Ali Çelik, President of TÜBİTAK Prof. Dr. A. Arif Ergin, Konya Governor Yakup Canbolat, Konya Metropolitan Municipality Mayor Tahir Akyürek, TÜBİTAK administrators, scientific centers, museums, academicians, private sector and public representatives.

Within the scope of the conference, where presentations were made on science center exhibition design and production processes, education areas, planetarium, STEM education applications, TÜBİTAK Science and Society support, science and technology centers and companies opened stands.

- Istanbul Technical University Science Center [111]

In 2007, the Istanbul Technical University (ITU) established the University Science Center with the aim of making scientific knowledge more accessible to young people. About 20 thousand schoolchildren visit the University Science Center annually, but the Center aims to reach at least 200,000 visitors a year, given that 12 out of 75 million Turks live in Istanbul.

The center strives to attract young people by combining direct scientific facts with a fun approach: from optical illusions to theatrical performances and even birthdays. For example, with the support of TÜBİTAK (Scientific and Technological Research Council of Turkey), the Center can invite students from low-income families for two-week visits.

In 2007, there were only two or three research centers in Turkey, and in just five years their number reached ten. Now, a new plan, unveiled by the government, calls for an investment of one billion Turkish lira (428 million euros, 555 million USD) to build research centers in each of the 81 provinces by 2030.

The Turkish government supports scientific centers as science education in general is now in a priority. In early 2012, the FATİH project was launched to introduce smart boards and tablets in public schools.

FATİH means literally “conquering” and makes think of conquering pupils’ scientific imagination… Turkey is a very young country and it simply cannot afford youth

unemployment. That's why it is necessary to invest on scientific and technology literacy, to bring youngsters closer to the attention of future employers.

The FATİH project is promoted in collaboration with the Ministry of Education and the Ministry of Transport and Communications and will distribute IT education solutions to 570,000 classrooms in 42,000 state schools across Turkey.

Whilst some of the initiatives promoted by Turkey's government are highly impressive, its growing economy faces a number of daunting obstacles if it is to meet its pressing need for a competitive labour force.

Reducing drop-out rates, increasing girls' education and enhancing STEM education are the main challenges ahead, according to Çiğdem Tongal of Sabanci University.

At an inGenious summer school meeting in Istanbul, she highlighted the recent rise in the age of compulsory education – from 8 to 12 years old – as an important first step in meeting these objectives. In the meeting, attended by teachers from across Europe, she also pointed out that working in partnership with stakeholders and industry, and improving the quality of professional training are also key to reducing education inequality.

In fact, Çiğdem's own Sabanci University has been playing a leading role in societal reform since 2003, with the Education Reform Initiative (ERI). This was launched within a network of public and private organizations, in collaboration with the UNICEF and the World Bank, with the objective of bridging the gap between public and private schools and ensuring quality education for all.

- Izmir Yuksek Teknoloji Enstitusu (IYTE [112])

Education Application and Research Center STEM is Established for IYTE on September 27, 2019. The project, which has been worked on for a while, is brought to life with the aim of supporting the development processes of students of all age groups, developing the sense of curiosity and questioning motives, which are the basic arguments of scientific research, artistic creativity and thought, with educational methods and techniques. The center will come to life in IYTE, where children will be able to learn by doing and living with the teaching methods and techniques specific to their educational fields.

The opening of a kindergarten approved by the Ministry of National Education, which was felt lacking in the campus in recent months and started education and started its activities, turned a long-awaited service into a contribution to İYTE and the environment. It was decided that IYTE will carry out a study in this context, based on

the idea that universities should be environmentally friendly education centers. Thus, with the offer submitted to YÖK; The Center will operate by creating teaching environments and providing applied trainings, will also meet the need of the region and the country to raise qualified human resource potential.

Training programs for Science and Math teachers about STEM in Turkey [113].

One of this training was in Ege University in Izmir on 15th – 26th June 2015 and 2nd – 8th September 2015. It was about introducing STEM (FeTeMM) education to science teachers. There were collaborations between the Izmir Directorate of National Education and Ege University in this training. The trainers were three academicians who work on STEM (FeTeMM) education in the Ege and Dokuz Eylul University. During the first two days, they talked about on the following topics:

- Multidiciplinary Interactions in Education
- STEM (FeTeMM) Education
- What is the STEM (FeTeMM) literacy
- The importance of STEM (FeTeMM) Education and its components
- STEM (FeTeMM) Education in Turkey
- Engineering education in STEM and Engineering Design Process
- 5E Learning Cycle
- Design Process Applications
- STEM (FeTeMM) Education in Secondary School Science Curriculum
- STEM (STEM Fields) Content-Designing the Event-Applications

After these two days, the applications in STEM (FeTeMM) started. They were:

- Designing an electric torch. It is about electricity in our life. The aim of this activity is getting pupils to realize the electricity in their lives
- Designing a catapult. It is about force and the motion unit in the science curriculum
- In the last day, there were three training activities.
- A talk about the integration of STEM (FeTeMM) activities to the science curriculum
- Designing a lesson plan about a STEM (FeTeMM) activity
- Presentation of the STEM (FeTeMM) lesson plans.

There was a debate about STEM (FeTeMM) among the teachers in the end of the training program. The consensus after the debating is “STEM (FeTeMM) Education is

very important to catch up on modern science world. We must make STEM activities in our lessons to train the engineer and scientists of the future. We must attend to the training program like this to improve our knowledge and skills about STEM (FeTeMM) Education." The training programs are still going on to improve the knowledge and skills of Turkish teachers in TurkeyStay with STEM (FeTeMM).

STEM EDUCATION IN THE RUSSIAN FEDERATION

Context

It goes without saying that STEM qualifications and skills are necessary for current and future workforce in the Russian Federation due to political and economic pressures as well as improvement of knowledge delivery and employability skills development. Since the launch of the 1st soviet Sputnik, scientific, mathematical, and technological knowledge has been essential for keeping pace with technological developments. Skills related to STEM and ICT are crucial for sustainable economy in the 21st century, STEM performance drives innovation and job creation in leading industries. Nations see research, innovation and production of high-tech goods and services, military solutions, and consumer electronics as necessities for their economic progress and defense.

STEM-subjects are the basis for staff training of the scientific-technological elite for the innovative development of the country in the context of Scientific and Technological Development Strategy of the Russian Federation, as well as for the implementation of the national program "Digital Economy of the Russian Federation [114] and „National Technological Initiative" [115].

In this context, new requirements to curriculum development and syllabus design as well as implementation of new teaching methods determine continuous development of formal and non-formal/extracurriculum education practices in the following subject fields: Science, Technology, Engineering Creativity, Programming and Algorithms, Project Activities.

At the same time, little action has been undertaken on the national level to modify educational systems: we note that STEM as teaching and learning approach has not been implemented in schools yet. There is neither National STEM School Education Strategy / National STEM curriculum, nor regional STEM curriculums.

Furthermore, there is a lack of STEM-teachers and respective STEM-teachers training programs, insufficient skill level of STEM-teachers, a lack of modern professional development programs (teachers do not have the knowledge, skills and experiences, needed to provide integrated STEM education effectively + there is a lack of methodological approach to STEM education: Insufficient use of research, design and creative approach); STEM careers are not popular enough with young people + insufficient students' skill level in STEM subjects – according to Unified State Exam Statistics, 2017-2018-2019, Russia shows low popularity amongst High School

graduates and low academic achievement in STEM subjects (about 50%) [116] – as well as low mathematics and science performances across PISA cycles (30th place) [117]. A new School-University-Industry vocational guidance and partnership model, aimed at engaging students in interactive extra-curriculum STEM activities and projects, is being implemented but has not been largely disseminated.

STEM-Related National Policies and Initiatives

However, over the past few years, STEM-related national policies and initiatives have been developed and implemented in the Russian Federation that, among other things, tend to meet the need to develop career and educational pathways that align with STEM. The "Need for STEM" trend in Russian educational policy is defined by the following strategic concepts, executive orders and national programs/projects:

- Executive Order on the Scientific and Technological Development Strategy of the Russian Federation [118]

The Strategy sets out the main objectives of Russia's scientific and technological development, the principles, priorities and measures for implementing the state policy in this sphere, as well as the expected results of the Strategy's implementation, namely Russia's sustainable, dynamic and balanced scientific and technological development in the long term. The goal of Russia's scientific and technological development is to ensure the country's independence and competitiveness providing for "Big challenges" by creating an efficient system for building up and using the nation's intellectual potential.

According to the Strategy, in the upcoming 10-15 years the priorities of scientific-technological development of the Russian Federation will be presented by will be those areas that will allow to obtain scientific and scientific-technical results and create technologies for innovative and sustainable development of Russia in the outer market, that will ensure the transition to digital, intelligent manufacturing technologies, robotic systems, new materials and design methods, Big data processing systems, Machine learning and AI, environmentally friendly and resource-saving energy, personalized medicine, high-tech healthcare, highly productive and environmentally agriculture, etc.

For the purpose of achieving the goal in scientific-technological development in relation with education and talent management, the strategy is held to imply a creation of opportunities for identifying talented youth and building a successful career in science, technology, innovation as well as the country's intellectual potential's

development, counting the development of a modern system of scientific and technical creativity of children and youth.

– Priority National Project "Affordable Supplementary Education and Extracurricular Activities" (2016-2021)

The key purpose of the project is to bring within the reach supplementary education for children, including technical and natural sciences [119]. By 2021, 25% of secondary school students will have been involved in extracurricular educational activities in the field of Engineering & Natural Sciences.

The project provides for implementation of modern regional systems of supplementary education and extracurricular activities for children (inter alia from rural areas) in every constituent of the Russian Federation. These systems based on best practices ensure the implementation of modern and popular in the region supplementary general educational programs of various directions, including technical and natural-scientific ones. Such regional systems involve networking cooperation of educational organizations of various types, including colleges and universities, as well as scientific organizations, social communities and industries.

According to the project a model center for children's supplementary education is on-stream in every constituent of the Russian Federation, inter alia based on children's technology parks "Quantorium", as a core element of the system [120].

"Quantorium" children's technology parks network is being put in place in every constituent of the Russian Federation. These are spaces fitted with high-tech equipment, aimed at new highly qualified engineering staff training, development, testing and implementation of innovative technologies and ideas in supplementary education.

Quantoriums offer modern technology (PBL, EBL, EduScrum, etc.) and unique educational three-month programs – "Quantums" (16 to 72 hours) in accordance with the key areas of innovative development of the Russian Federation (Auto-Quantum, Aero-Quantum, Data-Quantum, IT-Quantum, VR/AR--Quantum, Bio-Quantum, Geo-Quantum, Nano-Quantum, Robo-Quantum, etc.) for students over the age of 10 years old who are interested in Engineering and Natural Sciences. Quantoriums ensure the involvement of different ages' children in solving real cases (trade tasks), design and research activities in high-tech industries. The programs are free.

Quantoriums enable students to develop necessary STEM skills as a combination of the following hard skills (3D modeling and prototyping, programming, data analysis,

network and information security, computer networking, blockchain, AI, web architecture, research skills, NLP and image processing, operating skills, etc.) and soft skills (time management, critical and system thinking, leadership, communication, collaboration, teamwork and project management skills, working on large amounts of information, spatial thinking, data presentation).

At the time being 80 thousand children are engaged on an ongoing basis in "Quantorium" children's technology parks in 62 regions and about 600 thousand are involved in educational activities of the network.

In the capacity of students 'achievements accounting mechanisms, a system of competitive educational events (exhibitions, contests and team competitions) is implemented with feedback for educational organizations and families, aimed at increasing the children's motivation, discovering and developing abilities and early vocational orientation.

- National Project "Education" (2019-2024) [121]

One of the main tasks of the national project "Education" is to ensure the global competitiveness of Russian education, to make the Russian Federation one of the 10 leading countries in the world in terms of the quality of general education. Project activities are primarily aimed at implementing the following key areas of education system's development: updating the content, creating the necessary modern infrastructure, teaching staff training and continuing professional development (lifelong learning), as well as creating the most effective mechanisms of education management.

- Federal Project "Modern School"

This project is aimed at introducing new methods of training and education, educational technologies that provide learners with the basic skills and abilities, increasing their learning motivation enhancement and involvement in the educational process (incl. in particular PBL, EBL, etc.), as well as implementation of a new concept of "Technology" as a school subject (2018) [122].

The new concept orientation towards the 21st century technological literacy, ICT, project and research skills, critical and creative thinking, digital tech, design & programming as well as vocational guidance and orientation (specifically in the context of NTI markets of the future) is of particular importance for the implementation of STEM education. Under this approach "Technology" as a school subject becomes an organizing core of entry into the world of technology, including material, information,

communication, cognitive and social technologies. Thanks to the improvement of teaching methods, the leading form of educational activity during the learning of the subject area “Technology” is Project-based learning. Project activity serves as the basis for the integration of academic subjects and is implemented in various formats. In every constituent of the Russian Federation the learning of “Technology” as a school subject is made possible based on highly equipped organizations, as well as “Quantorium” children’s technology parks.

Also, within the framework of federal project in schools situated in rural areas and small towns more than 3 000 Centers for Digital Education, Natural Science and Humanities “Growing Point” have been created (by 2024 it is planned to open more than 16 thousand). Growing Points are intended to ensure access to quality education for formation among schoolchildren the most in-demand skills of the future, become centers of modern digital, science and humanities education, a space for the introduction of new content and educational technologies, multidisciplinary / crossdisciplinary education practices and PBL in teaching Mathematics and Computer Science, Technology, Health and Wellness as well as extracurricular STEM activities.

– Federal Project “Success of Every Child”

This project aims to achieve the goal of the national project to educate a harmoniously developed and socially responsible person in the context of historical, cultural traditions, spiritual and moral values of the peoples of the Russian Federation, as well as breakthrough trends in the new technological paradigm. This project is implemented primarily through the development of regional systems of supplementary education and extracurricular activities for children, which includes measures to create a competitive environment and increase the availability and quality of children’s supplementary education.

The project provides for the mechanisms’ development of children’s early vocational orientation individual education plan implementation in accordance with the selected professional competencies in the framework of the “Ticket to the Future“ [123] and “Proektoria“ [124], projects as well as informal STEM-related practices such as «Lessons of the Present» [125] etc.

The project fosters setting up a network of Regional Education Centers for Talented Children implementing “Sirius” model (incl. short-term intensive project & inquiry-based programs in the “Science” direction) in every constituent of the Russian Federation. Apart from this, “Quantorium” technology parks are supposed to appear in every locality numbering more than 60 thousand (altogether 245 “Quantorium”

children's technology parks in Russian Federation in 2024). Development of distance forms of supplementary education and the implementation of such projects as "Mobile Quantorium" (a car-based platform for workshops on 3D prototyping, VR simulation, UAV engineering etc. for schoolchildren), will allow to reach by 2024 at least 2 million schoolchildren with high-quality supplementary education, including those living in rural areas, small towns and inaccessible territories.

According to the results of the federal project, the enrollment of children in additional education will reach 80% by 2024, including at least 25% of children will be trained in supplementary general educational programs of Engineering and Natural Science.

- Federal Project "Digital Educational Environment"

This project is to create, by 2024, a modern and secure digital educational environment that provides high quality and affordable education of all types and levels. In order to ensure the creation of a modern digital educational environment, it is planned to create by 2024 a network of 340 "IT-Cube" Digital education centers for children [126]. "IT-Cube" is a STEM environment for the formation of relevant IT skills in a child.

The project implements popular educational programs developed together with partners - market and industry leaders, for children from 7 to 18 years old in the following areas: Mobile development (Java, Android, "Samsung IT-school" education program), Python programming («Yandex.Lyceum» education program), VR/AR-development, Cyberhigiene and Big Data ("Kribrum" education program), Fundamentals of Algorithmics and Logic («Algorithmika» education program), Robotics programming ("Lego Education" program). The programs are free.

- STEM for Inclusive and Special Education

The fundamental demand of the labor market relies on a special design of the educational environment for students with special needs. It also concerns STEM education.

A regional network of innovative technological environment *TechnoProfi* has been created in the Kaliningrad region. The initiative has been implemented due to the Federal project "Modern school" (within the National project "Education").

TechnoProfi is an educational project allowing all students with special needs to study, develop, acquire the necessary skills and abilities, regardless of nosology and place of residence and study. It comprises a network of educational laboratories and workrooms ("AgroLab", "MediaLab", "Mechatronics and Food Industry", "Home

Interior Design", “ProfiLab”, etc.) located in special boarding schools and aims at early career guiding in STEM as well as mastering adapted curriculum programmes.

"MediaLab" provides the facilities for photographing and producing video materials. It includes a printing shop with technical equipment for blind and visually impaired students which allows to publish newspapers in relief and dot print. The radio center is equipped with state-of-the-art studio equipment with specialized study places for visually impaired students. The robotics workshop is intended for engineering modeling. Various design and research activities can be carried out within the educational process.

“AgroLab” is a developing educational environment, represented by a showroom with a "living" green wall, a 3D modeling laboratory, a laboratory for project activities in landscape design, an agrolaboratory with modular furniture and mobile equipment for hydroponics, aeroponics, city farming, vertical gardening and phytodesign, modular greenhouse complex for a year-round use [127].

These two laboratories have become basic platforms for expert and participant training for “Abilympics”, a national championship on professional skills for students with special needs.

STEM-related Collaborative Projects (Government-Business-University) and Best Practices of Non-Formal / Informal STEM Education

– NTI or National Technology Initiative (2014-2035) [128]

The National Technology Initiative is a long-term comprehensive program aimed at creating conditions for ensuring the leadership of Russian companies in new high-tech markets (EnergyNet, NeuroNet, SafeNet, AeroNet, MariNet, AutoNet etc.) that will determine the structure of the global economy in the next 15-20 years. The NTI includes a set of projects and programs aimed at integrating of Russia into the formation of standards for global markets for the future and the receipt by Russian companies in these markets of a significant share.

According to the Scientific and Technological Development Strategy of the Russian Federation the National Technology Initiative should become one of the main tools for transforming fundamental knowledge, exploratory research and applied research into products and services that contribute to the achievement of leadership of Russian companies in promising markets.

– Federal Innovative Platform [129]

Upon the results of a competitive selection Immanuel Kant Baltic Federal University (IKBFU) has been included into the List of Federal Innovative Platforms in the infrastructure of the Russian educational system for 2021-2023 with the project "STEAMTeach: Managing the Professional Development of Pre-Service Teachers" developed by the team of the Institute of Education, IKBFU.

Advancing the implementation of STEAM-approach in pre-service teacher training within the socio-educational cluster of the Kaliningrad region is due to its internal potential to integrate all strategies and methods aimed at designing modern educational environment. STEAM approach, being based on interdisciplinarity and integration in teaching and training, can serve as a conceptual basis for the innovative model of a new type of teacher training.

A practice-oriented model for pre-service teacher training based on the STEAM-approach integrates the updated design of the curriculum with the focus on STEAM, the modernization of the educational environment and the development of a new type of School-University Partnership which contributes to the emergence of advanced educational practices through implementation of international, federal, regional, network and internal integrative projects in education.

Modeling the curriculum implies the design and development of educational modules for undergraduate programmes in pedagogy, focused on conditioning the required competencies in the implementation of STEAM-technologies in teaching, in the organization of the research and project activities of students, in effective design of a modern educational environment for reaching learning outcomes. The introduction of adaptive, practice-oriented educational events such as, for example, the system of professional competitions, into the curriculum is an effective tool for making undergraduates prepared to solve real professional problems.

The new model of network interaction in the School - University framework within the socio-educational cluster *STEAM Community*, is multifunctional. It, on the one hand, significantly strengthens the practice-oriented component in the pre-service teacher training by introducing new innovative forms of interaction between the stakeholders of the educational process, the development and implementation of modern supporting technologies for students, including students with disabilities, in the field of engineering and technical creativity. On the other hand, it contributes to managing the professional development of in-service teachers by acquiring new STEAM competencies and implementing interdisciplinary and integrative ties when

participating in the existing regional network projects. The development and implementation of technologies for accompanying students in the field of engineering and technical creativity serves as the basis for the implementation of their technical initiatives within project activities.

The model being implemented contributes not only to improving the quality of education, but also to the dissemination of international experience in designing the educational process based on the STEAM approach taking into account the concept of educational engineering.

– The NTI Kruzhok Movement [130]

The NTI Kruzhok Movement is on the one hand an all-Russian community of technology enthusiasts, based on the principle of horizontal connections among people, ideas and resources. On the other hand, it is a system of *kruzhoks* (children-adult communities of makers, who alongside the professionals in the field deal with current technological challenges and try to solve current technological issues) and engineering extracurriculum activities that is expected to enable schoolchildren to take part in various projects and initiatives in the field of technical creativity (design school contests and festivals), gain expert knowledge and access the equipment in resource centers (FabLabs, children's technology parks, etc.).

The NTI Kruzhok Movement can be considered as an analogue of Makers' movement since it is based on the same principles such as: freedom, do-it-yourself, open-mindedness, learning by doing, etc. However, it is an exceptional educational phenomenon that is intended to build an ecosystem bringing together technology enthusiasts and makers, big companies, state corporations and educational institutions, connecting education, science and tech business and creating feasible formats of cooperation of all the NTI Kruzhok Movement participants.

The following are the main educational initiatives of the NTI Kruzhok Movement: the first team engineering competitions for schoolchildren and students NTI Contest, NTI lesson, "RUKAMI" project (ideas and technology festivals), Project Mentors Academy, project schools "Practices of the Future" etc.

– The NTI Contest (Olympiad) [131]

This is a unique format of engineering competitions for schoolchildren of 8-11 grades (The NTI Contest Junior is held for ones of 5-7 grades) as well as HE students (a special "HE student" track) aimed at identifying and supporting talented children who are able

to solve complex interdisciplinary problems. The contest is organized to help schoolchildren interested in engineering enter top engineering universities.

The Contest includes an online selection stage, during which participants solve tasks individually, a team online stage, and, lastly, an on-site final, during which teams work with engineering equipment and develop engineering solutions in promising areas.

The Contest takes place in 30 educational profiles related to the development of markets of the future such as “Autonomous transport systems”, “Big data and machine learning”, "Intelligent Energy Systems", "Communication systems and remote sensing of the Earth”, "Unmanned aircraft systems", "Intellectual robotic systems", "Engineering biological systems", etc.

– The NTI Lesson event [132]

This is a “non-formal to formal” education STEM practice, which involves teachers conducting special vocational guidance lessons for schoolchildren of 7-11 grades in the areas of the National Technology Initiative on the content and teacher’s manual of the NTI Kruzhok Movement. Developed teaching/learning materials (interactive lectures, problem-based and game-based assignments, online-practice, feedback forms, etc.) intended for such STEM subjects as Mathematics and Computer Science, Physics, Technology, Geography, Biology, Chemistry; and cover the following topics and aspects: neurotechnology, AR, Big Data and Machine Learning, financial technology, robotics, energy, unmanned vehicles, composite materials, smart city, aerospace systems and satellites, IoT, geographical applications of space photography, urban studies, genomic editing, cognitive technologies, agrobiotechnology, nanotechnology. TLMs can also be used for extracurricular STEM activities. The objective of the NTI Lesson events is to show every schoolchild the importance of dealing with emerging technologies based on in-depth knowledge in STEM subject fields as well as to motivate and attract them to solve real-life technology problems participating in the NTI Contest, to help acquire and develop the skills needed to go through all the stages of the Contest and win.

– Project Schools “Practices of the Future” [133].

One-day and multi-day hackathons, as well as off-site schools, where teenagers get fully immersed in work on real-life tasks are among the most effective formats of project activity by The NTI Kruzhok Movement. The aim of the project school is to establish a systematic transfer of new technologies to the educational sphere and to support the values of the NTI Kruzhok Movement in the community. Within such

activities as hackathons and design schools, schoolchildren and students are involved into designing new practices of future that are related to solving urgent issues and challenges.

The following are the key focuses of the project: child-adult environment; comprehensive development of the education system in the region (training local tutors, involving regional universities, interacting with regional industries and businesses); thinking techniques and soft skills (situation analysis skills, working with a problem, task decomposition, goal setting and teamwork); industry experts (representatives of the NTI markets, start-ups and large corporations). The methodology is based on scientific and methodological materials and researches in partnership with High School of Economics, Moscow State University of Psychology and Education, Shiffers Institute etc.

Examples of the most interesting "Practices of the Future" events (2019-2020) include: Faculty "Practices of the Future" within the "Island 10-22 Educational Intensive Program" (120 students, The NTI Contest participants and "Practices of the Future "hackathon winners developed projects in three areas: neurotechnology, energy and satellite imagery analysis); "Local Hack Day" hackathon (600 schoolchildren and students from all over Russia, consisting of 15 teams, developed solutions to solve the problems caused by Covid-19); The Skolkovo Junior Challenge (Large-Scale Project Competitions for schoolchildren of 8-11 grades in the areas of *Energotech*, *Biomed* and *Promtech*, organized jointly with the Skolkovo International Gymnasium, is held with the aim of developing students' research and entrepreneurial competencies, leadership skills, productive communication, skills to create and promote interdisciplinary projects).

– "RUKAMI" project [134]

This is a series of educational events of the NTI Kruzhok Movement to promote technical creativity among young people. Its goal is to create an effective environment for the development of ideas and talents of Russian schoolchildren and students. The project comprises two tracks for children and teenagers: All-Russian project contest "RUKAMI" and a series of "RUKAMI" Festivals.

The Contest is intended to identify the best practices and technical projects of children and youth. Everyone can take part in the competition, regardless of age, individually or as part of a group. Projects must be implemented using modern technologies, be prototypes or MVP and comply with one of the following tracks: Bio, Tech, Art, Fun, Make the World a Better Place.

Regional “RUKAMI” festivals are events to popularize modern technologies, engineering, extracurricular STEM-activities and maker practices in regions. In 2019, regional festivals were held in 10 cities across Russia; in 2020, 15 regional festivals are planned. International “RUKAMI” festival (Moscow) is the central event and unites of inventors, makers, technology enthusiasts and artists from all over the world, who present their projects in the field of engineering and technical creativity. In real time, festival guests participate in interactive master classes, art performances, and participate in laboratory work.

– “Sirius” STEM-related education Practices

“Sirius” Educational Center for talented children in Sochi [135] was established in 2014 by educational foundation “Talent and Success” on the initiative of the President of the Russian Federation V. Putin. The main goal of the center is early identification, development and further support of gifted children showing talents in arts, sports, science, as well as the ones successful in technical engineering creativity.

About 30 educational programs in the field of “Science” (Mathematics, Physics, Computer science, Chemistry, Biology, Agrobiology and Plant Genetics, Biomedicine, “Start in Science”, “Introduction to the experiment”, and others) as well as multidisciplinary and Partner (“Mail.ru Group”, “Rostelecom”, “Rosneft”, “Roskosmos”, “Skolkovo”, “Yandex”, etc.) project programs for schoolchildren of grades 6-11 take place in **“**Sirius” Educational Center every year. STEM-related project programs give schoolchildren an opportunity to use their knowledge, skills and creativity to solve real-life challenges and carry out hands-on experiments and projects on a range of topics (Space, AI, IT, Healthcare, Nanotechnology, Electronics etc.) developed in cooperation with major universities and companies [136].

– Project Science and Technology Program “Big Challenges” [137]

The “Big Challenges” program is the most large-scale annual project program for schoolchildren in Russia, aimed at a full cycle innovative activity on priority scientific and technological areas. For three weeks of the program project teams of schoolchildren of 8-10 grades solve engineering and technology tasks presented by Russian tech companies and businesses, research institutes and leading universities. Apart from project activities, the students attend lectures and workshops by top scientists and experts, participate in masterclasses and operate high-tech equipment. The following are the main project/research areas of the “Big Challenges” program: Big Data, Artificial Intelligence, Cybersecurity, Autonomous Transport, Modern Energy,

Smart City, Space Exploration and Technology, Agriculture Industry and Biotechnology, Cognitive Research, Genetics, Personalized Medicine, Nanotechnology, New materials.

– All-Russian Competition of Scientific and Technological projects “Big Challenges” [138]

The competition is organized as a special event for schoolchildren selection for the annual “Big Challenges” program. Similar to the program, the competition takes place in the following directions: Big Data, Artificial Intelligence, Autonomous Transport, Space Exploration and Technology, Agriculture Industry Nanotechnology, etc. The regional stage of the competition takes place in more than 45 regions of the Russian Federation. Schoolchildren can also apply on-line if there is no relevant direction in their region.

On the regional stage a mutual expertise of the projects is carried out which allows the experts to get acquainted with the projects from other regions and form an expert community. The main idea of the competition is to involve regional experts and companies in working with children, facilitate further work on projects due to the geographical proximity of schoolchildren and project managers, expand the pool of partners, mentors and teachers of the competition and educational programs [136].

Another example of non-formal STEM-related practices by “Sirius” Educational Center for talented children is “The lessons of the present” Volunteer Project for School Science and Technology Studios [125].

“The lessons of the present” project is aimed at organizing cooperation, joint project and research activities of schoolchildren and scientific leaders of the country, popularization of the Strategy for the Scientific and Technological Development of the Russian Federation ideas. The thematic palette of “The lessons of the present” is about responding to “Big challenges” in areas such as new materials, big data, Space Exploration and Technology, Agriculture Industry and Biotechnology, Modern Energy, Autonomous Transport, etc.

As part of the project, scientific-technological studios are being formed in schools. Schoolchildren of 8-10 grades from “The lessons of the present” studios participate in offline and online meetings, discussions with scientists, technology leaders and entrepreneurs, as well as develop projects and conduct research with them. The studio managers are usually “Sirius” Educational Center alumni.

The activities of the studios are divided into cycles. A cycle lasts for four weeks. Every month studio members / participants get acquainted with one of the leading scientific

and technological areas and solve the problem that is set by a scientist or a company representing this area. All decisions are evaluated by an expert group and give feedback to the project participants. The studios open in September and close in May. Thus, the project goes through 9 educational cycles in one academic year.

The studios work on the basis of PBL and "flipped classroom" blended learning model using the online platform, the Sirius Educational Center Online Courses service [139], and the Vkontakte social network [140] as a space for interaction of all project participants.

In 2019, there were 80 studios participating in 33 regions in Russia. The participants solved the problem from Yandex, they developed new skills for the "Alice" voice assistant. For "Roskosmos" studio members developed a program that automatically binds photographs taken from the ISS to a specific geographical area. They also improved the method of assessing the solubility of granular fertilizer for the "PhosAgro" company. "KAMAZ" proposed to develop a program for the assembly of a modern car.

Likewise, Regional Education Centers for Talented Children implementing "Sirius" model such as "Steps to Success" (Rostov-on-Don) [141], "Golden Ratio" (Ekaterinburg) [142], "Talent Academy" [143] (Saint-Petersburg), "Kazan open university of talents 2.0" (Kazan) [144] etc. develop and deliver project & inquiry-based educational programs and non-formal STEM-activities (summer camps, hackathons, project sessions, etc.) in cooperation with universities and regional industries/businesses.

- All-Russian on-line educational project "Digital Lesson" [145]

All-Russian on-line educational project "Digital Lesson" is an example of successful "non-formal to formal" STEM education projects carried out within The National Program "Digital Economy of the Russian Federation" [146], federal project "Staff for Digital Economy" [147].

"Digital lesson" is an online course for schoolchildren of grades 1-11 initiated by the Ministry of Education, Ministry of Communications of the Russian Federation and the ANCO "Digital Economy" and developed in cooperation with top tech companies such as "Mail.ru group", "Sberbank", "1C", "Kaspersky Lab", "Yandex' as well as "Codvards" and "Algorithmika" online educational platforms. The project was initiated in 2016 as a Russian counterpart of the global movement "Hour of Code" [148].

Since 2019, the project designed to inspire STEM leaders of the future involves acquainting schoolchildren with the directions of the digital economy development (video lectures, webinars for teachers, teaching and learning materials) and their involvement in practical activities (gamification, online simulator activities for 3 groups of schoolchildren: 1-4, 5-7 and 8-11 grades) in the context of real tasks in the field of Programming, Big Data, Networking and Cloud technology, AI, Personal Assistants, Digital Security etc. Traditionally, from 1,500,000 to 3,500,000 schoolchildren take part in each lesson.

– STEM Centers of the All-Russian Festival of Science 0+ [149]

In 2015, Intel and All-Russian Festival of Science 0+ announced the regional expansion of a joint project involving industrial partners to create centers for scientific and technological activities for schoolchildren. By that time there existed about 155 STEM centers in Moscow, the Moscow region and the Volga Federal District. The STEM Centers project is focused on attracting students' interest in engineering and technical specialties, early career guidance, and aims to educate a new generation of inventors, innovators and entrepreneurs working on high-tech projects.

STEM Centers of the All-Russian Festival of Science 0+ is the network of research and engineering laboratories supporting scientific, technical and engineering components in extracurricular activities [150]. Laboratories implement educational programs based on Project-Based Learning and networking with industrial partners through network research projects, contests and competitions, project camps and summer schools such as Junior Skills Challenges, FIRST (FLL-Junior, FLL, FTC), «Scientists of the Future», «Baltic SEF», “NRJ camp”, “NANO camp”, “Smartcamp”, “Rosatomcamp”, etc.

The project participants are universities, scientific laboratories, children's supplementary education centers, schools meeting the following criteria: educational programs in the field of natural sciences, technology, programming or robotics for schoolchildren of 7-11 grades; specialists with scientific or technical expertise, ready to manage the project activities of children; necessary equipment; motivational programs to maintain interest in research and engineering activities etc.

At the end of 2019, there are 226 STEM centers [151] in 40 regions in Russia. 17,000 schoolchildren in grades 7-11 were trained in STEM centers. Schoolchildren were trained in more than 200 educational programs. 750 projects were completed, 287 of them were presented at various conferences or competitions.

– Skolkovo MAKERspace STEM Education Center for schoolchildren

This space was opened in 2017 as a joint project of LEGO Education, Skolkovo Technopark, as well as LINTEH, TETRIX and Standart-21 companies, basic element of comprehensive lifelong learning programs for future engineers and researchers (kindergarden – school – university – industry/business). At the center, primary and secondary school students study engineering and information technologies: blockchain, internet of things, mobile robotics etc. The center's task is to develop children's interest in scientific and technical creativity, robotics and IT. Education in the STEM-center Skolkovo MAKERspace is carried out on the basis of robotic educational solutions Lego Education, TETRIX and SKART IOT, which are used in the course of professional training in the discipline "Engineer-designer of Internet of Things systems". The set includes an educational and methodological training module, designed for 72 hours; a universal mock-up stand "Smart House JS", a set for the study of neuro-biosignals Bitronics LAB, as well as a Lego EV3 set with SmartBRICKS sensors.

– Robooky: STEM Engineering Creativity Programs for Children [152]

A good example of non-formal STEM education is represented by an international network (Russia, CIS countries, USA) of “Robooky” robotics and engineering schools that numbers 35 education centers, more than 11 000 students/course leavers and 130 winners of international STEM contests. The mission of “Robooky” is to help schoolchildren from 5 to 16 decide on their future profession (acquaintance with “professions of tomorrow”), develop skills in entrepreneurial skills and engineering / project thinking. STEM engineering creativity program consists of 13 modules, every two months the child studies a new subject field and profession: Aerospace Engineering, Civil Engineering, Robotics Lego WeDo and Mindstorms, Scratch Programming, Marine Engineering, Industrial Engineering, Environmental Engineering, Arduino Basics, etc.

Individual and group lessons are held once a week based on Game-based and Project-based learning using own online platform and copyright teaching / learning materials and also include excursions to IT companies, children's participation in coding & engineering competitions.

Robooky, together with other STEM centers, organizes the annual World Robooky Competition in engineering and robotics for children from 5 to 16 years old. The Olympiad includes such competitions as: Goldberg miniCup, competitions with robots Lego EV3 and Wedo 2.0 Competitions, as well as the creative category “Medicine for the Planet”.

– Practices of Formal STEM Education in Russia: the case of the private school “Khoroshevskaya Shkola” (“Khoroshkola”) [153]

Since the school was founded in 2017, the science education in “Khoroshkola” has been based on the concept of STEM education which implies project-based integration of science and technology. Student projects (design, research, laboratory) play a leading role in the educational process, generating information and capturing the necessary theoretical knowledge. Practical problems allow to include the 21st century skills directly in the process of studying the subject. The educational process is recorded, evaluated and supported by the digital environment and digital tools.

The goal of Khoroshkola's natural science education is to develop the ability to independently solve various life tasks in a modern, rapidly changing, high-tech world, on the basis of research context, project-based approach; 21 century skills (4К); knowledge mastery and science process skills.

Khoroshkola Science education cluster encompasses Physics, Chemistry, Biology, Physical geography / Earth Science and Astronomy. Schoolchildren of 5-9 grades study natural sciences within the framework of integrated subject field “Natural Science” (4-6 hours a week for laboratory work and 1 hour for individual work), participating in laboratory work with research elements, self-study hours, project work, demo-lectures, teacher-moderated discussions (the discussion of practical work results in large groups), lectures by representatives of hi-tech business and industry, hackathons (1-2 days project sessions); – field practices and excursions; - conferences, presentations and project defense.

The distribution of topics and sections by years of study follows the logic of intersubject connections on which the study of natural sciences in general is built. In grades 7-8, each of the natural science subjects is studied in the format of training 2-3-week modules, involving the study of one subject. The sequence of subjects throughout the year is built in the logic of intersubject connections (example: before studying the topic "Atmosphere" in geography, 7th grade students are engaged in physics for 2 weeks, mastering the concepts: Archimedean force, atmospheric pressure, thermal expansion, convection).

Problem-based science courses motivate children to deal with real-life practical issues, do laboratory works and projects in small groups (2-4 человека). They also design and develop equipment and installations, plan and carry out research and make individual reports.

Three methods of assessment are used: operational feedback, a high-quality formative assessment of each completed practical work, and criteria-based assessment (scoring) based on the results of the final work. The main form of assessment is formative assessment: students receive assignments not to test the availability of knowledge and skills, but to form them. The main form of the result is a report on laboratory work, which is the subject of a qualitative assessment (feedback), since it allows you to assess knowledge and understanding of the subject studied, as well as hard and soft skills demonstrated.

Khoroshkola's teachers combine the functions of a teacher-facilitator of group work, an expert who evaluates the work of students in accordance with a system of criteria, a scientist and an instructional designer - teachers independently and with the participation of professionals develop all teaching / learning materials, project tasks, tests and rubrics for assessment.

A specially designed educational environment plays a special role. The school has no division into chemistry, physics and biology classrooms. There are 4 large specialized spaces: 1) Megalab (900 m^2) is equipped with all the necessary equipment for laboratory research, group discussion, educational work on projects in mini-groups, as well as lectures, presentations, conferences, viewing videos in 360°; 2) Experimentarium (250 m^2) allows doing practical works, design different devices and hold demonstrations; 3) FabLab (300 m^2) is a real maker space for any research / engineering project; 4) Robotics and Microelectronics lab (180 m^2).

STEM-Teacher Training Programs and Courses

The reviewed STEM-related national policies and initiatives, school-university-industry collaborative projects in the field of non-formal STEM education as well as particular cases of non-formal and formal STEM practices in Russia call for new types of modern Science, Technology, Mathematics, Primary School and Supplementary Education teachers. Such STEM teachers have to be aware of project-based learning, enquiry-based learning, gamification methodologies, experienced in designing integrated STEM curriculum, engaging students in real-life research and engineering projects in contexts that make connections between school, community, industry etc. They also have to be able to play the parts of instructional designer, educational project manager, classroom game designer, group facilitator as well as soft skills trainer.

The system of STEM teacher life-long learning in Russia hasn't been formed yet. However, there is a number of successful practices in the field such as MOOCS, summer schools and master's degree programs.

– NTI Kruzhok Movement Project Mentors Academy [154]

NTI Kruzhok Movement Project Mentors Academy is a joint project of the Skolkovo Foundation, the Agency for Strategic Initiatives, the Skolkovo Open University (OpUS) and the NTI working group Kruzhok Association. The goal of the project is to create a system of mass training and certification for project/PBL mentors. To do this, online courses are created, and full-time intensive courses called Mentors Schools are held to train managers and mentors of project-based learning. It is also planned to create a «mentors' exchange» – a space for employing mentors for school and university student projects and teams.

– "How to become a mentor of project-based learning" [155]

"How to become a mentor of project-based learning" online course on "Lektorium" online education platform [156] is a two-month MOOK on organizing extracurricular project activities and PBL at schools, working with student project teams, managing projects in education for those who plan to participate in a Mentors School by Project Mentors Academy as well as for schoolteachers, supplementary education teachers and trainers, Quantorium tutors, FabLab project managers etc.

– "Lektorium" online course "From hackathon to project school" [157]

The MOOC comprises three modules devoted to different educational intensive formats: engineering competitions, hackathons and project schools. Each module deals with peculiarities of the format, the educational process organization and specific skills and responsibilities of PBL mentor.

– Master's degree program in Moscow City University "Teaching Physics and STEM-education" [158]

The program is intended to train future teacher of Science and Engineering. Graduates of the program develop the necessary professional skills to solve the complex pedagogical task of providing an initiation in the engineering profession. The teacher of Science and Engineering, in addition to mastering modern educational technologies, also possesses engineering competencies, primarily the ability to plan and implement complex projects.

The educational process is based on solving practical problems. Lectures are replaced by trainings, laboratory work and pedagogical practice. Part of the program is implemented in the format of master classes and pedagogical workshops, including at the sites of innovative educational organizations (technology parks of the Kurchatov Institute and the Moscow State Polytechnic University, Khoroshkola and School No. 1799). The research work of the master's degree student is focused on the development of teaching and learning materials.

The Curriculum consists of four modules: 1. Research module. In this module, students carry out research and write their master's thesis. 2. Module "Education and Psychology", in which undergraduates learn to understand and use the age characteristics of a child and the patterns of situations of pedagogical interaction between a child and an adult. 3. Methodical module. In this module, the development of modern educational technologies and approaches based on the material of physics, technology, computer science takes place. 4. The technology module involves the study of educational robotics, electronics and programming for technology lessons, computer science and the implementation of additional educational programs (extracurricular activities).

– Master's degree program in Immanuel Kant Baltic Federal University "STEAM Practices in Education" [158]

Master's program STEAM Practices in Education in Immanuel Kant Baltic Federal University, Russia, Kaliningrad, provides systemic knowledge in the field of Teacher Education and Teacher Training with the intersection of technical sciences and creative activity. The programme is designed within the framework of ERUSMUS+ KA2 "Integrated approach to STEM teachers training / STEM". It takes into account current professional standards, employers' requirements and the opinions of international experts. The program is aimed at training teachers-to be who are able not only to design basic and additional educational programmes, but also to develop high-tech ways of their implementation, such as the establishment of School Technoparks and Technopolises, STEAM Education Studios and Project Offices. The students mastering the programme get acquainted with the experience and best practices of national and international education systems. They are taught to create special educational spaces that allow teachers and trainers of all levels to implement STEM and STEAM approaches and interdisciplinarity into teaching, launch high-tech educational startups and projects, organize and manage innovative research and project activities of students. This programme allows the graduates to become professionals with the

relevant expertise in-demand not only in the context of the national education system, but also on the international labor market. There are multiple positions a graduate of the program can apply for. The programme is intended for those who work or plan to work in the field of education, in public and private schools, in the systems of additional education for children and adults, Centers for Advanced Training of educators, additional professional education, in the field of organizing cultural and educational activities in scientific museums, Innovation Centers for young learners, etc. The career with the MA in Education can develop both horizontally with expanding professional opportunities and going beyond the functional roles of teachers of basic and core subjects into an interdisciplinary field, or becoming a mentor teacher and creating one's own methodological school; and vertically, when the graduates move up the career ladder to administrative positions in educational authorities at various levels.

The experts of the programme are renowned specialists in the field: Dr. Keelin Leahy, Lecturer in Technology Education, University of Limerick, Ireland; Janerik Lundquist, Senior Lecturer, Linköping University, Sweden; Prof. Merrilyn Goos, Professor of STEM Education, Director of EPI*STEM, the National Centre for STEM Education, University of Limerick, Ireland; Prof. Dr. Gultekin Cakmakci, Professor of Science Education, Hacettepe University, Turkey.

The purpose of the programme is in-depth training of a modern teacher-researcher and teacher-practitioner who is able to successfully design and implement STEM/STEAM technologies to stimulate students' interest in the study of Sciences and Arts, the development of creativity and technical creativity of the basic and core subjects at schools. The modules of the programme comprise innovative processes in education, methodology of STEM and STEAM education, methods and principles of life-long learning, current educational technologies (including STEAM methods, design thinking and visualization technologies, Art education in modern contexts, ecosystems of project activities in additional education, Educational Robotics).

The syllabus is designed with off-line and on-line lectures, seminars, e-learning technologies, design workshops, trainings and master classes, individual educational track opportunities, internships, training and immersion in industrial and scientific laboratories, public presentation of learning outcomes in microteaching formats, TED format project presentations, professional identity trainings within learning-by-doing environment, in which students get the opportunity to apply the acquired competencies and skills in industrial practice at the leading educational institutions of the Kaliningrad region and on the basis of University Resource Centers and laboratories

from the very first year of study. The programme gives the opportunity of international internships.

As for the career opportunities, the graduates are able to carry out successful professional activities in psychological, pedagogical, scientific, methodological, research, expert consulting, organizational and management spheres in educational institutions of various levels, at the institutions of additional education, scientific museums, Innovation Centers for young learners, Technoparks and Technopolises, STEM/STEAM education studios, project offices engaged in the development of educational projects.

STEM-EDUCATION IN KAZAKHSTAN

Context

STEM Education policy in Kazakhstan.

The development of STEM education takes its place also in Kazakhstan. This initiative is confirmed by the designated transition to the updated content of school education in the context of STEM within the framework of the State Program for the Development of Education and Science for 2016-2019 [159]. By means of implementation of the new educational policy, it is planned to include STEM elements in the curricula aimed at the development of new technologies, scientific innovations, and mathematical modeling.

The main goals to be implemented are:

- A new interdisciplinary and project-based approach to teaching that will allow students to strengthen their research and scientific and technological potential, develop skills for critical, innovative and creative thinking, problem solving, communication and teamwork.
- In the State Compulsory Standard of Primary Education, new enlarged-integrated educational areas “Mathematics and Informatics”, “Natural Science” and “Technology and Art” have appeared which provide for the study of new academic subjects such as “Information and Communication Technologies”, “Natural Science” and “Artistic work For students of primary and high school, new academic subjects "Graphics and Design", "Fundamentals of Entrepreneurship and Business" and elective courses, the so-called elective courses, have been introduced.
- The State program "Digital Kazakhstan" [160]

The State program "Digital Kazakhstan" was approved on December 12, 2017, provides for the gradual introduction of the subject "Fundamentals of Programming" in secondary education in order to develop the creative abilities and critical thinking of the younger generation, starting from the 2nd grade. The programs (grades 5-11) will also be updated, primarily in terms of revising programming languages, taking into account the inclusion of STEM elements (robotics, virtual reality, 3D printing and others)

The government of the Republic was instructed to develop and adopt a separate program "Digital Kazakhstan", to develop in the country such promising industries as

3D printing, online commerce, mobile banking, digital services, including in healthcare and education, and others.

The task - “improving the quality of human capital” - is to make education the central link in the new model of economic growth. Therefore, modern curricula should be aimed at developing the critical thinking abilities of students and the skills of independent search for information, it is necessary to pay great attention to the formation of IT knowledge, financial literacy and the education of patriotism of youth.

In accordance with the Strategic Development Plan of the Republic of Kazakhstan until 2025, approved by the Decree of the President of the Republic of Kazakhstan dated February 15, 2018 No. 636, STEM elements aimed at the development of new technologies, scientific innovations, mathematical modeling, programming, robotics and initial technological training. For this, additional education programs, extracurricular activities, scientific circles and extracurricular activities will also be organized, a network of children's technology parks and business incubators with all the necessary infrastructure and mechanisms for their maintenance will be created. In high school, a number of subjects will be taught in English [161].

- The State Program for the Development of Education and Science of the Republic of Kazakhstan for 2020 - 2025 [162]

This program was adopted by the Decree of the Government of the Republic of Kazakhstan dated December 27, 2019 No. 988. According to this program, the development of digital infrastructure of educational organizations (wireless communications, cloud technologies, microservers, computers and peripheral equipment, local network, broadband Internet access, etc.) will continue. As part of the World Bank's Secondary Education Modernization project, over 5,000 schools will be provided with 100,000 laptops and 20,000 printers. More than 2,500 schools with no internet connection or slow connection speeds will receive 1,200 data centers. As a result, the project "1 teacher - 1 computer" will be implemented to provide all teachers with computers. Schools will be equipped with subject classrooms for chemistry, biology, physics, STEM classrooms. Labor training rooms will be modernized.

STEM centers at universities

- Pedagogical STEM-park of Abai Kazakh National Pedagogical University [163]

On March 17, 2018, in the Abai Kazakh National Pedagogical University, as part of the implementation of the Address of President Nursultan Nazarbayev to the people of Kazakhstan "New development opportunities in the context of the fourth industrial revolution" and support of the State program "Digital Kazakhstan", an international Kazakh-Russian seminar "Pedagogical STEM Park" was held.

The second meeting called "Pedagogical STEM Park" is aimed at discussing ways to implement STEM education in a pedagogical university, and the immediate task is to create a STEM park (or STEM center) at the university, which would contribute to the development of digital education, training bachelors and undergraduates for additional specialty "Computer Science and Robotics", the introduction of an elective course for all natural science specialties in digital robotics and STEM-training and the discipline "Digital Technologies in Education" for all pedagogical specialties. The implementation of the tasks set will ensure the training of highly qualified personnel in digital technologies associated with the main elements of the fourth industrial revolution, such as automation, robotization, artificial intelligence, and the exchange of "big data".

Discussed issues: "Pedagogical STEM-park" - a new format of partnership between the education system and business. Integration of the STEM park into the educational process. Familiarization with the products of companies for STEM laboratories in digital robotics and mechatronics.

To implement the above proposals, a STEM training center was created, i.e. The pedagogical STEM-park of Abai Kazakh National Pedagogical University, which is the most important step for systematizing the training of students of a pedagogical university for teaching schoolchildren in robotics and performing research work in the field of robotics and developing a methodological system for teaching schoolchildren in the field of robotics.

In 2018, the Ministry of Education and Science of the Republic of Kazakhstan announced the launch of the project "Modernization of secondary education" For its implementation; the government borrowed $ 75 million from the international bank for reconstruction and development. Within the framework of the project, a set of initiatives is planned to support the updated content of education, including the creation of robotics laboratories in 16 universities of the country, which included the Abai Kazakh National Pedagogical University.

On September 24, 2019, a class came to the Abai Kazakh National Pedagogical University, which includes 10 basic and 10 resource robotic kits Robotics Advanced

Fischertechnik, 2 Robot track "Basic" kits, 10 kits for experiments and robotic projects Arduino, 3d Printer E12 Anet, 6 monoblocks, JI-K3020 CNC machine for cutting and processing materials, infrared soldering station ACHI IR-6500, soldering station Saike-852d++ with analog-digital control, microscope for soldering chips, digital oscilloscope UTD2052CL 50MHz and much more.

For the training of specialists in the field of "Robotics" the following actions were performed:

- An educational program has been developed for the specialty "Electrical Engineering, Radio Electronics and Robotics" in the specialty "5B012000-Professional Training". Based on the developed educational program, MOP and RUP are drawn up for 2018/2019 and 2019/2020.
- Developed an educational program "Electrical Engineering, Electronics and Robotics" in the specialty "5B071600-Instrument Engineering" in the direction of professional activity "Mechatronics and Robotics". The necessary elective disciplines in basic and profiling modules have been selected. The qualification characteristic of bachelors of the specialty "5B071600-Instrument Engineering" is given. Based on the developed educational program, MOP and RUP are drawn up for 2018/2019 and 2019/2020.
- A work program for the discipline "Educational Robotics and Mechatronics" for technical and natural specialties for 3 credits has been developed, which includes the main topics of lectures and laboratory classes, assignments for Independent work of student, for Independent work of student with teacher and a map of educational and methodological provision.

- Nazarbayev University. NU program on training school teachers in teaching STEM subjects in English language proved compliance with international standards [164]

2018, November 23. An international independent expert successfully evaluated NU program on training schoolteachers in teaching STEM subjects in English language. The expert evaluated the program and gave a positive report. This assessment recognized the high quality of the educational program and revealed that it complied with international standards in terms of management, delivery, content, methodology, facilities and resources.

During 2017-2018, within the framework of the state policy on trilingual education, Nazarbayev University trained over five thousand urban and rural teachers of Chemistry, Physics, Biology and Computer Science. Training in these programs helped

the teachers achieve the B2 level in English, which was necessary to successfully pass the international language examination.

It is expected that starting from 1 September 2019, Kazakhstani schools will teach Chemistry, Physics, Biology and Computer Science in English for grades 10 and 11.

- Eurasian National University [165]

In ENU named by L.N. Gumilyov the masters are trained in the specialty "7M01525 STEM education" who are able to apply information technology with STEM elements in the field of educational activities, monitor and manage the educational process, who have the skills of research activities.

STEM training seminars, forums

Various training seminars and STEM forums are held in the country.

In January 2020. in Shchuchinsk (Akmola region) a training seminar "STEAM-education in the vocational education system" was held at the Higher Pedagogical College. The purpose of this event is to develop competencies based on the use of technology, modeling, art, mathematics, interdisciplinary and applied approaches, which are the main idea of STEAM - education.

On March 17, 2018, at the Abai Kazakh National Pedagogical University, on the basis of the international scientific laboratory of problems of informatization of education and educational technologies, an international Kazakh-Russian seminar "Pedagogical STEM Park" was held. Seminar participants: Moscow State Pedagogical University, KSPU, ZAO "Didactic Systems", Moscow, http://disys.ru. The participants of the seminar shared their experience of creating educational laboratories and a STEM park. STEM Pedagogical Park is a new format of partnership between the education system and business. To implement the above proposals, a STEM training center was created, i.e. Pedagogical STEM-park of KazNPU them. Abai, which is the most important step for the systematization of the preparation of students of a pedagogical university for teaching schoolchildren to robotics and the implementation of research work in the field of robotics and the development of a methodological system for teaching schoolchildren in the field of robotics. KazNPU has three laboratories: 1) Robotics laboratory 2) Measuring systems laboratory 3) Mechatronics laboratory

The STEM Pedagogical Park has implemented the following scientific and technical projects with high potential for future STEM education: System for automatic control of human wakefulness; A set of digital teaching laboratory facilities for physics;

Scientific and methodological basis for the development of laboratory work in educational robotics and mechatronics

Republican forum on STEM education "STEM innovations in education" On February 28, 2020 in the city of Nur-Sultan at the International School "Miras" the republican forum "STEM - innovations in education" was held. The purpose of the forum is to popularize STEM education among general education and specialized schools of the republic. More than 100 teachers and students took part in the republican forum.

As part of the STEM forum, master classes were held on the implementation of STEM technologies: Astana IT University, Introduction to Web, STEM education and it is future in education, Microsoft Hacking STEM resources, Robot league.

The forum hosted an exhibition of 27 STEM projects of students who proudly presented their inventions. Participation in the STEM forum forms the skills of project work in a team, the ability to create a practical solution based on academic knowledge, formalize and present your result. The children receive new knowledge and skills, are involved in research, which allows them to master in practice the skills of scientific work, which will be useful in their further education at universities.

- Methodical seminars "Orleu"

On November 4, 2019, the trainers of "Orleu" - Taraz B. Makhadieva, S. Kurmanova, A. Beisenkulova, Zh. Kosherbayeva for primary school teachers on the basis of secondary school No. 36 in Taraz, organized and conducted a methodological seminar "Features of planning for an updated educational program in primary school "as part of the implementation of STEM education.

The aim of the seminar is to develop skills of short-term planning among primary school teachers in the context of renewal of the content of education. During the workshop, the trainers gave teachers useful advice on short-term plans and provided methodological assistance in effective feedback.

The seminar ended with an examination of the features of planning short-term plans, the effectiveness of formative assessment and ways of developing the teacher's professional competence in organizing the educational process.

A two-day regional training seminar on the topic: "STEM education: organization of practical activities" began at the branch of the "National Center for Advanced Studies" Orleu ". During the seminar, the participants considered the possibilities of using STEM education in practice, shared their experience, identified the difficulties that exist at this stage. In particular, the teachers expressed their support for the creation of an

online platform for the introduction of the new system, and offered a number of recommendations. So far, STEM education is offered for familiarization, but this year the initiators of its promotion in Aktobe plans to open STEM laboratories on the basis of three schools for constant practical use in the learning process, and awakening interest in research activities among schoolchildren.

Senior lecturer G. Nurgazinova and doctoral student of the Department of Informatics of PSPU Mukhamedieva K. took an active part in a seminar on the introduction of STEM education in the curriculum of secondary schools. The seminar was organized by the Center for Innovative Education on the basis of school-lyceum №8.

Deputy directors of specialized educational organizations for gifted children attended the event. The issues of integration of subject areas of mathematics, physics and computer science in the direction of STEM education were also highlighted. One of the priority tools for implementing training in this direction is educational robotics. Teachers of the Department of Informatics shared their experience of implementing STEM education in the preparation of subject teachers.

STEM festivals and events

- STEM Olympiad at Nazarbayev University [166]

On November 1-2, 2019, the first Republican STEM Olympiad "STEM – Innovations in Education" was held at Nazarbayev University. The main purpose of this event was to popularize STEM education in Kazakhstan among students in general and specialized schools, as well as search for talented children in such technical areas as engineering, programming, design robotics and 3D modeling.

STEM Olympiad is an innovative educational competition that incorporates all the latest achievements in the field of technical education. In order to increase the popularity of STEM fields, the Olympiad's organizers used the most recent scientific and technical knowledge to create the competition events, while at the same time focusing on real world applications and using a format attractive to school children. This event will contribute to the growing popularity of STEM fields in Kazakhstan so that young Kazakhstanis will develop an interest in technical disciplines.

The event was attended by students from all over Kazakhstan, including from schools of the capital city Nur-Sultan, the cities of Almaty, Pavlodar, Karaganda, as well as from the East Kazakhstan Region. Leading experts and speakers in the field of education,

who shared their vision of the development and popularization of STEM education in Kazakhstan, attended the event.

The Olympiad was held under the auspices of Astana Innovations JSC by Nazarbayev University and STEM Academia LLP, with the support of the Astana Daryn Center for the Development of Giftedness and Psychological Support, GKKP Center for the Modernization of Education and ChU NURIS NU.

For two days, students from all over the republic competed in the ability to apply their knowledge in practice. For example, they had to build bridges from straws that can withstand a weight of 10 kg, build a vessel that can withstand up to 30 kg and float in an outdoor pool up to 20 meters, invent mechanisms to create safe cars, and so on.

- International festival of robotics, programming and innovative technologies "ROBOLAND2019" in Karaganda (since 2015) [167]

The annual international festival "RoboLand" is organized to promote the development of the creative activity of students, the formation of their engineering skills, the popularization of educational robotics and programming, the exchange of best practices, and the identification of the strongest teams.

According to the website of the International Robotics Festival, which is held annually, the number of teams representing Kazakhstani schools is noticeably increasing every year. For example, in 2015, teams from secondary schools of the Karaganda region, Nazarbayev Intellectual Schools in Karaganda and Kokshetau took part in the robotics championship held as part of the international festival. Teams competed for a spot in five nominations: minisumo, kegelring, line following, maze and creative projects. In 2016, teams from 12 regions of Kazakhstan, the city of Almaty and Astana participated in 14 nominations of the competition. 113 participants represented Nazarbayev Intellectual Schools. 392 teams from Kazakhstan and Russia took part in the 2017 competition.

- The VI International Festival of Robotics [167], Programming and Innovative Technologies "RoboLand 2020"

This event was supposed to take place on 27-28 March 2020 in Karaganda, Sports Complex "Zhastar".

The organizing committee of the VI International Festival of Robotics, Programming and Innovative Technologies "RoboLand 2020" announced the postponement of the event.

The reason is the introduction of restrictions on mass international events in connection with the threat of the penetration and spread of coronavirus in the territory of the Republic of Kazakhstan; the exact time of the festival will be announced later.

- First festival for STEM teachers in Kazakhstan (Astana) [168]

In October 2018, the Republican School of Physics and Mathematics, with the support of the Chevron company, in partnership with Science on Stage Europe and the Foundation of the First President of the Republic of Kazakhstan - Elbasy, held the first festival in Kazakhstan for STEM teachers. The aim of the festival was to improve the quality of teaching STEM subjects and create a platform for teachers to share their ideas and innovations in teaching.

The festival was attended by 25 teachers from different regions of Kazakhstan and 20 projects were presented in various categories, which were pre-selected. The best projects of the festival received the right to represent Kazakhstan at the European festival, which took place in November 2019 in the city of Cascais, Portugal.

Chevron is committed to contributing to the development and advancement of STEM (Science, Technology, Engineering and Mathematics) education in Kazakhstan. This collaborative project with Chevron hopes to take STEM teaching to a whole new level.

Responsible persons of the Republican Physics and Mathematics School, as one of the best Olympic schools in Kazakhstan in natural sciences, believe that the exchange of useful information between teachers is necessary and the festival will contribute to the development of national education, serve as a platform for the exchange of knowledge between teachers and help to instill love in schoolchildren to science.

For the first time, STEM teachers from all regions of Kazakhstan have found a single platform for the exchange of knowledge, methods and projects, thereby developing students' interest in science and innovation. As a result of the festival, each teacher was able to enrich himself with new ideas, which he could apply already the next day in his lessons.

The following projects won the competition:

AirGarden is based on the principle of using the knowledge of all STEM subjects in one separate project on the example of creating an aeroponic vertical structure for growing vegetables and greens.

Assistant robot - robot allows you to visualize the principle of programming algorithms and learn the basics of robotics.

Modern Science Class - the aim of the project is to popularize Pasco wireless sensors that allow you to quickly collect data and analyze it in the form of graphs. Thanks to sensors, the educational process is transferred outside the school and allows you to study the environment.

Creative plasticine - aimed at developing abstract thinking in mathematics lessons by visualizing complex geometric shapes and problems.

The festival consisted of two parts - thematic workshops and the event itself, during which teachers defended their projects in front of the jury. Workshops were conducted by teachers participating in the festival and by members of the jury. The projects were assessed according to the following criteria: the possibility of increasing the interest of students in the study of science; determination of a sustainable effect, the possibility of implementing the project in the daily life of the school; minimal funding costs and focus on solving specific problems.

In March 2018, Kazakhstan, represented by the RFMSh NJSC, entered the European STEM Teachers Association “Science on Stage Europe”. Science on Stage is a non-profit association that provides a European platform for STEM teachers to exchange teaching ideas and methodologies. Since its launch in 2000, “Science on Stage” has reached nearly 100,000 teachers in over 30 countries.

- August conference of pedagogical workers [169]

The conference was held on 27.08.2019 in Stepnogorsk "KELESHEKKE - KEMEL BILIMMEN!". The director of the interschool educational and production complex S.V. Kubrina made reports on STEM education. and methodologist-mentor of the Education Department of the city of Stepnogorsk Shcherbina V.A. The content of the reports is aimed at a primary, basic understanding of the essence and foundations of STEM education, promoted in Kazakhstan at the present stage of education development.

- The first city festival of STEM education "Deinde 4.0" [170]

The festival was held in Kostanay. 214 schoolchildren demonstrated their abilities. The festival "Deinde 4.0" was held at the school-gymnasium №3. It was held in five areas: "Paper Plane", "STEM Problem", "Robotics", "Pinkod", "Video".

International cooperations in the field of STEM education [171]

There is a positive experience of international cooperation. For example, since 2014, the five-year “Newton-Al-Farabi” Partnership Program of Great Britain [172] and Kazakhstan has been implemented with a total budget of £ 20 million. The goal of the Program is interaction between the two countries in strengthening scientific and innovative potential, exchanging personnel and creating joint research centers.

Thus, Kazakhstan country is moving in the same direction as developed countries. STEM education is the bridge between studies and careers. His concept prepares children for a technologically advanced world. Professionals of the future require comprehensive training and knowledge from a wide variety of educational fields in science, engineering, technology and mathematics.

- ERG (Eurasian Resources Group) grants.

Social projects in Kazakhstan aimed at developing innovative teaching methods and improving the quality of life of people are sometimes grandiose in scale. Eurasian Resources Group (ERG) invests heavily in the development of Kazakhstan. Since 2001, ERG's total social investment has amounted to 226 billion tenge.

In particular, ERG is a key partner in the implementation and expansion of STEM activities in Kazakhstan. STEM based on colleges and schools includes the study and implementation of innovative technologies (science, technology, engineering, math). There are already 12 such laboratories in Kazakhstan, worth more than 80 million tenge.

Today STEM laboratories, including with the support of ERG, are open in 5 percent of schools in Kazakhstan. To experience a significant effect from the introduction of these laboratories, it is necessary to equip at least 20 percent, or 1,500 schools. STEM Academia [173] expects to equip all these 1,500 schools by 2020 and create a critical mass of learners who will advance STEM learning and bring better change in society.

STEM in schools of Kazakhstan

- NIS

The curriculum of Nazarbayev Intellectual Schools *(NIS)* includes STEM elements aimed at the development of new technologies, scientific innovations, mathematical modeling, programming and robotics. Already today mathematics, statistics and informatics are actively used even in the humanitarian sphere [174].

Development of robotics at Nazarbayev Intellectual Schools

The autonomous organization of education "Nazarbayev Intellectual Schools" (hereinafter referred to as AEO), supporting technically gifted and talented children, developing creative thinking and stimulating students' interest in the field of innovation and high technology, makes a significant contribution to the development of educational robotics in the Republic of Kazakhstan.

Since 2014, AEO has been the national organizer of the Olympiads in robotics according to the rules of the World Robot Olympiad (hereinafter - WRO) in Kazakhstan. Every year, AEO conducts qualifying regional and republican stages of the Olympiad, according to the results of which a national team of Kazakhstan in robotics is formed to participate in the international stage of the WRO.

In 2014, AEO for the first time held a robotics Olympiad according to the WRO rules, which was attended by 90 students of the Intellectual Schools from 15 regions of the country. The winners of this Olympiad in November 2014 took part in the international stage of the WRO (Sochi, Russia), where, according to the results, they took the III place in the creative category, having developed a prototype of a robot that can be used to rotate space stations in space to obtain solar energy.

In 2015, the Republican Olympiad in robotics was held in Astana with the participation of 152 students, of which:

- 70 students of the Intellectual Schools;
- 82 students of general education schools.

In 2016, AEO organized and conducted regional and republican stages of the Olympiad in robotics with the participation of the following participants:

Regional stage of the Olympiad:

- 401 students of the Intellectual Schools;
- 84 students of general education schools.

Republican stage of the Olympiad:

- 140 students of the Intellectual Schools;
- 44 students of general education schools.

In December of the same year, the winners of this Olympiad took part in WRO-2016 (New Delhi, India) and won the Creativity Award nomination by creating a robotic orbital station for the destruction of space debris in near-earth orbit.

April 29, 2017 on the basis of the Nazarbayev Intellectual Schools of Astana (IB), Almaty, Aktobe, Atyrau, Kokshetau, Karaganda, Kostanay, Kyzylorda, Pavlodar, Petropavlovsk, Taldykorgan, Taraz, Ust-Kamenogorsk, Uralsk, Shymkent (chemical and biological direction) and the regional stage of the Olympiad in robotics was held within the framework of the World Robot Olympiad 2017 rules. The regional stage was held for one day in the following categories: "Basic", "Creative", "Free" (Kegelring, Sumo robots, Trajectory - movement along the line) and "Football of robots ". 1210 students took part in this stage of the competition, including 326 students of Nazarbayev Intellectual and 884 students of secondary schools from 8 to 19 years old. As a result of the regional stage of the Olympiad, 300 students (150 teams) received admission to participate in the Republican stage.

On 3-4 July 2017, on the basis of the Congress Center of the International Specialized Exhibition "EXPO 2017", Republican competitions in robotics (hereinafter referred to as the Competitions) were held. The competitions were held under the auspices of the World Robot Olympiad 2017 (WRO 2017) in the following categories: "Basic", "Creative" and "Football of Robots".

The competition was attended by 300 teams from 16 regions of the country, of which:

- 217 students of 21 Nazarbayev Intellectual Schools in Astana, Almaty, Aktobe, Atyrau, Aktau, Kokshetau, Karaganda, Kostanay, Kyzylorda, Pavlodar, Petropavlovsk, Taldykorgan, Taraz, Ust-Kamenogorsk, Semey, Uralsk, Shymkent
- 83 students from 35 secondary schools from all over the country
- One team of the Republic of Uzbekistan participated as a special guest.

The management of the Congress Center of the International Specialized Exhibition EXPO-2017 provided information that 1557 people (participants, officials, guests) attended the event in two days of the Competition.

These competitions became a qualifying stage before preparing for participation in the WRO. From among the winners, a list of participants in the training camp was formed, held from 7 to 14 September 2017 on the basis of the Nazarbayev Intellectual School of Physics and Mathematics direction in Uralsk.

As a result of the training camp, the composition of the national team was determined from among 15 students of the Intellectual Schools. Astana, Almaty, Taldykorgan, Uralsk, Kokshetau, Kostanay, Petropavlovsk, which took part in WRO-2017.

From November 8 to 13, 2017, the national team took part in WRO-2017 in San Jose (Republic of Costa Rica), taking 4th place in the creative category with a realized prototype of a firefighter robot for preventing and extinguishing forest fires.

In January 2017, two teams of the Intellectual School of Physics and Mathematics in Almaty took part in the IX All-Russian Robotic Festival in Moscow and took I and II places in the VEX EDR category. In April 2017, they took part in the international competition VEX Robotics Competition World Championship-2017, Luisville (USA), where they took the 36th place out of 80 teams in the team competition.

In July 2017, the combined team of the Intellectual Schools of Almaty took part in the Inaugural First Competition "First Global Challenge" in Washington (USA), where it took 8th place out of 163 teams.

Also, for the purpose of professional development of teachers of informatics and popularization of the development of robotics in secondary schools of the Republic of Kazakhstan in 2015, the AEO developed an elective course program "Robotics" and organized refresher courses for 2999 teachers of informatics of secondary schools of the country [174].

- RFMSh

In Kazakhstan, the only participant in the AEP (GE Additive Education Program) educational program is the Republican Physics and Mathematics School [175]. Now RFMSh is a member of the international consortium of STEM schools, fully meeting the goals and objectives of this direction. In middle and high school, students acquire deeper knowledge in the field of robotics, building 3D models in CAD environments. They study such programming languages as Python, C++, learn to work with controllers like Arduino.

STEM training courses [176]

On May 28-30, 2020, the Republican School of Physics and Mathematics, with the support of Chevron, organizes online programming courses for teachers of natural sciences and engineering disciplines. No special knowledge required.

During the 2019-2020 academic year, more than 500 teachers learned how to apply information technology in the teaching of science. The teachers mastered the basic skills of working with automation systems on the Arduino platform, got acquainted with the methods of constructing an interactive lesson, and also assembled their own programmable installations for demonstration in the lesson.

The course content includes:

- Modern methods and technologies of teaching physics
- Organization of research projects using Internet resources
- Solving educational problems using programming
- Electronics and microcontrollers in design activities
- Innovative processes in education: authentic and foreign experience.

The Republican Physics and Mathematics School [177] has developed a program that will teach teachers across Kazakhstan to teach in a new way - exciting, interesting, effective.

RFMSh has launched free trainings for teachers of physics, mathematics, computer science, biology, chemistry and geography from other schools. More than 560 teachers have already passed them. The peculiarity of the program is that it teaches STEM teachers to integrate their subjects with each other and to actively engage children in science. Now any teacher from any school can undergo training at the RFMSh and improve their qualifications. The Republican Physics and Mathematics School is ready to share the experience and pedagogical competencies accumulated during its existence. After all, openness and willingness to cooperate is a new trend in education. RFMSh follows this trend and supports all kinds of knowledge sharing initiatives.

For half a century of its existence, RFMSh has become the flagship of STEM education for gifted children. An own method was created, a whole galaxy of scientists, entrepreneurs, as well as statesmen, known not only in Kazakhstan, but also abroad, was released.

The uniqueness of the STEM approach is that all subjects in it are closely interrelated. Let's say a student is faced with the task of launching a space rocket, building a bridge, refining oil, or assembling a robot. Moreover, this cannot be done without broad knowledge in various fields of physics, chemistry, mathematics and programming. Therefore, STEM integrates them into a single learning scheme, when there are "projects" and not subjects. In such an educational environment, children acquire knowledge and immediately learn to use it. This approach will be disseminated by the teachers who participate in the program.

- Science to remote auls

In May, another 60 teachers from different villages and cities passed online trainings.

Who knows, maybe our Elon Musk is growing up in the aul right now, who lacks an innovative teacher and supportive environment. Our program can come to the village

to these children, teaching their mentors. It will cover 3,000 teachers across the country. Considering that, on average, one teacher conducts classes for two hundred students, and then eventually more than 600 thousand children will be able to study science in a new creative format.

The continuing education program for teachers, like many STEM programs, is supported by Chevron.

After the quarantine is lifted, RFMSh trainers will begin to travel to the regions and conduct training for local teachers.

- British schools Haileybury [178]

Haileybury are independent British schools based on English educational standards and have branches in the UK and Kazakhstan.

Haileybury Kazakhstan schools are located in Astana and Almaty and differ slightly in training programs - in Astana, students receive an International Baccalaureate (IB) diploma upon graduation, and in Almaty, they graduate with an A-level diploma.

A-level and IB are university entrance preparation programs that are recognized by universities around the world. The main difference between the programs is that students study several specialized subjects in depth. Typically, the program takes the last two years of school.

New technologies are also being actively introduced in schools - students have access to computer labs and robots, and in the future, they plan to open a STEM center here - a laboratory of new technologies with improved electronics and robotics.

Here they are actively introducing new methods of studying sciences, inviting practitioners to work and in every possible way motivating students to create their own projects.

At Haileybury [179], STEM disciplines are central. And this is not only traditional physics, mathematics or chemistry - students learn programming and are engaged in robotics at a serious level. In the classroom, teachers use special laboratory and educational equipment, 3D printers, and LEGO robotic sets.

In addition, Haileybury hosts its own STEM Olympiad every year. Hundreds of applications come from the strongest schoolchildren in the country, but only the best candidates make it to the final stage, who receive an invitation to further compete for a one hundred percent grant under the International Baccalaureate (IB) program. After

all, encouraging young engineers and scientists is an important mission of Haileybury Schools.

– STEM center school [180]

STEM center is a school for children aged 5 to 15 years, where 4 areas are studied simultaneously: engineering, programming, robotics and 3D modeling.

The founders of the company are students of the Bolashak program at Pennsylvania State University in the USA. The American education system pushed students to create such a school. They wanted to bring to Kazakhstan what they saw there. The first founders of the STEM center are two guys Bagdat and Erbol [181]. At the moment, the team of teachers includes either students who are now studying in technical specialties of NU and ENU or people who have already completed higher education in technical specialties. The main criterion for hiring is not the availability of pedagogical education, but the ability to transfer one's own knowledge. The person must be a specialist in AutoDesk, programming, engineering. Because there are people who understand physics, but do not know how to apply it in practice.

STEM center is represented in 16 regions of Kazakhstan, headquartered in Astana. Moreover, STEM is the first exporter of knowledge. It is located in four regions of Russia - Krasnodar Territory, Barnaul, Krasnoyarsk, Volgograd, from foreign countries the center is represented in Lithuania and the UAE. In Dubai, students study in English according to a program developed by Kazakhstani teachers.

About the technique

1. Engineering. The first step is to introduce children to engineering. For this, a separate office has been allocated, which is fully equipped with the materials necessary for work. There is wood, environmental plastic, drill, saw, screwdrivers and all those tools that real engineers use to build a real object. Children must work in gloves and special glasses under the supervision of a teacher. The purpose of this direction is to show children how the world works and teach them to understand it. After all, creating something with their own hands, they lose the barrier to research.

2. Programming. After children master engineering, they move on to programming. Everyone knows about the importance of knowledge of basic programming skills, so the second step in the STEM center is designated as it. Here children are taught not only to be able to do, but to understand how to do it.

Programming is taught in three languages: Scratch, C ++ and Python. They are considered the basics of any programming. Scratch is a program designed specifically

for children at MIT, C ++ is one of the main programming languages and Python is a higher level.

3. Robotics. The third step is robotics. Robotics goes through two modules. These are Lego Robotics and Arduino. After the children master Arduino, they move on to 3D modeling.

4. 3D modeling. 3D modeling is also in two directions. Autodesk and SolidWorks. At first, children learn to work on programs, then they do on a simulator in a 3D solution, and then they print what they have modeled.

More about STEM

In addition to these centers, there are also STEM laboratories. This is a completely new format - classrooms at the school. Nowadays, classrooms of robotics, physics, mathematics are very often used, what is already classically accepted. A STEM laboratory is a classroom that ideally covers all these disciplines. There, students are provided with computers and various simulators, programs. Training in such rooms is free.

STEM BOX is the ability to have all the necessary materials to work on experiments, in other words - every inventor's dream. These are complete sets with all the necessary accessories in every direction: engineering, experimental physics, chemistry, robotics and electronics.

STEAM BOOK. These are books that will bring a child's dream of becoming an engineer, architect, highly skilled builder, IT specialist, scientist, or, perhaps, a hacker closer to reality. The books are written in an accessible and interesting language for schoolchildren in Kazakh and Russian. STEAM BOOK's mission is to turn learning into an incredible adventure.

- MIRAS INTERNATIONAL SCHOOL (The Branch of Nursultan Nazarbayev Educational Foundation) [182]

Miras school started the STEM educational approach in 2014 to provide various and multidisciplinary opportunities for students to experience first-hand practical experience through a variety of activities and in-school practical projects within STEM. To acknowledge creativity, students expand and upgrade their skills, and exercise the role of young scientists to fulfil the 21st-century skills for further education.

The approach of school in education reflects in the technological, environmental and social importance of STEM in everyday life. In 2018-19, Miras school started a

comprehensive STEM approach by promoting project-based learning throughout the whole school starting from pre-school to high school. During the current academic year, Miras school celebrated the first STEM festival where more than 20 schools, together with students of school participated and shared their STEM practices and knowledge gained through their experience. In addition, Miras school is actively promoting teachers of all subjects to be trained to support STEM education.

Miras school is continuously investing time and resources to enhance further opportunities for students lifelong learning into the future.

A vivid example of the introduction of modern trends in the education system is secondary school No. 33 of the Rodina village [183] of the Tselinograd district of the Akmola region, which has been successfully working for a year already within the framework of the scientific grant project "Formation and development of entrepreneurial STEAM education in rural schools in Kazakhstan."

The participants of the project told the correspondent of MIA "Kazinform" about the nuances of their work and internship at Brunel University of Great Britain. Secondary school No. 33 of the Rodina village of the Tselinograd district of the Akmola region has been an experimental site for a year now and has been working within the framework of a scientific grant project aimed at developing the STEAM direction in education.

Thanks to participation in the project, the schoolteachers are in the thick of educational events and keep abreast of the latest trends.

During 2018 alone, the school was attended by foreign experts, invited teachers from the NIS of the city of Kokshetau, employees of the National Academy of Education named after I. S. Altynsarin, scientists from Nazarbayev University, representatives of Haileybury School Astana. Summer language school "You can STEAM it" was held this summer. But the most significant event for the rural school was the internship of the project research team at Brunel University in the UK.

- CARAVAN of KNOWLEDGE [184]

Kazakhstan has launched an interesting, interactive and relevant educational project- "Caravan of knowledge". The project is dedicated to advancing STEM areas: Science, Technology, Engineering, Math and topical issues of education. Chevron Munaigas Inc. supports the project in Kazakhstan and the team of Kazakhstan professionals in the field of education and digitalization.

The active development of STEM education has started in Kazakhstan. The proof of this is the State program of development of education and science in 2019. To implement

the new educational policy, it is planned to include STEM-elements in the curriculum, designed to develop new technologies, scientific innovation, mathematical modeling.

Conclusion

The Atlas of Best Practices in STEM Education presents an aspirational vision for STEM teaching and learning having been introduced in Finland, Ireland, Sweden, Turkey, The Russian Federation and Kazakhstan. Data collected in the given Atlas deliver a clear message: A key challenge is to implement STEM approach to all spheres of education at all levels. Due to the development of a digital economy and the changing paradigm of industrial production this philosophy has become the core focus of the state national policies as well as the mainstream in most educational systems. World tendencies such as globalization, global economic integration underpin the necessity of meeting the requirements of brand-new career ladders.

Having moved front, STEM education is implemented at different state (national, regional), educational (school, university, professional development, supplementary, informal education), collaborative (Government-Business-University) levels. Various approaches, like project-based science learning (PBSL), inquiry-based learning (IBL), have become an integral part of education systems in the countries under review. A number of projects (Co4Lab, the Growing Mind research, New Creative Expertise - Combining Primary and Continuing Teacher Education, Numeracy Across the Curriculum, Career Mathways, ATSSTEM, Integrated Approach to Stem Teacher Training, STEM PD Net, Scientix, International Stem Education Summit, Quantorium, NTI Kruzhok Movement, RUKAMI, Big Challenges, Modern Science Class, etc.) and national platforms of STEM education (LUMA, Federal Innovative Platform STEAMTeach) support the development of national and international collaborative ecosystems.

Learning environments are changing. Being a foundation of STEM system, teachers around the world are increasingly likely to develop soft skills and core competencies in their learners. While many countries have made progress in preparing teachers to support students in STEM, to engage them professionally in project collaboration with each other, a lot of work is still to be done. Teachers introducing STEM need to receive sufficient and appropriate in-service professional development to be equipped with the skills for implementing STEM approach and providing cross-disciplinary working environments.

Nevertheless, a number of challenges for implementing STEM is visible. Lack of motivation and initiative on the part of teachers can be caused by the deficiency in teaching aids and the inconsistency of national curricula and educational programmes with a new type education, which complicates interdisciplinary collaboration in the educational process at school. STEM education research as a national research priority could foster STEM scientific background and give a boost to the appearance of innovative educational experiences that include interdisciplinary approaches to solving "grand challenges". Inconsistency in continuum of education at different levels disrupts the unity of training system in STEM which results in the absence of engaged and networked communities of practice. Private risks can also include undeveloped criteria for assessing student achievement and lack of innovative and accessible measures of learning, shortage in flexible and inclusive learning spaces as well as limited space within the school territory.

The above mentioned challenges mainstream introducing new partnership models within the educational ecosystems, which will promote new forms of direct collaboration between a University and a School including methodological support to teachers through a line of ongoing CPD programs in the field of STEM education, development of supplementary education and the club movement with the focus on STEM, evolving a sustainable system of international events and festivals on technologies and STEM ideas with active engagement of participants from the countries where STEM development is at the initial phase. University in this model is to act not only as a provider of societal and cultural images and environments that promote diversity and opportunity in STEM, but also as a multiplier of innovative products, a resource base with a wide range of material and technical support and an innovative training platform both for teachers and students.

Bearing this in mind, the staff in-training and teacher training in STEM is essential. Questions remain about what constitutes high-quality STEM-training and how it should be delivered in different parts of the world. As this Atlas has shown, a range of efforts are under way. A number of STEM educational programmes at different levels have appeared worldwide. They facilitate teachers' involvement and pooling of resources, bring forth the research, ensure the access to innovative STEM learning experiences.

Students, parents, communities, educational institutions and organizations are the pillars on which to build a favourable environment in support of STEM practices. Key stakeholder groups can be valuable allies but need sufficient information and positive interactions within the paradigm of STEM education. Dialogue among all parties and a

coordinated approach, aligned with national education policies, will result in powerfully transforming all students' access to and engagement in STEM.

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