# Integration of Transdisciplinary STEM Approach to Single Discipline-Based National Education Systems

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## Introduction

The global competition environment requires continuous self-renewal of professions and citizens. For this, countries, sectors, universities, schools, academicians, teachers and students should acquire new knowledge, skills and competences. This requirement can be met by STEM training. STEM is an interactive combination of science, technology, engineering and mathematics. STEM is a transdisciplinary phenomenon. It is multidisciplinary but, much more than a simple sum of these disciplines. STEM is a holistic approach. As in many other countries there are single-disciplinary training system and curriculum in Turkey. In occupations, the situation is a little further. Mechatronics and software development are a good example of this, but not insufficient. The training provided at our K12 schools includes all the elements of STEM, but due to their inadequacy, we remain at the bottom of PISA, TALIS, TIMMS and similar international assessments. The situation is also valid for our universities and faculties. Our universities cannot enter to the upper rank of scientific success and their graduates cannot find a job for employment at national or international markets. On the other hand, with the grant support of the 4000 series programs of TUBITAK's Science and Society Department, hundreds' of STEM projects were being realized eve year at different schools. We are very interested in the efforts of Erasmus + projects on STEM. In these activities, we see that the interdisciplinary STEM projects were conducted by the students and teachers of disciplinary-based national curricula and education system. We feel the hidden walls between the STEM approach and science, physics, chemistry, biology lessons. Mathematic teaching is completely a problem as in all countries. In this digesting article, we will discuss how this interdisciplinary education required by the STEM approach will be adapted to our current discipline education system. For this, the documents were reviewed and the subjects was discussed with the teachers, parents and education faculties during the different STEM activities.

The curriculum is a framework for setting out the aims of a program of education, including the knowledge and understanding to be gained at each stage (intent); for translating that framework over time into a structure and narrative, within an institutional context (implementation) and for evaluating what knowledge and understanding pupils have gained against expectations (impact/achievement).

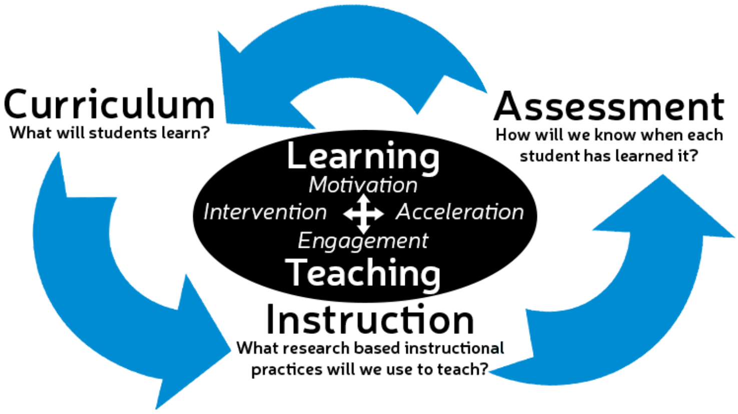


Figure 1. The Interaction of Curriculum, Assessment and Instruction

To understand the necessity pf the STEM approach, we will first summarize the international education and training policies, targets and strategies. The 21st century skills are a set of abilities that students need to develop in order to succeed in the information age, as given in the following diagram.

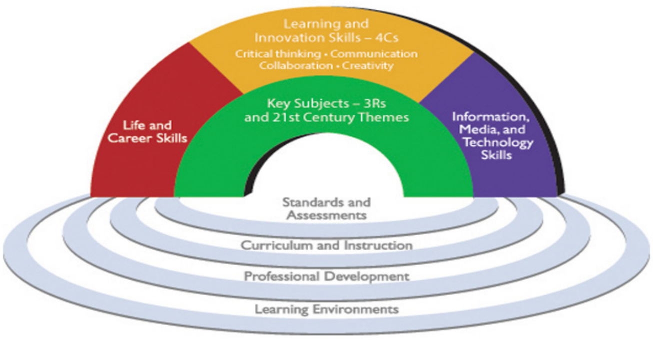


Figure 2. 21st Century Skills

## Sustainable Development Goals

STEM education have an important role and impact in preparation of the pupils for 21st century skills such as complex problem solving, critical thinking, digital literacy and collaboration skills. United Nations defines the fourth goal of sustainable development as quality education.


Figure 3. Sustainable Development Goals by UN

## Eight Basic Competencies

European Commission's Recommendation 2006/962/EC defines the key competences for lifelong learning as follow. Turkey targets this competencies in her national education strategy.

1. Communicating in a **mother tongue**: ability to express and interpret concepts, thoughts, feelings, facts and opinions both orally and in writing.
2. Communicating in a **foreign language**: as above, but includes mediation skills (i.e. summarizing, paraphrasing, interpreting or translating) and intercultural understanding.
3. **Mathematical, scientific and technological competence**: sound mastery of numeracy, an understanding of the natural world and an ability to apply knowledge and technology to perceived human needs (such as medicine, transport or communication).
4. **Digital competence**: confident and critical usage of information and communications technology for work, leisure and communication.
5. **Learning to learn**: ability to effectively manage one's own learning, either individually or in groups.
6. **Social and civic competences**: ability to participate effectively and constructively in one's social and working life and engage in active and democratic participation, especially in increasingly diverse societies.
7. **Sense of initiative and entrepreneurship**: ability to turn ideas into action through creativity, innovation and risk taking as well as ability to plan and manage projects.
8. **Cultural awareness and expression**: ability to appreciate the creative importance of ideas, experiences and emotions in a range of media such as music, literature and visual and performing arts.

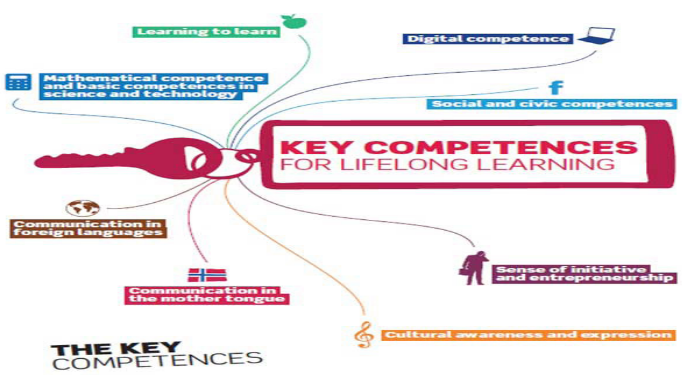


Figure 4. Key Competencies for Lifelong Learning


Figure 5. Students Competencies

## The National Curriculum of MoNE Turkey

In Turkey, there is continuously rising interest in the STEM approach and applications. Public schools, as well as private schools, carry out many STEM practices, seminars, applications, festivals etc. The interest is mostly in secondary and high school level. Science fairs and science olympics by the financial and technical support of the Science and Society Department of TUBITAK highly increased this interest. In many schools coding training was provided and robot competitions were organized. STEM and Maker festivals are held. There is an increase in the number of thesis studies completed and scientific articles published on STEM. Our schools participate in STEM projects within the scope of Erasmus. In the national education curriculum and training strategy, STEM professions, STEM courses and practices was given importance. In addition to science courses technology, design and entrepreneurship courses are offered to students as compulsory or elective. However, we cannot say that the national curriculum and STEM practices and approaches strictly matching. The systematic studies are not sufficient. The national curriculum and the depending textbooks, programs, laboratories, teaching and learning techniques do not encounter the requirements and the needs of the future economy and competitiveness. The effects of single-disciplinary education have been observed in schools and teachers for many years. So, the change from single discipline to transdisciplinary system of education needs some time and huge effort. Each of the teachers of physics, chemistry, biology, mathematics and technology speaks positively about STEM. However, we do not see that teachers from different disciplines come together and do common activities. The laboratories of our schools are insufficient. The capacity of education faculties which are more than 80 all over the Tukey, is not sufficient for the STEM education. No program exists on STEM teacher training in university curriculums. In developed countries, STEM is considered to be a tool for more human resource preparation in engineering. However, the situation is somewhat different in Turkey. STEM subject is considered as a means of improving the quality of education in K12 schools in Turkey.

## HASS and STEM

We may group the sciences as STEM disciplines, CAD (Creative Arts and Design) disciplines, Humanities, Social Sciences. We may call the non-STEM disciplines as HASS (Humanities, Arts and Social Sciences). STEM disciplines have been regarded as the primary source of innovation and competitiveness.

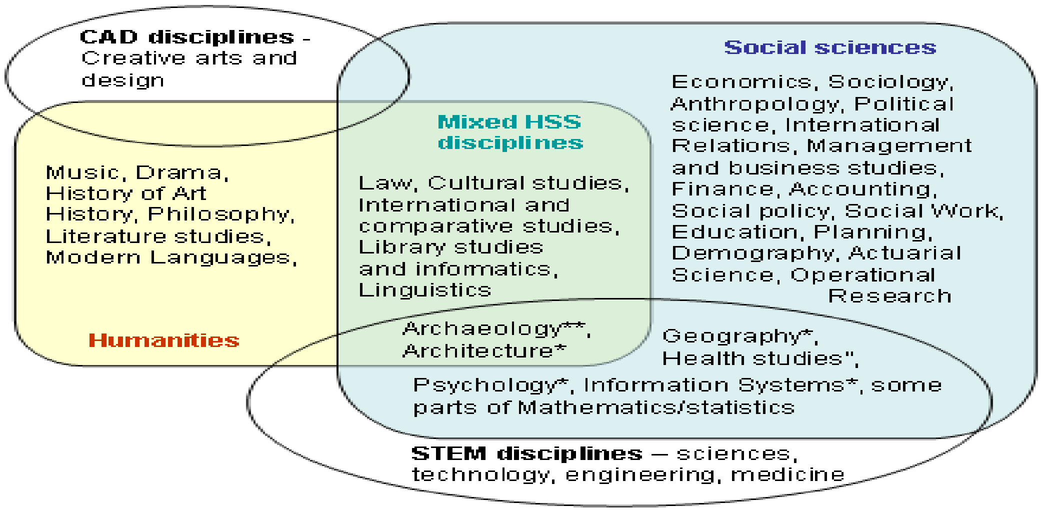


Figure 6. HASS and STEM Disciplines

### Learning Objectives

To understand better the importance of STEM approach, we have to have brief look to the learning domains. The Learning Objectives were classified as cognitive, affective and psychomotor as shown in Figure 7.

- Cognitive domain (intellectual capability, i.e., knowledge, or 'think')
- Affective domain (feelings, emotions and behavior, i.e. attitude, or 'feel')
- Psychomotor domain (manual and physical skills, i.e. skills, or 'do')

Each of the domains were explained at the following table 1. So, you may think on the relations of STEM approach on each domain and steps. STEM and in general, education and training is closely related and interconnected with the world of work. So, we have to look a short look to the international coding system of education. ISCED is also interconnected with ISCO International Code of Occupation.

### International Standard Code of Education

00 Generic programs and qualifications

01 Education

02 Arts and Humanities

03 Social Sciences, Journalism and Information

04 Business, Administration and Law

05 Natural Sciences, Mathematics and Statistics

06 Information and Communication Technologies

07 Engineering, Manufacturing and Construction

08 Agriculture, Forestry, Fisheries and Veterinary

09 Health and Welfare

10 Services

Table 1. Learning Domains and the Instructional Behavioral Term

| | |
|---|---|
| **Cognitive Domain of Learning (mental skills: KNOWLEDGE)** | |
| Remembering | Identify, label, list, recall, recognize, match, name, select, tell |
| Understanding | Classify, compare, contrast, demonstrate, explain, extend, illustrate, infer, interpret, relate, outline, show, summarize, translate |
| Applying | Use, carry out, provide, respond, apply, build, choose, develop, model, organize, select, solve, utilize |
| Analyzing | Analyze, assume, categorize, classify, compare, conclude, contrast, discover, dissect, distinguish, examine, inspect |
| Evaluating | Appraise, assess, award, choose, criticize, defend, disprove, estimate, interpret, judge, rate, support, justify |
| Creating | Create, design, assemble, generate, build, change, choose, combine, formulate, elaborate, modify, compose, invent, improve, predict, plan |
| **Psychomotor Domain of Learning (manual or physical SKILLS)** | |
| Perception | Distinguish, hear, see, smell, taste, touch |
| Set | Adjust, approach, locate, place, position, prepare |
| Guided Response | Copy, determine, discover, duplicate, imitate, inject, repeat |
| Mechanism | Adjust, build, illustrate, indicate, manipulate, mix, set up |
| Adaptation | Adapt, built, change, develop, supply |
| Organization | Construct, create, design, produce |
| **Affective Domain of Learning (growth in feelings and emotional areas: ATTITUDE)** | |
| Receiving | Asks, chooses, describes, follows, gibes, holds, locates, points to, relies, uses |
| Responding | Answers, assists, complies, conforms, greets, performs, practices, presents, recites, reports |
| Valuing | Completes, explains, initiates, invites, joins, justifies, proposes, shares, studies |
| Organization | Adheres, alters, arranges, defends, generalizes, integrates, orders, prepares, relates |
| Characterization | Acts, discriminates, displays, influences, modifies, proposes, qualifies, questions, revises, serves, solves, verifies |

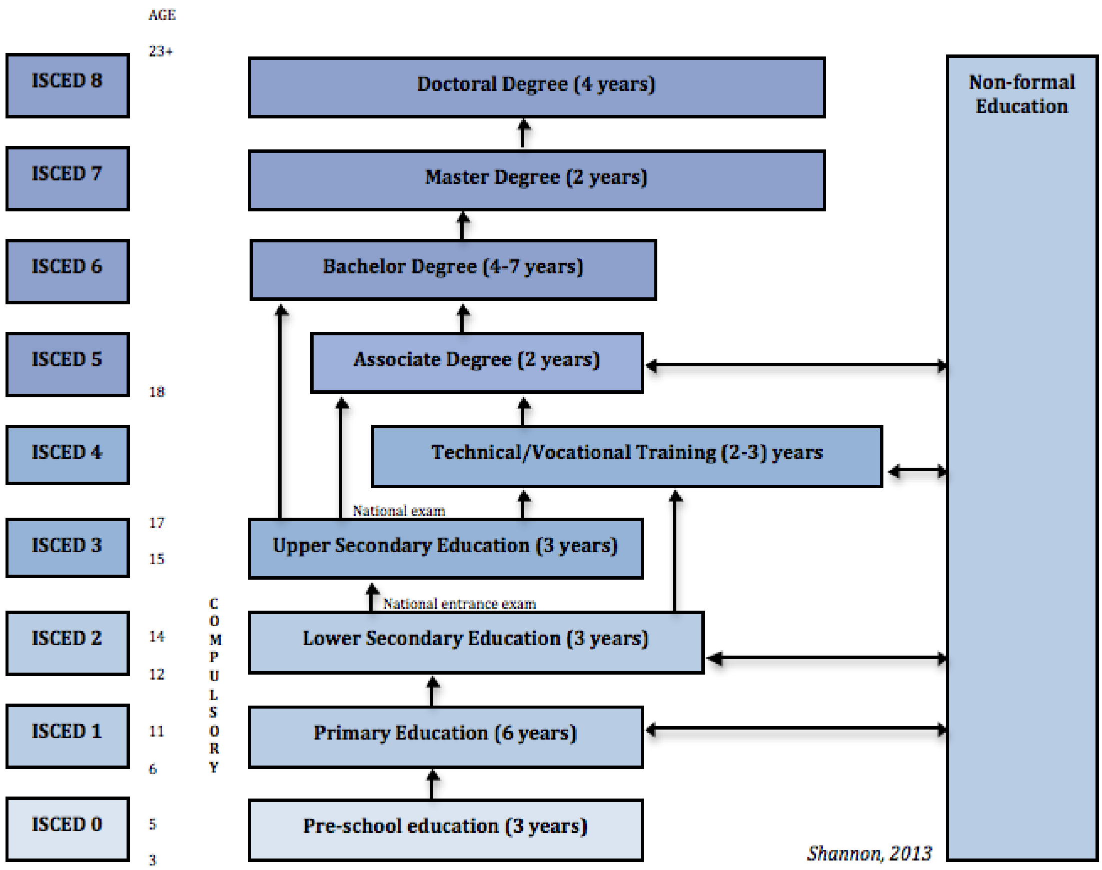


Figure 7. ISCED Codes of Level of Education

## Types of Disciplines

Disciplinarities may be defined as follow over a theme;

- Intradisciplinary: working within a single discipline.
- Crossdisciplinary: viewing one discipline from the perspective of another.
- Multidisciplinary: people from different disciplines working together, each drawing on their disciplinary knowledge.
- Interdisciplinary: integrating knowledge and methods from different disciplines, using a real synthesis of approaches.
- Transdisciplinary: creating a unity of intellectual frameworks beyond the disciplinary perspectives.

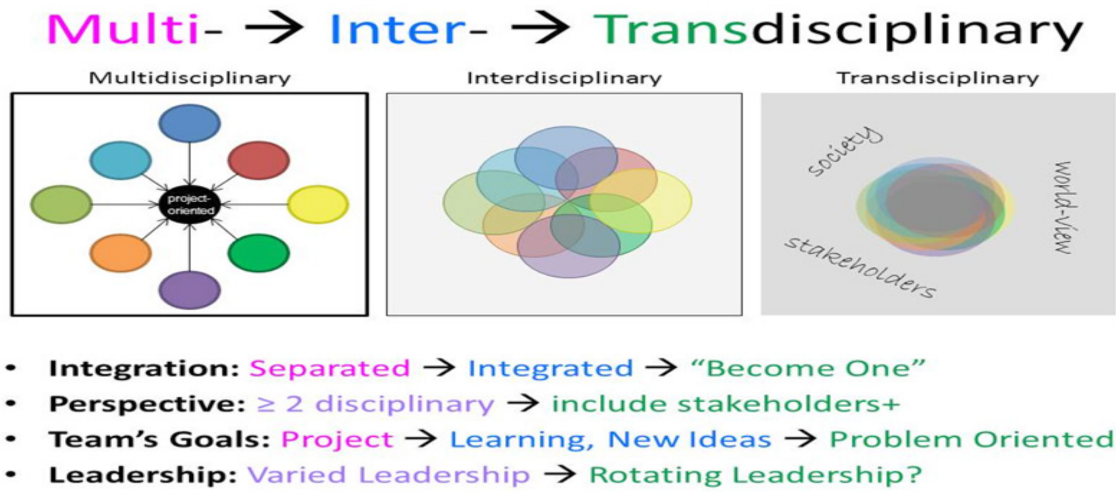


Figure 8: The Order of Disciplines

## Definition of STEM and its primary objectives

STEM includes physical and natural sciences, technology, engineering and mathematics disciplines, topics, or issues including environmental science education or environmental stewardship. The STEM education have one of the followings as a primary objective;

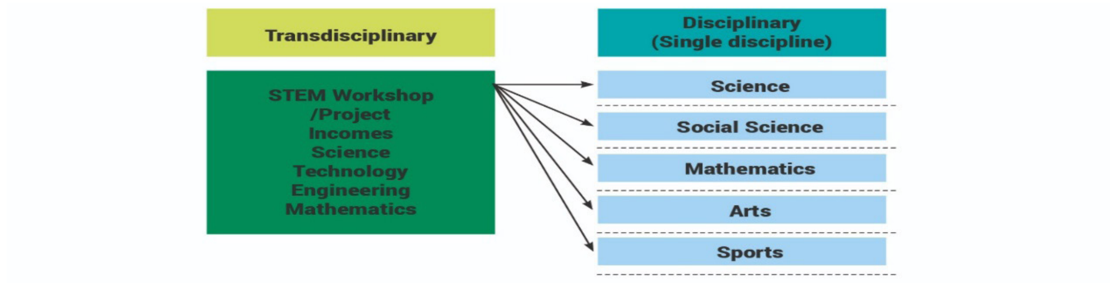


Figure 10. Transdisciplinary Education and STEM Approach

- Learning to develop STEM skills, practices, or knowledge of students or the public.
- Engagement to increase learners' interest in STEM, their perception of its value to their lives, or their ability to participate in STEM.
- Pre- and In-Service Educator or Education Leader Performance to train or retain STEM educators (K– 12 pre-service or in-service, postsecondary, and informal) and education leaders to improve their content knowledge and pedagogical skills.
- Postsecondary STEM Degrees to increase the number of students who enroll in STEM majors, complete STEM credentials or degree programs, or are prepared to enter STEM careers or advanced education.
- STEM Careers to prepare people to enter into the STEM workforce with training or certification (where STEM-discipline-specific knowledge and skill are the primary

focus of the education investment).

- STEM System Reform to improve STEM education through a focus on education system reform.
- Institutional Capacity to support advancement and development of STEM personnel, programs, and infrastructure in educational institutions such as universities, informal education institutions, and state and local education agencies.
- Education Research and Development for the evidence-based STEM education models and practices

STEM approach is not only transdisciplinary but also a holistic approach. It is explained at Figure 11 as the combination of the scientific disciplines, learning theories, learning paradigms and key concepts.


Figure 11. The Holistic Approach and Learning Theories

## STEM Skills

Morrison defined the STEM integration classroom students as problem solvers, innovators, inventors, logical thinkers, capable to understand and develop the skills needed for self-reliance and technological literacy. STEM skills include numeracy and the ability to generate, understand and analyze empirical data including critical analysis, an understanding of scientific and mathematical principles, the ability to apply a systematic and critical assessment of complex problems with an emphasis on solving them and applying the theoretical knowledge of the subject to practical problems, the ability to communicate scientific issues to stakeholders and others, ingenuity, logical reasoning and practical intelligence.

## STEM Integration

It was defined by Moore as the merging of the four pillar disciplines of science, technology, engineering, and mathematics in order to,

- deepen student understanding of each discipline by contextualizing concepts,
- broaden student understanding of STEM disciplines through exposure to socially and culturally relevant STEM contexts,
- increase interest in STEM disciplines by increasing the pathways for students to enter the STEM fields.

STEM integration is an interdisciplinary teaching approach, which removes the barriers between the four disciplines and goes beyond simply blending traditional types of understandings. Jan Morrison at all accepts STEM as a unitary idea, not simply a grouping of the four disciplines in a convenient, pronounceable acronym.

## Blended Learning

STEM is somehow different from the traditional science and mathematics education. STEM is the blended learning environment and showing students how the scientific method can be applied to everyday life. It teaches students computational thinking and focuses on the real world applications of problem solving. As mentioned before, STEM education begins while students are very young and must continue at undergraduate, graduate and lifelong learning levels.

- **Elementary school**: STEM education focuses on the introductory level STEM courses, as well as awareness of the STEM fields and occupations. This initial step provides standards-based structured inquiry-based and real world problem-based learning, connecting all four of the STEM subjects. The goal is to pique students' interest into them wanting to pursue the courses, not because they have to. There is also an emphasis placed on bridging in-school and out-of-school STEM learning opportunities.
- **Middle school**: At this stage, the courses become more rigorous and challenging. Student awareness of STEM fields and occupations is still pursued, as well as the academic requirements of such fields. Student exploration of STEM related careers begins at this level, particularly for underrepresented populations.

- **High school**: The program of study focuses on the application of the subjects in a challenging and rigorous manner. Courses and pathways are now available in STEM fields and occupations, as well as preparation for post-secondary education and employment. More emphasis is placed on bridging in-school and out-of-school STEM opportunities.

## Some Countries' STEM Strategies

The educational systems of all countries naturally are the ones which may be remedied as it continue. Due to nature of education, there is no chance for countries to stop the education system, wait for designing a new one and to start again with a new program or curricula. So educational strategies must be determined so that its actions will adapt the existing cases and members to the ones as the education and training goes on.

The STEM Strategy of USA started 30 years before to keep itself as the most competitive in the global economy. The National Science Board (NSB) report titled as the Undergraduate Science, Mathematics and Engineering Education in 1986 was the first U.S. policy guidance document on STEM education. Strategies for Revitalizing Undergraduate Education in 1996, American Competitiveness Initiative in 2006 and Change the Equation in 2010 and STEM 2026 was the update of policy documents. As an action, the followings qualitative and quantitative targets was planned to realize;

- Improve STEM Instruction: Prepare 100,000 excellent new K-12 STEM teachers by 2020, and support the existing STEM teacher workforce;

- Increase and Sustain Youth and Public Engagement in STEM: Support a 50 percent increase in the number of U.S. youth who have an authentic STEM experience each year prior to completing high school;

- Enhance STEM Experience of Undergraduate Students: Graduate one million additional students with degrees in STEM fields over the next 10 years;

- Better Serve Groups Historically Under-represented in STEM Fields: Increase the number of students from groups that have been underrepresented in STEM fields that graduate with STEM degrees in the next 10 years and improve women's participation in areas of STEM where they are significantly underrepresented;

- Design Graduate Education for Tomorrow's STEM Workforce: Provide graduate-trained STEM professionals with basic and applied research expertise, options to acquire specialized skills in areas of national importance, mission-critical workforce needs for the CoSTEM agencies, and ancillary skills needed for success in a broad range of careers.

## Some of the STEM Programs at USA

Many programs were started at USA to integrate STEM to schools. Some of them are the followings;

- The Programs with Primary STEM Emphasis
- Math Science Partnerships
- Teacher Incentive Fund - STEM
- RESPECT and the STEM Master Teacher Corps
- Minority Science and Engineering Improvement Program
- Hispanic Serving Institutions STEM and Articulation Programs
- Fund for the Improvement of Education – K-16 Math Initiative
- Upward Bound Math and Science Program
- National Science and Mathematics Access to Retain Talent Grant Programs
- Research Programs with Primary STEM Emphasis
- Mathematics and Science Education
- Education Research Grants—Effective Teachers and Effective Teaching Topics
- Education Technology
- Special Education Research Grants—Professional Development for Teachers
- Mathematics and Science Education: Special Education Research
- Technology for Special Education
- Programs with STEM Grantee Selection Priority:
- Race to the Top
- Investing in Innovation
- 21st Century Community Learning Centers
- National Professional Development Program
- Supporting Effective Educator Development

- Transition to Teaching
- Teacher Quality Partnership
- Magnet Schools Assistance
- Advanced Placement Incentive Program
- Fund for the Improvement of Postsecondary Education
- Predominately Black Institutions
- Teachers for a Competitive Tomorrow
- Graduate Assistance in Areas of National Need
- Ronald. E. McNair Post-baccalaureate Achievement Program
- Master's Degree Programs at Historically Black Colleges and Universities
- General Programs that Support STEM Education:
- ESEA Flexibility
- Career and Technical Education: Basic Grants to States
- Trade Adjustment Assistance Community College and Career Training Grants
- Small Business Innovation Research
- U.S. Department of Education Green Ribbon Schools

## EU Strategy for STEM

European Commission highly supports the integration of STEM to pre-school, K12 and university mainly by the ERASMUS+ program. Really, the EU needs STEM skilled human sources to reach the EU2030 goals and to rise its competitiveness. STEM Alliance and SCIENTIX are the most important tools of the European Commission on STEM.

## China STEM Strategy

China Office of the State Council issued The Chinese STEM Action Plan in 2016. The plan support the horizontal cooperation among disciplines and conducting interdisciplinary practice and inquiry activities in secondary school. Educational Informatization Planning in 13th Five-Year issued by China Ministry of Education explores the application of information technology in new education modes such as Maker Space, Interdisciplinary

Learning and Maker Education, enhancing students' information literacy, innovative awareness, innovative ability and digital learning habits. Full-time compulsory education primary school science curriculum standards in 2017 stated that science education should start from real situations that help students take the initiative to learn. Science education should encourage students to study actively. Students should be endowed with personality to continuously improve their inquiry skills. The standards also point out that science is closely related to other subjects and advocate interdisciplinary learning, namely STEM education. In this condition, Primary and secondary general practice curriculum guidelines suggests four types of activities: investigation and inquiry, community service, design and production, professional experience. In 2001, Student Research Program was launched in all over the country, listed the high school compulsory curricula. Different models have been developed in the Chinese curriculum. As it can be seen in the table given below, the main discipline of biology is chemistry. The other disciplines i.e. technology, mechanics, informatics can support the discipline of biology. In the second model, a discipline can be combined with disciplines such as AI or MM. The third model is the merge of more than three disciplines.

Table 2. STEM Models in Chinese Curriculum

| Model | Couple A+B | Star A + X | NESTED Multidiscipline 'A+B+C' |
|---|---|---|---|
| Field | Biochemistry<br>Biotechnology<br>Biomechanics<br>Bioinformatics<br>Social psychology<br>Geography VR Design | Artificial Intelligence<br>Mathematical Modeling | Computing and visualization<br>Robotics<br>Technology and Design<br>Virtual Reality<br>Digital Image Processing and Pattern Recognition<br>Traditional Handicraft<br>UAV Science and engineering<br>UAV Technology Innovation Practice<br>Mechatronics<br>Space Science<br>Aerospace<br>Computer Vision and Deep Learning<br>Electronic and Information Engineering<br>Information and Communication Engineering |

## German STEM Strategy

The STEM education in Germany was as called MINT (Mathematik, Informatik, Naturwissenschaft und Technik) which was connected with vocational education.

MINT offer special curriculum, program and scholarship for the talented youth through extracurricular school lab collaboration.

## Australian STEM Strategy

The Australian federal government decided on a new policy National Innovation and Science Process in 2015 and the board of education accepted National Science, Technology, Engineering and Mathematics School Education Strategy 2016—2026. The universities and industries to create online demonstration modules for STEM teaching practices. They also establish STEM career learning exchange platforms.

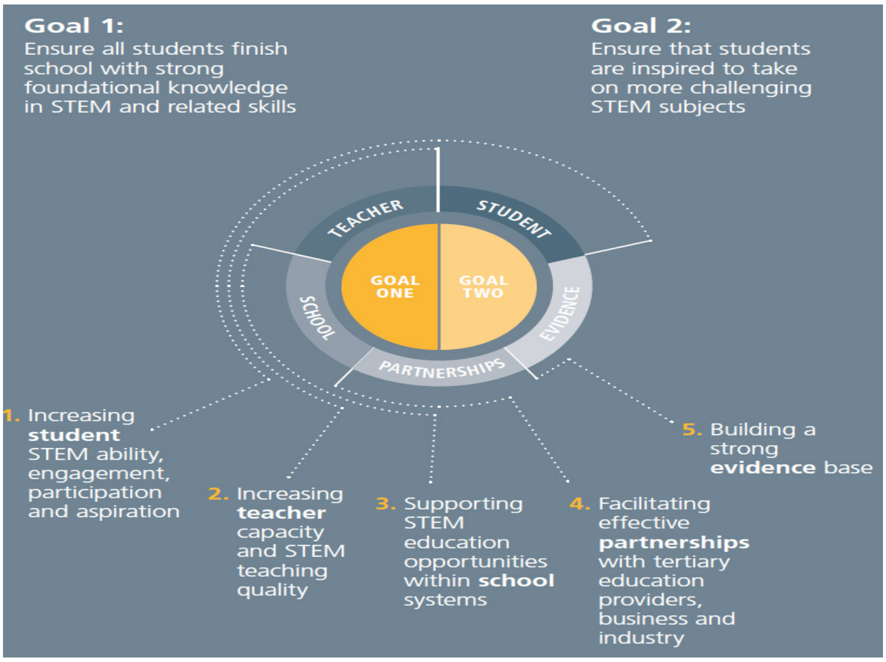


Figure 12. The Goals of STEM Strategy of Australian Education System

## STEM in Russia

When the communist regime in Russia came to an end in 1991, the education system was very strong in technology and engineering. Mathematics was compulsory in all areas. With the transition to the free market economy, the new job opportunities were arising outside the STEM. High wages were given to these areas as there were not enough human resources. Thus, young people started to focus mainly on service sectors such as banking, marketing etc. more than STEM areas. This led to a weakening of the STEM area in Russia. However, Russia is at high rank in international classifications like PISA. There is not enough literature about the Russia's STEM activities.

## Turkey STEM Strategy

The rapid change in science and technology, the changing needs of the individual and the society, the innovations and developments in the teaching theory and approaches of learning have directly affected the roles expected from the individuals. This change defines the individual who produces knowledge, can use functionally in life, can solve problems, think critically, have entrepreneurial, stable, communicate skills, empathy, contribute to society and culture. The educational programs that will serve to educate individuals with this qualitative texture are prepared in a simple and understandable manner, which takes individual differences into consideration rather than a structure that conveys information. For this purpose, it is aimed to repeat the achievements and explanations with a helical approach at different subject and class levels on the one hand, and the learning outcomes that are aimed to be acquired holistically and at once. The acquisitions and explanations in both groups are competent, up-to-date, valid and relevant to life. These achievements and explanations, which define their boundaries, point to a simple content from a perspective that provides integrity in the perspective of values, skills and competences at the level of classes and levels of education. Thus, a total of integrated curricula has been established around the values, skills and competencies associated with other disciplines and daily life, which lead to the use of metacognitive skills, provide meaningful and permanent learning, are associated with solid and prior learning. For realizing this targets, the teachers and school principal have a critical role. The function of teacher with single discipline system of curricular was changed importantly in the transdisciplinary system

STEM integration classroom students are not only classical one but also should be able to perform as problem solvers, innovators, inventors, logical thinkers, able to understand and develop the skills needed for self-reliance and technological literacy. The student also explores the engineering as a discipline and the engineering design cycle, mathematical connections to engineering design cycles lessons, exploring mathematical thinking through model-eliciting activities, integrating technology to enhance learning of science, engineering, and mathematics, orchestrating student discussions around STEM concepts. The education and training of the student is no more limited with the school and classroom. Out of school learning have more share now than ever before.

## Conclusion and Recommendations

The List of STEM Curriculum Articles indexed in ERIC Database gives 1.528 articles. The number of Erasmus+ projects on STEM is more than . TUBİTAK supports STEM projects of more than 6.000 schools per year. Robotics, coding, maker etc. training is expanding at university and K12 school levels. But, STEM activities are not sufficient and sustainable yet in Turkey. Content integration and context integration of STEM activities with national curriculum is not sufficient.

We may offer the following precautions for the integration of national curriculum to STEM for supporting the competitiveness of Turkey.

- Change of mind and understanding the STEM at all levels of the national education system,
- Integration of national curriculum and programs to the STEM approach.
- Integration of assessment and other regulations to STEM applications
- Integration of in-service teacher training programs to STEM requirements
- Integrate the curriculum of education faculties in training of teachers
- Integration of school principals and teachers for conducting STEM projects.
- Develop STEM Leaders at school.
- Integration of textbooks to STEM
- Donation of the laboratories with STEM equipment
- Integration of parents and students who are highly interested in STEM disciplines
- Content integration and context integration of STEM activities with national curriculum must be realized as soon as possible.

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