Promoting STEM Education for All Students

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The American Association for the Advancement of Science (AAAS) reports *Project 2061: Science for All Americans* (1989) and *Benchmarks for Science Literacy* (1993) as well as the National Research Council (NRC, 1996) in the *National Science Education Standards* (NSES) emphasize the importance of science and technology. These social aspects of science and technology are a form of content for K-12 science. The Standards state that, "a person should be able to identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed" (NRC, 1996, p.22). These reports also describe the relationship among science, technology, and society. "Science and technology are closely related. A single problem often has both scientific and technological aspects (NRC, 1996, p.24). The AAAS Benchmarks also state that "Technology usually affects society more directly than science because it solves practical problems and serves human needs. Science affects society mainly by stimulating and satisfying people's curiosity and occasionally by enlarging or changing their views of what the world is like" (AAAS, 1993, p. 45).

The National Science Education Standards also emphasize a goal that students should achieve scientific literacy, which is defined as the knowledge and understanding of scientific concepts needed for daily living. The National Science Teachers Association declares that a scientifically literate person is one who can ask and determine answers to questions derived from curiosity about everyday life experiences (NSTA, 1996). Rutherford and Ahlgren, authors of Science for Americans, state that " the world has changed in such ways that scientific literacy has become necessary for everyone, not just a privileged few; science education will have to change to make that possible" (AAAS, 1993; Hollenbeck 2003). Bybee (1993) suggests that students should learn basic concepts of science, process, and problem-solving skills, and the interactions of STS as they apply their knowledge to real-life concerns and issues (Lumpe, Haney & Czerniak, 1998).

Scientific literacy enables people to not only use scientific principles and processes in making personal decisions but also enables them to participate in discussions about scientific issues that affect society. Scientific literacy increases many skills that people use in everyday life, like being able to solve problems creatively, thinking critically, working cooperatively in teams, and using technology effectively. Understanding scientific knowledge and processes contributes in essential ways to developing these skills. The economic productivity of society is related to the scientific and technological skills of the people. However, achieving scientific literacy will take time, because the

National Science Education Standards call for dramatic changes in what students are taught, how student performances are assessed, how teachers are educated and stay current, and the complex relationships between school and community (NRC, 1996). Ramsey (1993) suggests that there is a relationship between scientific literacy and social responsibility. Merely memorizing facts for a science test is not sufficient in a world in which background of scientific and technologic knowledge is imperative for making decisions on personal, community, national and global levels.

A focus on the relationship among science, technology, and society is essential for achieving basic science literacy. Students, the next generation, need to be able to analyze evidence, to understand the relevance of science based issues to their everyday lives, and to understand that the scientific endeavor is governed by social values (NRC, 1996; deBettencourt, 2000). Seventeen features are identified by NSTA to define quality of scientifically literate person. These features include being able to:

- Use concepts of science and of technology as well as an informed reflection of ethical values in solving everyday problems and making responsible decisions in everyday life, including work and leisure;
- Engage in responsible personal and civic actions after weighing the possible consequences of alternative options;
- Defend decisions and actions using rational arguments based on evidence;
- Engage in science and technology for the excitement and the explanations they provide;
- Display curiosity about and appreciation of the natural and human-made world;
- Apply skepticism, careful methods, logical reasoning, and creativity in investigating the observable universe;
- Value scientific research and technological problem solving;
- Locate, collect, analyze, and evaluate sources of scientific and technological information and use these sources in solving problems, making decisions, and taking action;
- Distinguish between scientific/technological evidence and personal opinion and between reliable and unreliable information;
- Remain open to new evidence and the tentativeness of scientific/technological knowledge;
- Recognize that science and technology are human endeavors;
- Weigh the benefits and burdens of scientific and technological development;

- Recognize the strengths and limitations of science and technology for advancing human welfare;
- Analyze interactions among science, technology, and society;
- Connect science and technology to other human endeavors, e.g., history, mathematics, the arts, and the humanities;
- Consider the political, economic, moral, and ethical aspects of science and technology as they relate to personal and global issues;
- Offer explanations of natural phenomena which may be tested for their validity (NSTA, 1990).

Scientific Literacy

Scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity. In the National Science Education Standards, the content standards define scientific literacy as following; scientific literacy means that a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a person has the ability to describe, explain, and predict natural phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it. Scientific literacy also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately (NRC, 1996)

Scientific literacy is important for two views. The first one is macro view that promotes scientific literacy that includes benefits to national economics, science itself, science policymakers, and democratic practices, as well as to society as a whole. Second one is micro view that turns to the direct benefits of scientific literacy to individuals, it has been suggested that improved understanding of science and technology is advantageous to anyone living in science and technology dominated society.

Bybee (2013) clearly articulates that the overall purpose of STEM education is to further develop a STEM literate society. His definition of "STEM literacy" refers to an individual's:

- Knowledge, attitudes, and skills to identify questions and problems in life situations, explain the natural and designed world, and draw evidence-based conclusions about STEM-related issues.
- Understanding of the characteristic features of STEM disciplines as forms of human knowledge, inquiry and design;
- Awareness of how STEM disciplines shape our material, intellectual, and cultural environments; and
- Willingness to engage in STEM-related issues and with the ideas of science, technology, engineering and mathematics as a constructive, concerned, and reflective citizen." (p.101).

What is STEM education and why do we need it?

Although STEM education have attracted attentions of thousands of researcher from all over the world recently, it has its origins in 1990s (Bybee, 2013). There are different views about it. In their study, Breiner and colleagues (2012) found that there is not certain definition or conceptualization of STEM even among faculty members. Whereas some part of researcher think that STEM education occurs when integrating science, technology, engineering and mathematic curriculums to familiarize students about how scientists and engineers work in their real context, some other advocate that the goal of STEM education is to direct students into sub-branches of it in order to have qualified scientists and engineers in the future and to be competitive among developed and developing countries (Breiner, Harkness, Johnson & Koehler, 2012). In general, it can be said that STEM education enables students to produce products through multidisciplinary knowledge. STEM education is the intentional integration of science, technology, engineering, and mathematics, and their associated practices to create a student-centered learning environment in which students investigate and engineer solutions to problems, and construct evidence-based explanations of real-world phenomena with a focus on a student's social, emotional, physical, and academic needs through shared contributions of schools, families, and community partners.

There are two main ideas behind STEM education, one of which is about political and societal reasons and the other one is educational deficiencies. In political and societal perspective, nations need an innovative STEM workforce to be competitive in the 21st century (Corlu, Capraro & Capraro, 2014, p. 75). When the US realized this fact, they launched the STEM project more accurately. Innovations in science and technology will give rise to be competitive for countries in this century and one of the major ways for such innovations seems as educating students through STEM education. The National Academies of Sciences, Engineering and Medicine (2011) state that innovations in science and technology mainly results of developments in science, technology, engineering and mathematics. In another report published by the Committee on Prospering in the Global Economy of the 21st century (2007), it is stated that for the nation's welfare and well-being, STEM skills should be focused much more and three major advices were published in the report. These are (1) augmenting the number of successful students in science and mathematics at K-12 level through developing teaching strategies for that level, (2) supporting the projects about security and quality of life and (3) increasing the prompts for innovation (Committee on Prospering in the Global Economy of the 21st century, 2007). There are a lot of reports (e. g. U.S. Commission on National Security/21st Century, 2001) which emphasize that focusing on science, technology and mathematics are crucial for economic growth, the nation's development and security and competitiveness among other developed and developing countries.

In terms of educational deficiency viewpoint, in traditional teaching approaches it is common to teach the subjects separately. In other words, there is less emphasis on the connections among disciplines. In STEM education, the important concept is 'integration'. Integrating science, technology, engineering and mathematics is vital cornerstone of it. For instance, an engineer needs different scientific disciplines knowledge and mathematics and technology information in order to produce highly qualified engineering designs (Breiner et al., 2012). This can be achieved by STEM education easily, which requires integration of various disciplines. This lack of integration in traditional teaching approaches necessitated STEM education as a powerful approaches in educational context. The following tables identify several points of contrast between STEM-based program and standard (traditional) science programs concerning goals, instruction, teacher, students and evaluation. Table 1 indicates the differences between STEM-based program and traditional science program in terms of the goals of science education.

Table 1. Contrast between STEM-based and Traditional Classrooms –Goals

STEM-Based Classrooms	Traditional Classrooms
Curriculum is problem-centered, flexible, and culturally as well as scientifically valid Multifaceted questions used as organizers, often with local and community relevance Use of natural environment, community resources, and students themselves as part of the study Information is in the context of the student as a person in cultural/social environment	Curriculum is textbook-centered, inflexible; only scientific validity is considered Textbook controlled; student questions often ignored because the course structure is set Contrived materials, kits, classroom bound resources Information is the context of the logic and structure of the disipline

Table 2 indicates the differences between STEM-based program and traditional science program in terms of the instructional model of science education

Table 2. Contrast between STEM-Based and Traditional Classrooms-Instruction

STEM-Based Classrooms	Traditional Classrooms
Student centered Individualized and personalized, recognizing student diversity Cooperative work on problems and issues Students are considered in instruction (active partners) Teachers build on student experiences, assuming that students learn only from their own experiences	Teacher centered Some group work, primarily in the laboratory, following textbook directions Students seen as recipients of instruction Teachers ignore students in terms of what they might bring to the instructional process; use information assumed to follow rote learning

Table 3 indicates the differences between STEM-based program and traditional science program in terms of the role of science teachers.

Table 3. Contrast between STEM-Based and Traditional Classrooms- Teachers

STEM-Based Classrooms	Traditional Classrooms
Teachers are seen as model learners Teachers exercise freedom to stimulate student interest and involvement Teachers have a well-thought out research based rationale for teaching science Philosophical position influences all aspects of curriculum planning and teaching practices	Teachers are seen as disseminators of information Teachers see their role as delivering content and determining the exact structure of their courses Teachers typically do not have a research based rationale for teaching science Curriculum and teaching practices generally routine

Table 4 indicates the differences between STEM-based program and traditional science program in terms of the role of students in science classroom

Table 4. Contrast between STEM-Based and Traditional Classrooms- Students

STEM-Based Classrooms	Traditional Classrooms
Students are at the center of classroom Students are more active, involve in real life problem solution Students can transfer their learning to their daily living and to meeting social needs Students extend the classroom activities outside the school Students indicate interest Students question more; student question used	Students are recipients of what the teachers dictates Students involved in directed activities unrelated to their own lives There is no demonstration of the use of information taught and learned outside the classroom Students rarely practice or think science outside the science classroom Student express lack of interest in science classes Students questions less; student questions often ignored

Table 5 indicates the differences between STEM-based program and traditional science program in terms of the student evaluation in science classes.

Table 5: Contrast between STEM-Based and Traditional Classrooms- Evaluation

STEM-Based Classrooms	Traditional Classrooms
Testing and evaluation stress the use of concepts and processes to interpret personal and social problems and issues Student evaluation is based on growth in rational decision-making Creativity skills and positive attitudes are stressed and used for assessment	Starting correct solutions to preplanned problems is focus Application is rarely approached in teaching and evaluation Typical assessments do not facilitate development of creativity skills nor positive attitudes Assessment is often provided by external examiners or by textbook authors

Why do we need STEM?

Integrated education, such as STEM, has enormous benefits for students (Stohlmann, Moore & Roehrig, 2012). It has an impact on students' problem solving skills, develops higher order skills and support deep understandings (c.f. Stohlmann et. al, 2012). Specifically, STEM education enables learner to be innovative and problem solver, logical thinkers, to use technology appropriately and effectively (Morrison, 2006). In their study, Basham and Marino (2013) state that STEM learning forces students to use higher order thinking skills instead of lower ones such as calling knowledge in a simple form. Out of the effects of STEM education on students' cognitive skills, the other crucial acquisition of it is that it enables students to get familiar with and to experience engineering design, which is important for developing solutions about the problems in society (Basham & Marino, 2013) such as air pollution, traffic jam and so on. Bybee (2013) summarizes four main points between STEM education and other educational approaches. These are

- Addressing global challenges that citizens must understand
- Changing perceptions of environmental and associated problems
- Recognizing 21st century workforce skills
- Continuing issues of national security (Bybee, 2013, p. 33).

To sum up, STEM education tries to find solutions for problems mainly related with real life context-based issues. It is believed that educating learners based on this approach, and then the nation's welfare and competitiveness will increase in international context. The reasons behind this view are that STEM education help students to develop their higher order skills, creativity and understandings.

How do we integrate STEM in schools / How do we prepare STEM curriculum?

Project based learning and inquiry learning might be two main teaching methods in STEM curriculum. In such learning environments, curriculum materials should be appropriate with the teaching methods (Baran, Canbazoğlu-Bilici & Mesutoğlu, 2015). The crucial point is that enabling students to act as real scientists such as generating products through discovery learning techniques.

One of the efficient ways to provide STEM education in schools is that increasing usage of information technologies (Ministry of National Education, 2016). MNE (2010) launched FATIH project (Action of Enhancing Opportunities and Improving Technology) and encouraged teachers to use EBA (Educational Informatics Network). Both of them provided interactive boards, internet connection and tablet computer for students and teachers. The importance of technology enhanced learning environments can be explained that it provides opportunities like problem determining to research, data collection and analyze, product development and creating new inventions and designing innovations (MNE, 2016). On the other hand, usage of information technologies also provides opportunities for everyone in the classroom, which is important for promoting STEM education for all students. In the report published by MNE (2016) summarizes the importance of technology enhanced learning environments in STEM education as following:

- Facilitating STEM education which is based on questioning, researching, product development and inventing,
- Providing an environment to students independent from time and location for STEM education,
- Supporting STEM education by using digital multimedia laboratory materials,
- Providing equal opportunities in STEM education for children at socioeconomically low and high background, and
- Helping students to learn with lesson activities based on questioning, researching, product development and inventing (NME, 2016, p. 54).

Furthermore teaching coding in computer systems is another crucial step in STEM education for students in order to development technologically developed products.

All these need highly educated teachers to reach the goals through STEM education. For this reason, universities and NME should increase the collaboration for helping teachers to get familiar with usage of technology in classrooms in terms of pedagogic approaches. For example, in US, there are high collaborations between universities and the primary, middle or high schools to develop and apply qualified STEM curriculums (Stohlmann, Moore & Roehrig, 2012).

Conclusion

Although STEM education has roots from last decade, it attracted scholars' attention mainly in the last 10 years. The primary reason of being popular in recent term is usually related with U.S policies. In other words, to have competitive generations in future among developed or developing countries, it is believed that STEM education helps learners in order to be innovative, problem solver, designer and producer. There have been conducting many researches, which usually concluded with supporting the view. Students, who expose to multi-disciplined teaching approach, like STEM gives better result when compared to their counterparts in terms of productivity, innovative outcomes and accomplishment. Such findings also supported STEM education to be used in different regions and countries.

In other respect, it is important to provide equal opportunities for students so as to take advantage of STEM education abundantly. One of the efficient ways is that using information technologies in the classrooms. Technology enhanced learning environments enable learners and teachers to determine problem, data gathering and analyzing, visualization and designing easily. Information technologies also serve as time and location independence.

The other crucial point in STEM education is that teacher education. Because of the fact that teachers are mainly responsible for teaching in the classroom, it is vital to have qualified teachers in terms of STEM education. Teachers should be aware of integration of different disciplines through teaching process and should act as guidance in the classroom. In order to help teachers, universities and schools should increase collaboration and teacher should be supported through workshops and in-service teacher education activities.

References

American Association for the Advancement of Science (AAAS) (1990). *Science for All Americans*. New York: Oxford University Press.

American Association for the Advancement of Science (AAAS) (1993). *Benchmarks for Science Literacy: A Project 2061 Report.* New York: Oxford University Press.

American Association for the Advancement of Science (1989). *Project 2061: Science for all Americans*. Washington, DC: American Association for the Advancement of Science.

Baran, E., Canbazoğlu-Bilici, S. & Mesutoğlu, C. (2015). Fen, teknoloji, mühendislik ve matematik eğitimi (FeTeMM) spotu geliştirme etkinliği [Science, technology, engineering and mathematics (STEM) public service announcement (PSA) development activity]. *Araştırma Temelli Etkinlik Dergisi (ATED), 5*(2), 60-69.

Basham, J. D. & Marino, M. T. (2013). Understanding STEM education and supporting students through universal design for learning. *Teaching Exceptional Children, 45*(4), 8-15.

Breiner, J. M., Harkness, S. S., Johnson, C. C. & Koehler, C. M. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics, 112*(1), 3-11.

Bybee, R. W. (1993). Reforming science education: Social perspectives and personal reflections. New York, NY: Teachers College Press.

Bybee, R. W. (2013). *The Case of STEM Education: Challenges and Opportunities*. Arlington, VA: NSTA Press.

Committee on Prospering in the Global Economy of the 21st Century (2007). *Rising Above the Gathering Storm: Energizing and Empowering America for Brighter Economic Future.* Washington, DC: The National Academies Press.

Corlu, M. S., Capraro, R. M. & Capraro, M. M. (2014). Introducing STEM education: Implications for educating our teachers for the age of innovation. *Education and Science, 39*(171), 74-85.

deBettencourt, K.B. (2000). Science technology society and the environment: Scientiic literacy for the future. In Kumar,D.D. and Chubin, D.E. (eds.), Science Technology and Society A Sourcebook on Research and practice. (pp. 141-164). New York, NY: Kluwer Academic Publishers.

Hollenbeck, J. E. (2003). Using a Constructivist Strategy and STS Methodology To Teach Science with the Humanities.

Lumpe, A. T., Haney, J.J. & Czerniak, C. M. (1998). Science teachers beliefs and intensions to implement Science-Technology-Society (STS) in the classroom. Journal of Science Teacher Education, 9, (1), 1-24.

Ministry of National Education (MNE) (2010). FATİH projesi [FATIH project]. Retrieved from http://fatihprojesi.meb.gov.tr/

Ministry of National Education (MNE) (2016). STEM eğitim raporu [STEM education report]. Retrieved from http://yegitek.meb.gov.tr/www/meb-yegitek-genel-mudurlugu-stem-fen-teknoloji-muhendislik-matematik-egitim-raporu-hazirladi/icerik/719

Morrison, J. (2006). *TIES STEM Education Monograph Series: Attributes of STEM Education.* Baltimore, MD: TIES.

National Academies of Sciences, Engineering & Medicine (2011). *Rising above the gathering storm revisited: Rapidly approaching category 5: Condensed version*. Washington, DC: The National Academies Press.

National Research Council (NRC). (1996). National science education standards. Washington, DC: National Academic Press.

National Science Teacher Association (1990). Science/Technology/Society: A New Effort for Providing Appropriate Science for All (Position Statement) In NSTA Handbook. 47-48.

Ramsey, J. (1993). The science education reform movement: Implication for social responsibility. Science Education, 77,2, 235-258.

Stohlmann, M., Moore, T. J. & Roehrig, G. H. (2012). Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering Education Research (J-PEER), 2*(1), 28-34.

U.S. Commission on National Security/21st Century. (2001). Road map for national security: Imperative for change. The Phase III report of the U.S. Commission on National Security/21st Century, Washington, DC.

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