STEM Education Dimensions: from STEM Literacy to STEM Assessment

Ismail Donmez
Mus Alparslan University

Introduction

Social and economic development requires an education system to provide young people with the skills and abilities that enable them to benefit from the emergence of new forms of social and economic development in order to contribute their knowledge to the system's core assets (Techakosit & Nilsook, 2016). The importance of education in STEM disciplines is a matter of debate among policymakers and scientists. Researchers focus on how to encourage educational research on problems and practices, and how to accelerate change in educators' pathways. While Policymakers make demands for STEM education to meet the expected workforce (Bybee, 2013; National Research Council [NRC], 2011; Becker & Park, 2011; Alberts, 2013). In order to serve this purpose, there is a considerable interest towards the research and development of content with regard to K-12 that includes the curriculum, learning environment, career development and the embracement of teachers. This interest in STEM education reaches more than 450 million items with a simple Google search that includes the terms "STEM", "STEM education" or "STEM education research". Such a voluminous search shows that STEM education is a rapidly developing and vibrant field (Li et al., 2020). There are many studies that show STEM education contributes to students in various ways such as attitude, motivation and interest. However, STEM education has no equivalent as a separate course such as science and mathematics, this has led to confusion about which of the concepts constituting STEM should be more dominant (Ejiwale, 2013). Researchers have interpreted the integration between different disciplines of STEM differently using various terms such as multidisciplinary, interdisciplinary and interdisciplinary (Vasquez, Sneider & Comer, 2013). However, these have led to uncertainty and complexity in explaining and determining what constitutes STEM (Li et al., 2020). Many authors have prepared activities for STEM education over time, but it is another discussion about which activity exactly reflects STEM education in the best and most correct way. Since STEM education does not have a direct counterpart in terms of science or mathematics, teachers who want to carry their STEM education practices to their classes feel insecure (Ford, 2007). Therefore, the dimensions of STEM education need to be redefined.

To define STEM education, STEM literacy, STEM curriculum and content, STEM learning environments, STEM professional development and STEM assessment steps need to be defined. In education, first of all, goals and expectations should be defined.

Every society defines the educational expectations by focusing on the demands of both the educators and politicians and the expectations of the society (Skinner, Saxton, Currie, & Shusterman, 2017). The expectation in STEM education is that students become STEM literate and develop their problem-solving skills. For the teaching of these skills, the STEM curriculum and its contents need to be created first. Most educators want to enrich STEM activities without a curriculum and content. However, it would be a futile expectation to expect STEM to reach its goals without the STEM curriculum and content (Scaramozzino, 2010). Therefore, STEM curriculum and its contents will increase teachers' trust in STEM education and facilitate classroom practices. The curriculum should be structured around the current problems in order to meet the expectations of educators and policymakers. After the curriculum is completed, teachers need to be made competent in this field. Unless teachers are competent and well-equipped in STEM fields, practices cannot be expected to achieve their goals. A learning environment is needed for the implementation of STEM activities. The learning environment must meet expectations with psycho-social, infrastructure-equipment, space and time dimensions. After all these stages are implemented, teaching activities and teaching practices should be evaluated. it should not be forgotten that these dimensions interact with STEM components..

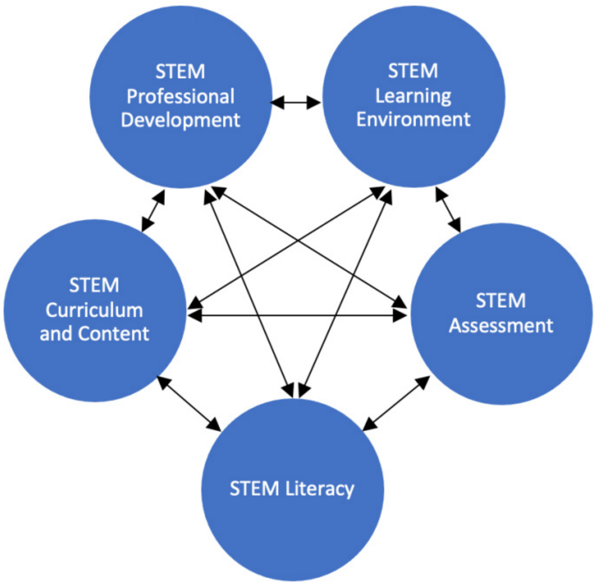

Figure 1. STEM Dimensions

STEM Literacy

STEM education is an approach that aims to provide students with better problem-solving skills, innovation, self-confidence, logical thinking and helps them become STEM literate (Morrison, 2006). In this context, it is seen that there is a transformation from science literacy to STEM literacy. STEM literacy is an interdisciplinary educational approach that enables individuals to improve their competitive ability in the economic field and enables learning by applying science, technology, engineering and mathematics (Tsupros, Kohler & Hallinen, 2009). STEM literacy is to define, apply and integrate science, technology, engineering and mathematical concepts, to solve complex problems and to renovate them to solve them (Balka, 2011). STEM literacy is important for students as a step towards their future career. It is at the center of the basic skills needed in the twenty-first century for students to become top-level problem solvers, innovators, technologists, engineers and to build an educated population (International Technology Education Association [ITEEA], 2009). STEM literacy refers to the ability to apply an individual's understanding of how the laws of the world work within and across four interrelated areas. STEM literacy does not only mean achieving literacy in these four areas separately (National Governors Association [NGA], 2007). It also means more than mapping numerous overlapping interdisciplinary skills, concepts and processes. STEM literacy is the synergy of these areas - so STEM literacy cannot be expected to be improved through separate courses. As Aristotle put it, "The whole is greater than the sum of its parts." Starting from the first year of education, students' gaining STEM literacy will enable them to move towards a STEM-related field of study in the future (Tang & Williams, 2019). For this reason, it is important to teach STEM education lessons from an early age. Having a lesson called STEM education in primary and middle school will contribute to the development of STEM literacy. In high school and university years, the separate presentation of the dimensions that make up STEM, based on specialization, will contribute to the development of students' expertise in these areas. It seems that there is a need for a learning model that can facilitate the development of students' STEM literacy. By applying engineering design principles, students are required to apply their knowledge to the real-world situations and use the project-based STEM components in this process. Problem-solving and analytical thinking skills will be developed with engineering design skills. Also, it will respond to the expectations of policymakers and increase student’s orientation towards STEM career interests. Therefore, the starting point should be STEM literacy. STEM literacy is the ability to apply concepts in STEM to solve problems that cannot be solved using a single discipline or would benefit from a creative solution involving multiple disciplines.

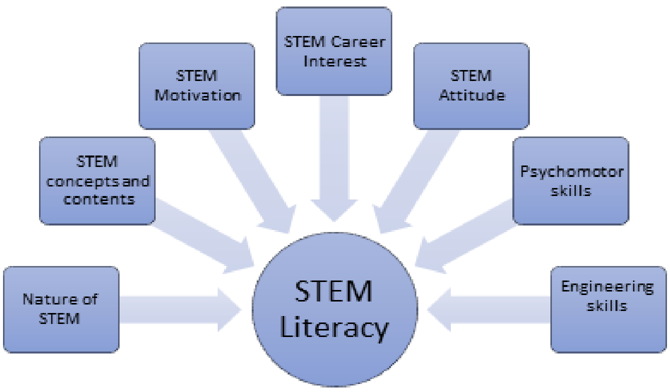

Figure 2. STEM Literacy Dimensions

For students to be STEM Literate, students should understand the nature of STEM. Basic concepts that compose STEM should be included in the course process. Students should use engineering skills during the course process, as a result of this, it is expected that their STEM attitude, motivation and career interest will increase.

STEM Curriculum and Content

Equal access to the high-quality STEM curriculum and opportunities for active participation focusing on student interest are considered as key elements of successful programs (Aldemir & Kermani, 2017). It is more important to have a curriculum that combines knowledge and competencies that can be applied in new situations than to have a curriculum that teaches pioneering technology but may become obsolete in a few years (Carracedo, et al., 2018). As the knowledge and skills required to solve technological problems become increasingly integrated and complex, the ability to apply interdisciplinary knowledge to solve these problems is greatly needed (Bybee, 2013; Havice, 2009). However, traditional school programs have long been organized separately in their subjects. Many reports state that school education cannot prepare our students to solve real-world problems due to the unconnected knowledge gained from individual school subjects. (Bybee, 2013; NRC, 2009). However, the lack of a common and clear understanding of integration continues to be a major obstacle to effective implementation (Stinson, Harkness, Meyer, & Stallworth, 2009). For example, integration approaches such as disciplinary, interdisciplinary, multidisciplinary (Berlin & White, 1995) are used in the literature instead of the education program. Due to the lack of STEM-specific teaching programs, it is seen that the contents of STEM are tried to be eliminated with uncontrolled and short-term practices. Some of the STEM activities focus on in-school and out-of-school education practices. In out-of-school activities, contexts such as field trips, summer camps, science clubs, science museums and science fairs and university workshops provide flexible learning environments for interdisciplinary STEM activities (Baran et al., 2019). Many studies state that out-of-school STEM practices increase students' attitude, interest and motivation towards STEM (Bell et al., 2009; Denson et al., 2015; Brown et al., 2016). However, most of these activities are short-term and semi-structured activities. For this reason, it is understood that there is a need for an inclusive and formal STEM lesson at preschool, primary school and middle school levels. Having a general lesson and curriculum on STEM itself will contribute to STEM literacy. A structured curriculum will enable students to pursue careers, interests and attitudes in STEM fields. STEM curriculum should indicate being based on social values, to be applicable, being suitable for the economy, being suitable for national education, being scientific.

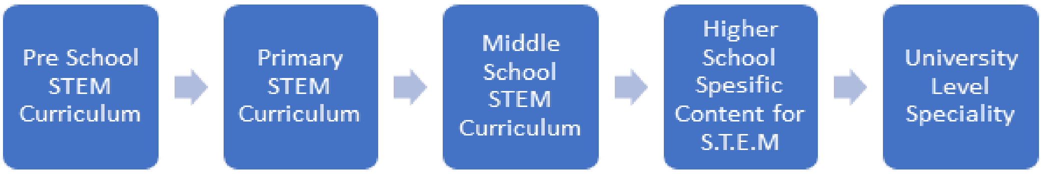

Figure 3. Suggestion STEM Curriculum Stages in Education Levels

The preschool period is the period in which mental development is the fastest. Students' acquaintance with STEM in this period is critical for the development of problem-solving thinking skills. For this reason, there is a need for an inclusive program that will support the mental development of students between the ages of 3-6. The Primary school era is a period in which students gain literary experiences and then develop these experiences. In most countries, the curriculum includes mathematics lessons in the 2nd grade and science lessons in the 3rd grade. However, design and technology education start in the middle school years. For this reason, having a STEM course in primary school will contribute to students' ability to reason and think creatively on daily life problems while using science and mathematics. One of the ways to achieve this is to make activities with a project-based learning model based on STEM in this period. It is known that the choices of middle school students affect their future education and career searches (Trusty, Niles, & Carney, 2005). However, there is often not enough information about their STEM careers to make informed decisions about their future (Wyss et al., 2012). For this reason, it is necessary to use a STEM curriculum in which vocational introductions are made to increase the professional interest of students in the middle school period. In high school and university years, separate training can be given for the fields that constitute STEM.

This educational model will provide a deductive understanding, first of all, to have a general understanding of STEM and then to focus on more specific and professional areas. Although there is a difference, a similar one is applied in medical education. Medical students first learn general subjects and then turn to other areas that require expertise.

Planning and implementation of course contents are other problems while drawing the general lines of the STEM curriculum. Most institutions and organizations organize STEM planning competitions. Because how STEM contents should be structured is still a problem. STEM education practices should be structured with an inquiry-based approach. Which discipline should be centered is another matter of discussion? It is seen that most science teachers adopt STEM education more and therefore take science to the center. Some activities seem to be activities under the name of science and technology integration. It cannot be said that these activities completely reflect the nature of STEM.

.

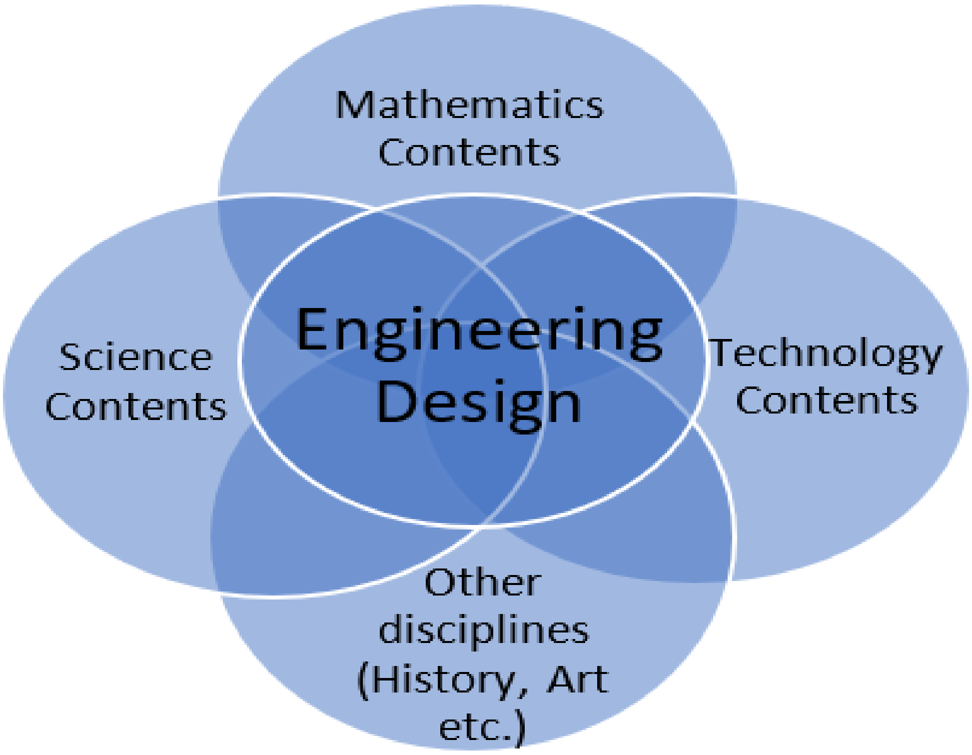

Figure 4. STEM Content Model

Engineering design skills should be at the center of STEM education. Although engineering is not a discipline, it is the only profession that uses the outputs of other disciplines. Therefore, engineering design skills should be taken to the center in effective STEM content. Engineering design skills should be aimed at solving daily life problems. as well as being a problem that concerns the whole society, it also can be a problem seen in certain regions. STEM teaching should not only focus on the development of content knowledge but also encourage the development of skills such as innovative problem solving and inquiry skills (Wang et al., 2011). The lesson content is designed within the framework of the engineering problem, a plan is made while producing solutions, science, mathematics and technology are used when testing the plan. If the solution fails, it will go back to the beginning. Since STEM education is an interdisciplinary approach, it can be used as an effective tool for problem-solving in other disciplines such as art and history.

STEM Professional Development

Teacher candidates and professional teachers should have content-specific knowledge as well as teaching skills and confidence across subjects to effectively integrate STEM learning experiences in their classrooms (Honey et al., 2014). It is seen that teachers need continuous training to improve their STEM teaching preparation (Nadelson et al, 2013). However, there is no lesson content on STEM education at university level. Teachers reach STEM with out-of-school activities. It is seen that the teachers who are the main implementers of STEM programs do not have sufficient knowledge about

STEM. Many primary school teachers do not have enough plan information for students to learn STEM, in addition they lack confidence and competence. For this reason, it would be appropriate to take a course on STEM education at the pre-school level and the primary school level. Since there are specialization lessons at middle school level, there should be a separate lesson for STEM teaching. In this section, it is suggested that STEM activities should be structured in a way that it strengthens the interdisciplinary curriculum. Professional development activities that will strengthen STEM knowledge and skills are recommended for teachers who have completed their departments. Today, many teachers avoid introducing innovative activities into the classroom environment due to their lack of self-confidence. For this reason, it is recommended that activities for students such as summer camps are designed in a way that allows teachers to be supported by new practices. Increasing the subject knowledge of teachers through many out-of-school practices such as workshops and courses will contribute to their professional development (Hewson, 2007).

Figure 5. STEM Teacher Education Model

Since teachers are required to provide STEM education in pre-school and primary school years, they are required to receive four years of education structured on STEM education at the university level. STEM teachers who will teach at the middle school level must graduate from the STEM department as a separate specialty. Because, considering the STEM approach as a course that only science teachers give in extracurricular times creates a limited perspective against STEM, it is not an effective way to reach the goals of STEM. In these sections, pedagogy, the nature of STEM, STEM concept information, STEM philosophy, STEM Curriculum, effective practices, evaluation contents can be presented. For teachers to be effective in handling STEM misconceptions, they must have the correct knowledge of STEM concepts and be ready to teach the relevant content effectively (Ginns & Watters, 1995).

STEM Learning Environments

The learning environment has been defined as an element that contributes to successful STEM teaching (Maltese & Tai, 2010), and great importance has been attached to student and teacher perceptions of learning environments in individual STEM disciplines (Afari et al., 2013). A student-centered learning environment provides students with opportunity to take a more active role in their learning rather than being passive learners (Anderson, 2007). When we refer to STEM learning environments, it is specifically expressed as classrooms or schools where conscious and explicit efforts are made to coordinate the learning goals and learning activities of two or more STEM disciplines. (Glancy &

Moore, 2013). However, today, very few schools have STEM learning environments. Schools are generally designed for traditional education. Interactive science classes can be given as examples of classes in which learning environments are designed according to the course content. STEM classrooms should be designed to allow STEM activities. Therefore, STEM learning environments should be designed to allow for psycho-social, space, infrastructure-equipment and time dimensions

Psycho-Social Dimension: The psycho-social environment dimension of learning environments in STEM teaching should define a positive climate for learning-teaching. STEM education should create a supportive and convenient environment for learning instead of traditional practices. The psycho-social environment should take into account the individual differences of students such as motivation, interest, skills and learning styles. The psychosocial environment should encourage students to reflect, discuss and evaluate alternative thoughts that are put forward. It should give students opportunities to use the new concepts they have constructed in different situations. It should allow students to use their scientific process skills.

Infrastructure-Equipment Dimensions: One of the most confusing factors for educators about STEM education is which tools should be used in STEM education. Some researchers argue that STEM activities can be done with simple materials, while others recommend the use of robotic kits. This is because there is no consensus on which activities are STEM. The tools and materials that are going to be used in STEM education should be designed in a way that will arouse the interest of students in learning and help the emergence of new interests. Appropriate educational material will give students the ability to focus their attention and make decisions. In learning, students will be directed to various activities such as research, examination, experiment and observation, listening and reading. Appropriate materials appeal to multiple sensory organs such as vision, hearing and touch, providing accurate and complete learning that will give students a variety of experiences.

Space Dimension: For STEM education, it can be used not only in the classroom but also outside the school environment. However, it is recommended to have some characteristics in the classroom or school environment. the STEM classroom should be organized as an environment that encourages students to ask questions and at the same time allows them to use content such as observation, classification, data collection, explanation and experimenting. Instead of traditional education classes, environments, where students can work in groups, should be preferred. Students should have easy access to the environments that will allow them to conduct their research in the classroom. Students should be able to access computers, the internet, interactive whiteboard, etc. in school. It is recommended that students have mechanisms such as cameras to transfer the materials they produce as a result of STEM activities to the internet.

Time Dimension: Although time is a relative concept, it refers to the required time for STEM activities. Most educators state that they cannot find enough time for the activities they want to perform in the classroom environment. In STEM activities, more than one class hour is required for understanding and discussing the problem, producing solutions to the problem and testing it. Therefore, a STEM activity compressed or integrated into science class cannot be expected to be effective. Therefore, having a separate course for STEM applications will positively affect the use of time in STEM education. A well-planned lesson will reduce the waste of time and increase the time spent on learning in the lesson, allowing students to grasp new knowledge and absorb previous knowledge better.

STEM Assessment

The learning process, formative assessment, is an important element in improving teaching and learning. Formative assessment tracks the process by which students build knowledge and progress towards the final product. It encourages students to acquire high-level thinking skills (Lombardi, 2008). Although STEM has been an important movement in the last decade (Martín-Páez, Aguilera, Perales-Palacios, and Vílchez-González, 2019), research focuses more on teacher practices, student outcomes and STEM education design. Assessment approaches and their development are almost overlooked (Sondergeld, Koskey, Stone, & Peters-Burton, 2015).

More research is needed to develop competency-based assessments to explore how and to what extent STEM learning can improve students' inquiry abilities, higher-order thinking skills, or creativity (Fang & Hsu, 2019). First, it is important to identify the intended STEM learning outcomes (knowledge, attitudes or skills) to be developed in the learning process, and second, to consider how to design assessments that create evidence of STEM learning. A versatile STEM evaluation framework needs to be made. In this respect, it is necessary to focus on process evaluation instead of standard evaluation methods (Capraro & Corlu, 2013). In addition, evaluating the concepts that make up STEM one by one will only form a part of the evaluation process. It is necessary to take part in the evaluation process in variables such as teamwork, product and motivation. A three-stage model can be proposed in the STEM assessment processes. To examine students' STEM knowledge, knowledge, skills and values should be measured in the first stage. In the second stage, the skills of the concepts of STEM components should be measured. And in the third stage, observation, product evaluation and presentation skills can be evaluated through rubrics to measure the achievements of students in STEM activities.

Results and Discussions

All over the world, there is a growing need to provide high-quality STEM education to students at the K-12 level to enable students to participate and follow STEM-related issues and careers (Metcalf, 2010). STEM education requires new teaching methods that go beyond the teaching of a specific discipline to teaching that involves the integration of different disciplines (Kelley & Knowles, 2016). However, the higher the expectations, the less likely it is to implement STEM education. This is because in most countries there is no consistent program for STEM. To solve this problem, educators need to repair the broken link between STEM education research education policy and practice. This study focuses on five dimensions of STEM education that need to be strengthened. To avoid this confusion in STEM education: STEM Literacy - STEM Curriculum and Content - STEM Professional Development - STEM Learning Environment, STEM Assessment dimensions should be strengthened. With this model proposal, the need for STEM education has been defined: Improving STEM education will contribute to the scientific, technological, mathematical and other integrated literacy of all people across the population. STEM literacy will enable students to compete in a new knowledge-based economic age. Developing STEM literacy is also the focus of STEM education (Krajcik & Sutherland, 2010). It is recommended to reorganize the training program after the goals are determined. With this model proposal, the applications of STEM education have been defined: STEM curriculum and its contents should be designed in a way that supports STEM literacy in a way that supports creativity, problem-based, project-based, daily life problems and critical thinking skills. The contents should be prepared in a way to guide teachers appropriately, with a focus on engineering design skills, using science, technology, mathematics and other disciplines. Teachers should be able to work flexibly through these applications.

With this model proposal, the need for STEM teachers was defined: Integrated teacher education programs should prepare the future teachers equipped with the knowledge, skills and beliefs to effectively implement STEM education that increases students' innovation capacity (Cuadra & Moreno, 2005). Prospective teachers who graduate from STEM teacher education programs with integrated teaching knowledge understand and teach STEM as an interconnected entity with a strong collaborative connection to life (Corlu, Capraro, & Capraro, 2014). The fact that teachers receive STEM education at the kindergarten and primary school level shows that there is a need for a new department specializing in STEM teaching at the middle school level. Because they are often trained as science, math or technology teachers, they rarely have the opportunity to experience multidisciplinary and interdisciplinary STEM education, collaborate with peers from different STEM backgrounds, or use technology to participate in STEM education (Martinovic, 2011). Graduated teachers, on the other hand, need to inform the education policy and participate in reliable and generalizable STEM education practices that can empower practitioners. Participation in activities that will allow teachers to develop their STEM education skills will encourage them in classroom practices. Trainees should have the opportunity to experience the value of educational research for their teaching practice and to design and implement research-based pedagogies. This section has been associated with the concepts of STEM dimensions, which are related to each other.

With this model proposal, it is recommended to strengthen STEM learning environments: Although most research focuses on out-of-school practices, the majority of students spend most of their time at school. Providing STEM education to students in a short period is an obstacle for STEM education to reach its goals. Most schools experience problems in the psycho-social environment, space, infrastructure, equipment and time dimensions required by STEM learning environments. Therefore, it is important to strengthen STEM learning environments according to the specified dimensions.

With this model proposal, the need to re-evaluate STEM students' outcomes has been defined: With STEM education, it is aimed that students become productive individuals with a critical perspective. However, it is unthinkable to evaluate STEM education with classical tests and methods. Instead, it is necessary to evaluate students' achievements with multiple tools that focus on process evaluation. STEM attitude, motivation and career interest development of students should be followed regularly.

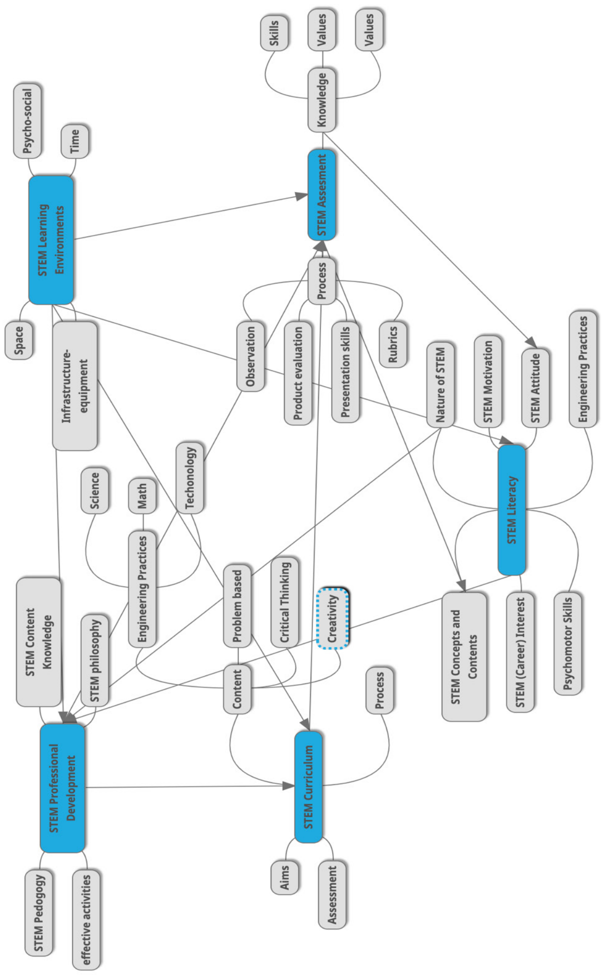

Figure 6. STEM Dimensions and Contents

Suggestions

• The aim of STEM education should enable students to be STEM literate. STEM literacy does not only mean gaining literacy in science, technology, engineering, and mathematics (Toulmin & Meghan, 2007). It also implies more than mapping numerous overlapping interdisciplinary skills, concepts and processes. STEM literacy is the synergy of these areas (Zollman, 2012).

• An accepted curriculum and contents for STEM education should be produced. Most applications refer to American-based studies. However, most countries in Europe and Asia do not have a STEM curriculum.

• STEM education experts that specialize only in this field should be trained in universities. It is a mistake to associate STEM curriculum and its contents with only science education. A science teacher cannot be expected to fully master other fields and cannot meet the students' expectations. Therefore, for effective STEM education, manpower trained in this field is needed.

• Professional development of teachers towards STEM should be supported. It is necessary to increase the activities for the professional development of teachers in STEM fields through universities.

• Assessment of STEM education should be emphasized. The assessment comes to the fore in meeting STEM education practices and expectations. However, STEM assessment studies are very new. Studies in this area are needed.

References

Alberts, B. (2013). Prioritizing science education. *Science, 340*(6130), 249. http://dx.doi.org/10.1126/science.1239041

Aldemir, J. & Kermani, H. (2017) Integrated STEM curriculum: improving educational outcomes for Head Start children, *Early Child Development and Care, 187*(11), 1694-1706, http://doi.10.1080/03004430.2016.1185102

Afari, E., Aldridge, J. M., Fraser, B. J., & Khine, M. S. (2013). Students' perceptions of the learning environment and attitudes in game-based mathematics classrooms. *Learning Environments Research, 16*, 131–150.

Anderson, R. D. (2007). Inquiry as an organizing theme for science curricula. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 807–830). New Jersey: Lawrence Erlbaum Associates

Baran, E., Canbazoglu Bilici, S., Mesutoglu, C., & Ocak, C. (2019). The impact of an out-of-school STEM education program on students' attitudes toward STEM and STEM careers. *School Science and Mathematics*, *119*(4), 223-235.

Bell, P., Lewenstein, B., Shouse, A. W., & Feder, M. A. (Eds.). (2009). *Learning science in informal environments: people, places, and pursuits*. National Academies Press. https://doi.org/10.17226/12190

Becker, K., & Park, K. (2011). Effects of integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students' learning: A preliminary meta-analysis. *Journal of STEM Education: Innovations & Research, 12*, 23-37.

Berlin, D., & White, A. (1995). *Connecting school science and mathematics*. In P. House & A. Coxford (Eds.), Connecting mathematics across the curriculum (pp. 22-33). Reston, VA: National Council of Teachers of Mathematics.

Brown, P. L., Concannon, J. P., Marx, D., Donaldson, C. W., & Black, A. (2016). An examination of middle school students' STEM self-efficacy with relation to interest and perceptions of STEM. *Journal of STEM Education: Innovations and Research, 17*(3), 27-38.

Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities*. Arlington, VA: NSTA Press.

Capraro, R. M., & Corlu, M. S. (2013). *Changing views on assessment for STEM project–based learning*. In R. M. Capraro, M. M. Capraro, & J. Morgan (Eds.), STEM project-based learning: An integrated Science, Technology, Engineering, and Mathematics (STEM) approach (2nd ed., pp. 109-118). Rotterdam, the Netherlands: Sense Publishers.

Carracedo, F. S., Soler, A., Martín, C., López, D., Ageno, A., Cabré, J., ... & Gibert, K. (2018). Competency maps: An effective model to integrate professional competencies across a STEM curriculum. *Journal of Science Education and Technology*, *27*(5), 448-468.

Capraro RM, Slough SW 2013 *Why PBL? Why STEM? Why now? An introduction to STEM project-based learning: An integrated science, technology, engineering, and mathematics (STEM) approach*. InSTEM Project-Based Learning. Rotterdam: SensePublishers.

Corlu, M. S., Capraro, R. M., & Capraro, M. M. (2014). Introducing STEM education: Implications for educating our teachers in the age of innovation. *Education and*

Science, *39*(171), 74-85.

Cuadra, E., & Moreno, J. M. (2005*). Expanding opportunities and building competencies for young people: A new agenda for secondary education*. Washington, DC: The World Bank.

Denson, C. D., Hailey, C., Stallworth, C. A., & Householder, D. L. (2015). Benefits of informal learning environments: A focused examination of STEM-based program environments. *Journal of STEM Education: Innovations and Research, 16*(1), 11-15.

Fang, S. C., & Hsu, Y. S. (2019). *Assessment Challenges in STEM Reforms and Innovations.* In Asia-Pacific STEM Teaching Practices (pp. 191-203). Springer, Singapore.

Ford, B. A. (2007). *Teaching and learning: Novice teachers' descriptions of their confidence to teach science content*. Doctoral dissertation. Available from ProQuest Dissertations and Theses database. (UMI No.AAT 3272874)

Ejiwale, J. A. (2013). Barriers to successful implementation of STEM education. *Journal of Education and Learning, 7*(2), 63-74.

Glancy, A. W., & Moore, T. J. (2013). Theoretical foundations for effective STEM learning environments. *School of Engineering Education Working Papers, 1*, 1-23.

Ginns, I. S., & Watters, J. J. (1995). An analysis of scientific understandings of preservice elementary teacher education students. *Journal of Research in Science Teaching, 32,* 1098–2736.

Havice, W. (2009). *The power and promise of a STEM education: Thriving in a complex technological world.* In ITEEA (Ed.), The overlooked STEM imperatives: Technology and engineering (pp. 10–17). Reston, VA: ITEEA.

Hewson, P. (2007), *Teacher professional development in science*. In S. K. Abel and N. G. Lederman (eds.): Handbook of research on science education, Mahwah: Lawrence Erlbaum, pp. 1179–1203.

Honey, M., Pearson, G., & Schweingruber, H. (2014). *STEM integration in K–12 education: Status, prospects, and an agenda for research*. Washington, DC: National Academies Press.

Fang S. C. & Hsu Y. S. (2019). Asia-Pacific STEM Teaching Practices: From Theoretical Frameworks to Practices. Hsu, Y. S., & Yeh, Y. F. (Eds.). *Assessment Challenges in*

STEM Reforms and Innovations. (pp. 191-203). Springer Nature.

ITEEA board of directors, "Proclamation: ITEEA's Position on the "T" & "E" of STEM," 2009 [Online]. Available: http://www.iteaconnect.org/AboutITEEA/STEMProclamation.pdf.

Kelley, T., & Kellam, N. (2009). A theoretical framework to guide the Re-engineering of technology education. *Journal of Technology Education, 20*(2), 37–49.

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education, 3*(1), 1-11.

Krajcik, J. S., & Sutherland, L. M. (2010). Supporting students in developing literacy in science. *Science, 328*(5977), 456-459.

Li, Y., Wang, K., Xiao, Y., & Froyd, J. E. (2020). Research and trends in STEM education: a systematic review of journal publications. *International Journal of STEM Education, 7*(11), 1-16.

Lombardi, M. M. (2008). Making the grade: The role of assessment in authentic learning. Educause Learning Initiative, *International Journal of STEM Education, 1,* 1-16.

Maltese, A., & Tai, R. S. (2010). Pipeline persistence: Examining the association of educational experiences with earned degrees in STEM among U.S. students. *Science Education, 95,* 877 – 907.

Martín-Páez, T., Aguilera, D., Perales-Palacios, F. J., & Vílchez-González, J. M. (2019). What are we talking about when we talk about STEM education? A review of literature. Science Education. 103(4), 799-822.

Metcalf, H. (2010). Stuck in the pipeline: A critical review of STEM workforce literature. InterActions: UCLA. *Journal of Education and Information Studies, 6*(2), 1–20.

Nadelson, L. S., Callahan, J., Pyke, P., Hay, A., Dance, M., & Pfiester, J. (2013). Teacher STEM perception and preparation: Inquiry-based STEM professional development for elementary teachers. *The Journal of Educational Research*, *106*(2), 157-168.

National Research Council. (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. Washington, DC: The National Academies Press.

National Research Council. (2011). *Successful K-12 STEM education: Identifying* *effective approaches in science, technology, engineering, and mathem*atics. National Academies Press.

National Governors Association (2007). Innovation America: Building a Science, Technology, Engineering and Math Agenda, http://www.nga.org/files/live/sites/NGA/files/ pdf/0702INNOVATIONSTEM.PDF

Nurlaely, N., Permanasari, A., & Riandi, R. (2017, September). Student's STEM literacy in biotechnology learning at junior high school. In *Journal of physics: conference series* (Vol. 895, No. 1, p. 012155).

Scaramozzino, J. M. (2010). Integrating STEM information competencies into an undergraduate curriculum. *Journal of Library Administration, 50*(4), 315-333.

Skinner, E., Saxton, E., Currie, C., & Shusterman, G. (2017). A motivational account of the undergraduate experience in science: Brief measures of students' self-system appraisals, engagement in coursework, and identity as a scientist. *International Journal of Science Education, 39*(17), 2433–2459.

Sondergeld, T. A., Koskey, K. L. K., Stone, G. E., & Peters-Burton, E. E. (2015). *Data-driven STEM assessment*. In C. C. Johnson, E. E. Peters-Burton, & T. J. Moore (Eds.), STEM road map: A framework for integrated STEM education. New York, NY: Routledge

Stinson, K., Harkness, S., Meyer, H., & Stallworth, J. (2009). Mathematics and science integration: Models and characterizations. *School Science and Mathematics, 109*, 153–161.

Tang, K. S., & Williams, P. J. (2019). STEM literacy or literacies? Examining the empirical basis of these constructs. *Review of Education*, *7*(3), 675-697.

Techakosit, S., & Nilsook, P. (2016). The learning process of scientific imagineering through AR in order to enhance STEM literacy. *International Journal of Emerging Technologies in Learning*, *11*(7), 57-63.

Trusty, J., Niles, S. G., & Carney, J. V. (2005). Education-career planning and middle school counselors. *Professional School Counseling, 9*(2), 136-143.

Vasquez, J., Sneider, C., & Comer, M. (2013). *STEM lesson essentials, grades 3–8: Integrating science, technology, engineering, and mathematics*. Portsmouth, NH: Heinemann

Wang, H.-H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research, 1*(2), 1–13.

Wyss, V. L., Heulskamp, D., & Siebert, C. J. (2012). Increasing middle school student interest in STEM careers with videos of scientists. *International Journal of Environmental and Science Education, 7*(4), 501–522.

Zollman, A. (2012). Learning for STEM literacy: STEM literacy for learning. *School Science and Mathematics*, *112*(1), 12-19.