STEM education to fulfil the 21st century demand: a literature review

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Abstract. STEM (science, technology, engineering, and math) was developed to answer challenges in the 21st century; where students are not only smart in terms of cognitive, but also skilled. STEM in education has the aim of preparing students to be competitive and ready to work according to their preferred fields. The benefits of applying STEM Education are to improve critical thinking skills and be creative, logical, innovative, productive and directly related to real conditions. The purpose of this study is to review the implementation of STEM Education models in the early 21st century. Technique of collecting data was through literature study. The results of this study: 1) STEM has been applied in various countries and in various branches of science; 2) History of STEM Education, 3) Implementation of STEM in non-western country, 4) Skill that required in 21st century, 5) STEM to face 21st challenge.

1. Introduction

The implementation of the curriculum 2013 in learning process has an impact on balancing the achievement of competencies in knowledge, attitudes, and skills[1]. One of the important principles in learning is that teachers not only provide knowledge to students, but teachers must familiarize students to actualize the knowledge gained in everyday life problem [2]. STEM education can improve students' abilities in problem solving, to be innovators, to be independent, and able to connect what was learned with daily activities [2]. STEM education is implemented in many countries to prepare their citizen to have multidimensional capabilities to use in modern life [3]. STEM Education prepare student to have personal and social skills to cooperate with the others[4]. Through STEM education, students not only have knowledges, but also able to apply that knowledge in their daily lives. Students need a learning atmosphere that is directly related to real life. According to some experts, through STEM education allows students to experience applied and real learning[5].

In fact, the knowledge given by the teachers in natural science and mathematical learning is only as information, while students are not conditioned to find and try the knowledge or information by themselves. As a result, knowledge is meaningless in everyday life and quickly forgotten. Students do not understand the scientific steps in constructing their knowledge, so they have not been able to describe the problem solving process. STEM education can answer these problems, because through STEM education students learn to use problem-solving based methods that can help students to construct knowledge and relate to problems encountered in daily life [2]. Many schools across the
country have eliminated the teaching of science and opportunities for students to have access to technology[6].

Implementation of STEM in science and mathematics learning is considered important in order to improve the quality of learning activities[7]. Learning science and mathematics are expected to be learning that refers to STEM education[2]. Teacher's understanding of STEM education is a key factor in its application. This is line with Kathleen Fulton's statement that teachers who understand STEM well can design learning more meaningful and enjoyable [7]. Teacher's understanding is one of the keys in implementing STEM education [8]. Teachers are expected to be able design learning that is fun and quality for students, so that the learning objectives can be achieved well [9]. High quality and valid learning devices should be an important part of the learning process [10], [11].

STEM education is one of the ways to face the challenges of the 21st century. Criteria for workers needed in the 21st century are workers who have good problem solving skills, creative, innovative, critical, and can work in teams [4]. The 21st century skill are digital age literacy which encompasses communication competency, analysing and interpretation of data, understanding and assessment of models, task management and task prioritization, involvement in problem solving, and ensuring wellbeing and safety [12]. And then, “The Foundation Document for Discussion” released competencies needed in the 21st century : communicative, managing information, using numbers, thinking and solve problems, demonstrate positive attitudes and behaviors, responsible, adaptive, learn continuously, work safely and teamwork skills[13]. Learning process that given to students should provide the skills needed in the 21st century. So that student received meaningful learning, related to the problems of everyday life [6]. The daily life problems within a powerful context supports students in making connection with the concepts they will learned [14],[16]. Through STEM education, a country can improve the quality of its human resources with fighting power and abilities to solve problems properly [2].

2. Research Methode
This article aims to describe about brief story of STEM education, STEM Education in several countries (especially Non Western Country), some approaches to implement of STEM education, why STEM Education must be applied in learning, the role of STEM Education in facing to the 21st century challenges. Data collection techniques used in this article are literature review. We have read some articles which related to STEM Education, natural science and mathematical learning.

3. Result of Literatur Review

3.1. Overview about STEM
STEM is acronym of science (S), technology (T), engineering (E) and mathematics (M) which do not exist alone and complex [3]. STEM education is a step to break down the four components and to ensure the student improve their problem solving abilities in every day life [17]. STEM education is a learning that integrates science, technology, engineering and mathematics to develop students' creativity through problem solving[2]. The world has recognized the need for science, technology, engineering and mathematics to be combined [11]. STEM integration is teaching and learning of the content practices of disciplinary knowledge which include science and/or mathematics through the integration of the practices of engineering and engineering design of relevant technologies [17]. Based on the experts, the above STEM education is a lesson that integrates the four components of STEM which needed in the professional world.

STEM education and research serve the fundamental role of advancing technology, medicine, sustainability, agriculture, national security, the economy and society, and the search for answers to many life’s questions[18].In some developed countries STEM education has been implemented, while in developing countries with STEM education it is being considered [7], [19]. The following are some reasons in various countries why they apply STEM education:
• To solve the problems of the low scores on international assessments such as TIMMS and PISA[3]
• The decreasing number of students who want to have a job related to science and technology[3]
• To increase math and science performance of some countries students in international comparisons [2], [6], [12]
• To increase graduates related to science and mathematics, many are taught by teachers lacking adequate subject matter knowledge[20]

The following statements are suggested attitudes and understanding of students studying with STEM Education:
• Problem-solvers: able to frame problems, able to apply understanding and learning to these new situations,
• Innovators: able to be independent and have original investigation,
• Inventor: able to recognize the needs, design and implement solution creatively
• Self-reliant : have an ability to arrange agendas and confident
• Logical thinkers: using the logic to make the kinds of connection to affect an understanding of natural phenomena
• Technologically literate: understand to use technology, master the skills needed and apply it appropriately

3.2. History of STEM Education
STEM has been used during technological inventions and began to be produced on a large scale, such as the invention of light bulbs and telephones. Another event that became the starting point for STEM's emergence was World War II when all the technologies developed were based on STEM. Scientists and the military work together to develop technology so that they can win the war. At the time of World War II many innovations were produced with STEM education, but STEM was not applied in education[2]. Russia has been developed STEM education since 1957 [17]. In America research and its application in new education in the early 1990s[2]. Actually in America research on STEM education has been carried out since 1969, where The National Assessment of Educational Progress (NAEP) reported on mathematics and sciences abilities of students that were still comparable with other countries. Amarika ranking in PISA and TIMSS is lower than in other developed countries such as new Zealand, Iceland, Denmark and others[20]. The quality of mathematics and science teachers and learning were still stagnant since 1990 -2005 [20]. After 2000 many companies have funded research on STEM and have positive impact to education quality[20]. After that STEM education began to be developed and applied in several non western countries, for example: Saudi Arabia. Malaysia, Korea, Thailand, and the others.

3.3. The Implementation Of STEM Education in Learning
There are three approaches to implement STEM education in learning process. Following a discussion of each of these approaches:

| SILO Approach | Information | Form |
|---------------|-------------|------|
|               | Isolate each individual STEM subject | ![STEM Education Diagram] |
|               | Main characterized: teacher driven-classroom | |
|               | Student have little opportunities to ‘learn by doing, rather they are taught to know | |
|               | The lack of SILO approach: SILO has a | |
tendency to isolate potential STEM contributors to real life, SILO can encourage students to maintain separate perceptions of all STEM components, the silo approach can inhibit growth of students’ academic. [5]

**Embedded Approach**

- Knowledge is gained through emphasis on real-world situations and problem solving
- It is like strengthening and completing the material that students learn through understanding and application
- It promotes learning through various contexts (different with SILO approach)
- The lack of embedded approach: student risk part of the lesson (student cannot associate the embedded content to the context of the lesson)

**Integrated Approach**

- Integrated approach eliminates boundaries between STEM components
- Integrated approach needs pedagogical training for the teachers, because Teachers often have difficulty teaching through integration[5]
- Integrated approach is the best approach in the stem field[2]

3.4. Teacher’s Perception of STEM Education

In several countries, STEM education has become a part of their curriculum, but some others are still at the introduction phase by experts. Therefore, we need to see teacher’s perception of STEM education in several countries:

3.4.1. Saudi Arabia. The aim of STEM implementation in Saudi Arabia is to shift traditional learning into inquiry, problem based learning and project based learning[19]. In Saudi Arabia mathematics and science have been taught in the tenth class[19]. There are some findings about implementation of STEM education in Saudi Arabia:

- Teachers are underprepared to use STEM applications with their students in the classroom. [19]
- Teachers did not have sufficient understanding of the T (technology) in STEM, majorities of teachers who participated in the study believed that technology as hardware like camera, laptop, etc.
- Teacher do not have an adequate understanding of the nature of science and technology
- The school culture plays a key role concerning the implementation of STEM at school, STEM integration required a different school culture than that in non-STEM schools
- Recommendation: teachers need in terms of pedagogical content knowledge to enact STEM education in class, the policy level to introduce programs for pre-service and in-service teacher that lead to developing a STEM partnership-based Professional Development in class.
3.4.2. *Malaysia*. The aim of implementing STEM in Malaysia is to improve students' mathematical and science skills, and prepare the next generation to face the challenges of the 21st century[4]. STEM apply knowledge, skills and values of STEM to solve problems in daily life, society and the environment as shown Figure 1:

![STEM Approach](image)

**Figure 1.** STEM Approach, Created by Ramli, NurFarhana

STEM has been implemented in schools beginning 2017, It’s aim to produce students with science literacy[17]. School environment is key factor for implementation of STEM. Teachers’ understanding in implementing STEM is insufficient in Malaysia, it is caused by lack information of authorities. Teacher suggest that school need to upgrade school facilities (laboratory and computer) and some training on STEM[12]. There were six major barriers appointed by the participants which are motivation, syllabus, skill (training), inadequate facilities, student involvement and responsive environment[17].

3.4.3. *Korea*. Korea has a good position in international assessment in PISA, but Korean students had the second lowest level of interest in learning science[21]. In 2011, Korean Ministry of Education (MOE)proposed a policy at the reconstruction STEM education via adding “Art” to STEM. Korean teachers believed that STEAM education would help to promote the student learning in terms of convergent thinking, creativity, and character building. Korean teachers have some problem when implement STEM (a) lack of administrative and financial support, (b) difficulties in finding time for preparing STEAM lessons, (c) increased workloads, and (d) difficulties in using new media and experimental equipment[21].

3.4.4. *Thailand*. Thailand has decreased in the number of students in the sciences field and has low score in mathematical and science [3]. In 2016, Prime Ministry of Thailand has promoted 4.0 economical model. STEM education is expected to prepare Thai to face 4.0 economical model. STEM education can prepare an inclusive society where everyone needs to have personal and social skills to work collaboratively with others [3]. Government of Thaiand believe that tachers perception is key factors to implement STEM Education[3][8]. The result research by Pattamaporn Pimthong show that preservice teachers in thailand have known about STEM Education, but They cannot explain detailly about it. They cannot explain how STEM integrated, but they can tell abot outcomes of STEM. Based on Pattamaporn Pimthong’s research, He suggested that preservise theacers need opportunities to study deeply about integreation of STEM[3].

3.5. *21st Century Competencies*. 21st Century Competencies related to the development level of cognitive, interpersonal, and intrapersonal domains [13]. 21st century competence has benefits for all scientific fields[13]. There are some competencies that required in 21st century:
- Character: qualities of the individual essential for being personally effective in a real world[13].
- Citizenship: considering issues based on deep on understanding diverse values [13].
- Critical thinking: related to abilities to plan a project, problem solving, and make good decisions[13].
- Comunicative; in 21st century communicative not only about clearly communicate, good in writing but also abilities to listening skills[13].
- Collaborative: ability to work in team, learning from the others, empathy in working, have collective intelligence, collaborative in digital[13].
- Creative and Innovative: ability to compete and to generate economic growth, related to abilities that can found many solution in one problem[13], [22].

21st century skill needs human resource which is competitive, knowledgeable, creative, and possesses positive ethics plays an important role[4]. 21st century skill prepared for student to face an survive in digital era. The four criteria of digital era are digital age literacy, inventive thinking, effective communication and high productivity. [4].

4. Discuss
STEM education is a new system of education that try to integrate four components in a learning. Through the implementation of these 4 components, students can use the knowledge gained to solve problems in everyday life and in accordance with current work demands. This is in line with the opinion of the Expert who stated that the application of STEM in education is a necessity of the world today (developing countries and developed countries). The application in education is also a step to answer the challenges in the 21st century. Students are expected to have a character in accordance with 21st century tutoring. Students are prepared to face 21st century era (digital era): comunicative, collaborative, critical thinking, creative and innovative. Then, the application of STEM education in education can also prepare workers who are experts in the fields of science, mathematics, and technology, because it is estimated in 2020, 60% of the field work related to technology, data, and count[4]. So, we must prepare our next generation to face the challenges.

STEM was implemented in developing countries and developed countries. In developing countries, STEM has been introduced by government to teachers and preservice teachers. Most of teachers in developing countries know about STEM, but they do not understand to integrate STEM in learning process. They have different in understanding about STEM. So, teacher in many countries need deeper introduction about STEM. Teacher understanding of STEM is key factor to implement it[3]. Teachers are expected to be able to use the best approach (integrated approach in learning, where the four components are related. Thus, the goal of implementing STEM can be realized: students have good numerical abilities, understand mathematics and science as a whole, and are able to apply it in everyday life.

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