# Challenges of STEM Education

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Abstract: STEM initiatives and STEM education tend to be assumed as the need to strengthen science, technology, engineering and/or mathematics separately as different subjects. This paper discusses the concept of STEM education, the need to focus on STEM, and the challenges that school teachers face in implementing STEM education. STEM education requires interdisciplinary approach to teaching that integrates at least two of the subjects in STEM. Lack of STEM participation which refers to students taking up science stream in upper secondary education in Malaysian schools consequently results in the country not meeting its enrolment target of 60 percent of students in science and technology related programmes in tertiary education. This paper also highlights on the state of mathematics learning which greatly influences the success of STEM education. The main contributing factor in the poor performance of Malaysian students in international mathematics tests is the students' inability to answer questions that require higher order thinking skills (HOTS). This has brought about revision of the school curriculum and assessment. Core competencies needed and strategies to enhance STEM education are suggested.

## 1 INTRODUCTION

The term STEM initiatives and STEM education are used by many educators in Malaysia to reflect the effort towards improving science, technology, engineering, or mathematics (STEM) especially at the school level. The elaboration of the four subjects as provided by the National Research Council, United States are as follows:

i. Science is the study of the natural world, including the laws of nature associated with physics, chemistry, and biology and the treatment or applications of facts, principles, concepts, or conventions associated with these disciplines.
ii. Technology comprises the entire system of people and organization, knowledge, processes and devices that go into creating and operating technological artifacts, as well as the artifacts themselves.
iii. Engineering is body of knowledge about the design and creation of products and a process for solving problems. Engineering utilizes concept in sciences and mathematics and technological tools.
iv. Mathematics is study of patterns and relationships among quantities, numbers, and shapes. Mathematics includes theoretical mathematics and apply mathematics.

STEM initiative in Malaysia is designed to prepare students with skills to meet the challenges of science and technology and to ensure that Malaysia has sufficient number of qualified STEM graduates. Special programmes for STEM include stimulating student interest in STEM through new learning approaches and an enhanced curriculum, sharpening the skills and abilities of teachers in STEM, and building public and student awareness of STEM. The number of instructional periods for science has been increased and science laboratories in secondary schools were upgraded. Likewise, science rooms are upgraded into laboratories in primary schools (Ministry of Education Malaysia, MOE 2014). Teachers are to conduct the STEM approaches in schools by getting students to:

i. Question and identify problems;
ii. Develop and use models;
iii. Plan and conduct experiments;
iv. Analyse and interpret data;
v. Use mathematics thinking and computational thinking;
vi. Explain and design solutions;



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vii. Be involved in debates and discussions based on evidences.

Malaysia had also developed the STEM Education Conceptual Framework (MOE, 2016) which details out the STEM experience for students according to the learning stages. Edy Hafizan, Ihsan and Halim (2017) indicated that during early childhood, children are given the freedom to explore so as to trigger and foster their interest through activities that can stimulate curiosity. At the primary school level, they are exposed to the basic of STEM knowledge allowing them to make connection with daily life situations through investigation and exploration activities and to have meaningful experiences. At the lower secondary education level, they are encouraged to analyse local and global issues as well as engaging in problem solving activities to help them grow and develop STEM skills. At the upper secondary level, the activities involve strengthening and enriching STEM skills. Lastly, at tertiary level, STEM education expose students with coping strategies to prepare them for STEM career challenges, the industry and community and to contribute to nation development through innovation.

# 2 STEM EDUCATION

In a small study conducted by Nur Farhana and Othman (2017), they concluded that teachers' understanding about implementation of STEM is insufficient. Teachers are talking about strengthening individual subjects rather than focusing on the interdisciplinary approach to implementation of STEM. The campaigns are on promoting "Love for Science" and "Love for Maths". Thus the initiatives that have been put forth in STEM movements include increasing STEM awareness, raising student outcomes and interest through new learning approaches, improving laboratory facilities and sharpening skills and abilities of teachers.

STEM Education may have been generally assumed by implementers as the enhancement of each of the four STEM subjects. Several authors provide almost similar definitions as the following.

> STEM education is an interdisciplinary approach to learning where rigorous academic concepts are coupled with real world lessons as students apply science, technology, engineering, and mathematics in contexts that make connections between school, community, work, and the global enterprise enabling the development of STEM literacy and with it the ability to compete in the new economy. (Southwest Regional STEM Network, 2009, p. 3)

STEM education has to be interdisciplinary, borderless and require learners to make connections with real life contexts. Thus, it would require integrating concepts of science, technology, education, and mathematics in projects, problem-based learning projects, or case studies to help students connect what they learn to authentic or real-world contexts. All these years, these concepts have been taught through separate subjects in schools and by different teachers who have different fields of expertise.

## 2.1 Challenges in Implementing STEM Education

In the context of higher education, STEM education is much easier realized because there are many opportunities for students to be involved in solving real world problems. They may integrate concepts that they have acquired through several courses and culminating them in capstone project, problem-based learning projects, case studies, industrial practices, research projects and field works. For this reason, university lecturers are encouraged to obtain their professional licence and to do industrial attachments allowing them to keep abreast with the demands of the workplace and to ensure the contents that they teach remain relevant to the needs of the industry. As such, professional engineers in Malaysia may use the designation "Ir" before their names to indicate that they have met the highest professional standards and is registered by the Board of Engineering Malaysia.

Before dwelling more on STEM education, we need to think whether there would be enough opportunities for school teachers to have the industry experience and on how we can get them connected to the industries. In the higher education context, lecturers have opportunities for sabbatical leave or industrial attachment leave. Similar kinds of benefits or opportunities need to be made available for teachers if STEM education is to be fully realized in the way that it should be conducted. They may not end up with Ir (for professional engineers) or Ar (for professional architects) since they probably have degrees in education rather than professional degrees such as engineering or architecture. But with degrees in education, would the teachers be able to connect with the people and gain as much from industries.

‘Getting connected’ is of utmost important for the teachers to acquire ‘STEM thinking’. Reeve (2015) introduced the term STEM thinking which he defined as ‘purposely thinking about how STEM concepts, principles, and practices are connected to most of the products and systems we use in our daily lives.’ The question is, if teachers do not have the chance to get connected, how do they develop STEM thinking? This is where experts from universities and industries may take it as their responsibility to conduct STEM programmes in the schools, provide instructional materials, and training-of-trainers for the teachers. Universities and industries should also bear some responsibility to share real world problems, give talks, guest lectures, briefings for teachers and provide opportunities for school visits. Parent-teacher association may also strengthen their role by coordinating parents’ active involvement in providing STEM education in schools.

In Malaysia, STEM education is more fully explored in technical vocational education and training (TVET) schools/institutions but less so, in normal academic schools. TVET schools/institutions were established to meet the needs of highly skilled workforce to support the growth of the industrial sector by providing formal, non-formal and informal learning that prepare young people with the knowledge and skills required in the world of work. Most of the tasks that need to be completed would require an integration of knowledge of STEM subjects or parts of it.

## 2.2 The Need to Strengthen STEM Education

Bertram (2014) in his book ‘One nation under-taught: Solving America’s science, technology, engineering, and math crisis’ highlights the importance of STEM education through his statement that the United States will produce more than 1.8 million STEM jobs by 2018 and is expected that STEM-related jobs will grow at a faster rate than other fields. What is alarming is that he asserted an estimated 1.2 million of these STEM jobs would not be filled because the current US workforce does not possess the skills to fill them. According to The National Council for Scientific Research and Development, Malaysia needs a workforce of 493,830 people in STEM related industries by 2020. This requires a rate of increase of STEM of about 31% per year (Ministry of Education Malaysia, 2013). Under-participation in STEM education could well be a global issue. For developing countries such as Malaysia and Indonesia, serious measures must be taken to produce the much needed workforce for STEM jobs.

Realizing the constraints in fully realizing STEM education in Malaysian Schools, STEM Initiative was boldly emphasized in Malaysia Education Blueprint (MEB) 2013-2025 (Ministry of Education Malaysia, 2013) as a ‘laying the foundations at the school level towards ensuring that Malaysia has a sufficient number of qualified STEM graduates to fulfil the employment needs of the industries that fuel its economy’ (pg 4-6).

Malaysian government instituted the 60:40 Science/Technical: Arts Policy in education in 1967 and started implementing it in 1970. This means intake for higher education should be 60% in science and technical fields while 40% are in Arts and Humanities fields. The target needs to be met in facing challenges and demands of STEM-driven economy by 2020 (Ministry of Education, 2013).

Malaysia has been facing fewer prospective students for higher education in science and technology. In upper secondary school (Year 9), students will have to choose the stream. The choices are academic stream (Science/Art), Technical and Vocational Stream, and Religious Stream. The number of students choosing science related fields continued to decline over the years (Halim and Subahan, 2016). Students who are eligible to be in the science stream but choose not to do science in the upper secondary school has increased to 15%.

The number of students who have chosen STEM fields has continued to decline in recent years (Halim & Subahan, 2016). As reported in 2016, only 42% of secondary school students in Malaysia chose to do Science, including technical and vocational programmes (Curriculum Development Centre, 2016). Thus, the target of 60:40 Science/Technical: Arts has not been achieved. There are not enough eligible science candidates from schools to fill up the places provided in higher education institutions. Among the factors identified by Ministry of Education on the declining participation in science stream are perceived difficulty of STEM and its content-heavy curriculum. Measures are undertaken to meet these aims which include (i) raising student interests through new learning approaches and an enhanced curriculum, (ii) sharpening skills and abilities of teachers, and (iii) building public and student awareness. Other strategies undertaken are establishing school improvement specialist coaches (SISC+) for Mathematics and Science and conducting diagnostic exercise to identify gaps in content knowledge and pedagogical skills among teachers. Schools have been giving special attention to inquiry-based learning, problem solving, contextual learning, collaborative learning, project-based learning to improve performance as well as getting students motivated in learning of STEM. The SISC+ play a critical role as the content as well as the pedagogy expert.

To ensure the success of implementing STEM and to get students ready for STEM-related jobs, they need to have considerable mathematical competence. This paper also focuses on the state of mathematics achievement of Malaysian students which influences the success of STEM education. Solving real world problems involving science, technology and engineering would require application of mathematical knowledge. In other words, mathematics is fundamental to STEM education. Volmert et al. (2013) explains the role of mathematics in STEM "math as part of the basics, science as important but secondary, and technology and engineering as supplementary add-ons that are only appropriate 'later' and for 'some students'" (p. 5).

# 3 STUDENTS' MATHEMATICS PERFORMANCE

The MEB 2013 - 2025 sets the target and direction for Malaysian Education to be at par with performance of developed countries. Thus, under-performance of Malaysian students' in mathematics has been a growing concern for all stakeholders. This had prompted major changes in teaching approaches and assessment methods. Curriculum planners, mathematics educators and researchers, and technology experts work collaboratively to provide better learning experiences for students.

Trends in Mathematics and Science Study (TIMMS) and Programme for International Student Assessment (PISA) have been used as benchmarks to indicate Malaysia's ranking based on international average scores in these major tests. TIMSS 2011 results triggered the alarm for Malaysia since the 2003 complacent stage. The declining results of Malaysian students in these international assessments are often publicised by media, meetings and forums and are frequently raised by ministers and politicians. As a result, The MEB 2013 – 2025 (Ministry of Education Malaysia MOE, 2013) paid special attention to student cognitive performance against international standards.

TIMSS which is conducted every four years by the International Association for the Evaluation of Educational Achievement (IEA) is a large scale assessment that inform participating countries and their policy makers on the students' performance and provide a cross country comparison. PISA, developed by the Organisation for Economic Cooperation and Development (OECD) is conducted every three years to measure students' performance in mathematics, science and reading literacies. The focus of PISA is on assessing understanding and application of knowledge and skills in solving problems to meet future challenges. In 1999, Malaysia exceeded the TIMSS international average with a score of 519 but the performance declined to merely 440 points in TIMSS 2011. However, with much effort and strategies, Malaysia managed to improve the score to 465 in TIMSS 2015. Singapore, Korea, Taipei, Hong Kong and Japan maintain as top achievers in TIMSS all these years.

The results of TIMSS and PISA revealed that Malaysian students lack the ability in doing problem solving. Through analysis and reflections on teaching and learning practices, it can be concluded that the students lack opportunity and exposure to develop higher order thinking skills (HOTS). Thus, it was timely to introduce the new curriculum for primary school known as Standard Curriculum for Primary School (KSSR) in 2011 starting with Year 1 and the new school-based assessment that focuses more on improving HOTS and to reduce 'teaching for examination' practices. HOTS is defined by MOE as the ability to apply knowledge, skills and values in reasoning and reflection in solving problems, making decision, to innovate and to create. In line with the emphasis on HOTS, major change in national examinations was also made and this include increasing apportionment of HOTS questions in the examinations. Other measures taken include retraining of teachers to integrate HOTS in classroom instruction and assessment.

The focus on HOTS had started to show some positive impact. According to the TIMSS 2015 report (Mullis et al, 2016), Malaysia was among 18 countries that recorded improvements when it scored 465 points, an increase of 25 points as compared to TIMSS 2011. However, the number of students at the advanced benchmark is only 3%, a mere increase of 1% from TIMSS 2011. The following table provides a comparison between Malaysia and Indonesia on percentage of respondents who are categorized in the advanced, high, intermediate and low benchmarks in TIMSS. Despite numerous efforts to improve students' learning, the percentage of the Malaysian respondents who score less than 400 (ie. low benchmark) is still high (28%). Indonesia has also shown some increase in TIMSS 2015 but the scores are far below the international benchmark with 50% of respondents in the low benchmark category.

Table 1: Malaysia and Indonesia Mathematics Achievements based on TIMSS International Benchmark

| Percentage | 2011 (%) | | 2015 (%) | |
|---|---|---|---|---|
| | IND | MY | IND | MY |
| Advanced Benchmark (>625) | 0 | 2 | 0 | 3 |
| High Benchmark (>550) | 2 | 12 | 3 | 18 |
| Intermediate Benchmark (>475) | 15 | 36 | 20 | 45 |
| Low Benchmark (>400) | 43 | 65 | 50 | 72 |

*IND – Indonesia, MY – Malaysia

TIMSS results should not be used to reflect the overall performance of students of the participating countries since there may be other contributing factors. Malaysian researchers and policy makers revealed possible reasons for the poor performance which include the following:

i. Standards of examinations are different.
   a. Require HOTS.
   b. Questions are unpredictable.
ii. Students are not trained or well exposed to answer TIMSS and PISA-like questions.
iii. Students had problems in understanding the question context and language.
iv. Students are not serious in answering TIMSS and PISA assessments because there are no implications to their performance and their future.

The benchmarking exercise in TIMSS and PISA shows how Malaysian students fare with other countries. This allows us to take immediate actions to help improve students' mathematics learning. The new mathematics curriculum allows students to be more engaged, allow teachers to assign project works as required in STEM education thus providing opportunities for students to work collaboratively, develop their critical thinking, creative thinking, problem solving skills, team work skill, and communication skills.

# 4 INTEGRATING STEM EDUCATION IN SCHOOL CURRICULUM

The content and pedagogy of the new primary school curriculum, KSSR as well as the new secondary curriculum (Curriculum Standard for Secondary School, KSSM) are well aligned to meet the needs in enhancing STEM education:

i. Content is restructured and improved to ensure students are provided with the knowledge, skills and values that are relevant to the current needs for the challenges of the 21st century.
ii. Pedagogical approaches emphasises on in-depth learning based on higher order thinking skills (HOTS). Focus is given to inquiry-based learning, problem solving, contextual learning, collaborative learning, project-based learning and Science, Technology, Engineering, and Mathematics (STEM) approach.
(Bahrum, Wahid & Ibrahim, 2017).

## 4.1 Core Competencies for STEM Education

In solving real world STEM problems, several core competencies apart from the content knowledge must be acquired and enhanced. One of the competencies required is reasoning ability. Malaysians students did poorly in TIMSS items that require reasoning (Lessani, 2015). In emphasizing reasoning, students are encouraged to estimate, predict and make intelligent guesses (conjectures) in the process of seeking solution and need to be provided opportunities to investigate their predictions or guesses by using concrete material, calculators, computers, mathematical representation etc. Logical reasoning needs to be integrated in the teaching of mathematics so that students can recognize, construct and evaluate predictions and mathematical arguments.

The New Jersey Mathematics Curriculum Framework (New Jersey Mathematics Coalition, 1996) provided an elaborate descriptive statement of mathematical reasoning as ‘the critical skill that enables a student to make use of all other mathematical skills. With the development of mathematical reasoning, students recognize that mathematics makes sense and can be understood. They learn how to evaluate situations, select problem-solving strategies, draw logical conclusions, develop and describe solutions, and recognize how those solutions can be applied. Mathematical reasoners are able to reflect on solutions to problems and determine whether or not they make sense’. Definitely STEM tasks would require students to apply their reasoning abilities for them to solve the tasks.

The Malaysian new curriculum (Curriculum Development Division, MOE Malaysia, 2011) emphasises on several core competencies that are also essential for STEM education. KSSR and KSSM emphasize on the development of holistic individuals who are critical, creative and innovative. The core of the curriculum framework is supported by the learning areas of mathematics, that are attitude and value, skills and process. The mathematical processes comprise of communication, reasoning, connection, problem solving and representations in mathematics. Communication skills include reading and understanding problems, interpreting diagrams and graphs, using correct and concise mathematical terms in oral presentation and writing, and listening. Focus on connection will enable students to link conceptual to procedural knowledge and relate topics within mathematics and other learning areas in mathematics. By making connections, students are able to see mathematics as an integrated whole rather than just a jumble of unconnected ideas.

KSSR uses the following general descriptors to indicate achievement based on performance standard:

Table 2: General descriptors of achievement

| Performance Level | Knowledge Performance Indicator |
|---|---|
| 1 | Know basic mathematics knowledge |
| 2 | Know and understand basic mathematics knowledge |
| 3 | Know and understand basic mathematics knowledge, able to apply basic arithmetic operations, able to apply knowledge on basic conversion |
| 4 | Know and understand mathematics knowledge, able to apply calculation procedures in solving routine daily problems |
| 5 | Able to apply mathematical knowledge and skills in solving routine daily problems using various strategies |
| 6 | Able to apply mathematical knowledge and skills in solving non-routine problems using various strategies creatively and innovatively. |

In teaching and in assessment, the emphasis on HOTs is intensified. The focus is on non-routine problems instead of routine ones. Non-routine problems require analysis and reasoning, may be solved in more than one way and may have many solutions as illustrated in Figure 1 below. STEM education focuses more on non-routine problems that relates to daily life such as this. On the other hand, routine problems are problems that can be solved using methods that students are familiar which may only require replicating previously learned algorithm. It only requires use of known procedures.

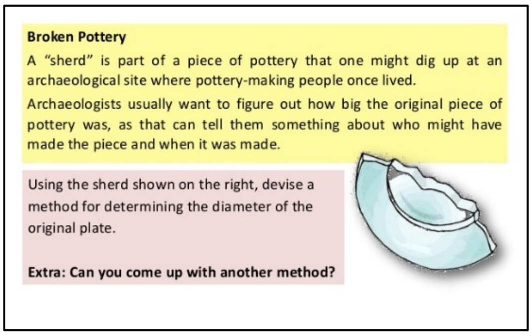


Figure 1: Example of a Non-Routine Problem
Source: Geometry PoW Packet Broken Pottery May 30, 2011 • http://mathforum.org/pows/

## 5 CONCLUSION

KSSR and KSSM are still in the infancy stage to judge whether the content of the curriculum would indeed produce students who are creative and innovative problem solvers and will contribute to the development of the country. It was also designed to support STEM education. One of the initiatives that was started in 2015 is a collaborative project with Massachusetts Institute of Technology (MIT) to develop Blended Learning Open Source Science or Math Studies (BLOSSOMS).

STEM education should be embedded within and beyond the curriculum. The following are some immediate and workable actions to help enhance STEM education:

i. establish communities of practice (CoP), that offer guide, support and teaching materials for STEM teaching and learning and how it can be implemented in specific contexts and with different types of learners.
ii. develop learning resources such as modules and videos.
iii. provide support for teachers by providing mentors, guides and videos to help them apply pedagogical approaches that emphasise on in-depth learning based on higher order thinking skills (HOTS) such inquiry-based learning, problem solving, contextual learning, collaborative learning, project-based learning and Science, Technology, Engineering, and Mathematics (STEM) approach.
iv. provide learning experiences that include interdisciplinary approaches to solving real world lessons that integrates STEM.
v. collaborate with higher education institutions, government agencies, research institutes, and industries to support STEM education in schools.

Literature had also highlighted on the need to create flexible learning spaces, well equipped science laboratories and design laboratories with advanced computer applications. However, STEM education in budget-constrained learning environments can still be conducted effectively if it is reinforced with the right resources and support. We need to stay tight with the philosophy of introducing STEM to students.

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