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INTEGRATING STEM IN AN ENGINEERING DESIGN PROCESS: THE LEARNING EXPERIENCE OF RURAL SECONDARY SCHOOL STUDENTS IN AN OUTREACH CHALLENGE PROGRAM

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Abstract: This research was conducted to evaluate the learning experience of Grade Ten students from two Malaysian rural secondary schools that adopted the integration of STEM in an Engineering Design Process (STEM-EDP) approach vis-á-vis an outreach challenge program. A total of 89 students undertook a ten hour program which engaged them in designing and building three different prototypes as well as answering higher order thinking questions. Data on students' learning experience were captured through teachers' field notes, and participants' responses to open-ended questions. The STEM-EDP outreach challenge program brought awareness to rural school students of their potential as problem solvers, thinkers, creators, and collaborators. Students were able to simultaneously broaden their boundaries in knowledge and competency even though they experienced difficulties in tackling challenges associated with STEM activities. Findings suggested that the STEM-EDP approach can be applied as a means for fostering creativity, problem solving skills, and thinking skills among rural secondary school students.

***Keywords*:** Engineering design process, higher order thinking, outreach challenge program, rural schools, STEM.

Introduction

The demand for a science, technology, engineering and mathematics (STEM) driven workforce in Malaysia has become a burgeoning need as the economy has evolved from a production-based economy to a knowledge-based economy. By the year 2020, it has been estimated that Malaysia will be in need of 500,000 skilled STEM workers (Academy of Sciences Malaysia, 2015). Undeniably the supply of STEM related workforce is highly dependent on new entrants into STEM related programmes in upper secondary as well as tertiary level. However, research has shown that only a total of 45% of students have enrolled in science stream, and technical and vocational secondary school classes in 2014, which is still far from the ideal ratio of 60:40 Science/Technical: Arts Policy set in 1970 (Yong & Phang, 2015; Ministry of Education Malaysia, 2014).

The challenge of achieving the 60:40 Science/Technical: Arts Policy is even tougher for the vast rural areas of Malaysia due to its limited infrastructure, lack of good schools and small population (Ling, Mahdib, Mohamadin & Manaf, 2015). Sabah, an East Malaysian state with a relatively high proportion of students in rural schools is facing a more challenging situation with respect to its efforts to reform rural schools. Many rural primary and secondary schools are located in wide and isolated areas with unique topography (Malaysian Digest, 2011). Some schools, for example, are located in areas with limited road access and as is often the case, water transport such as boats is used. According to the Sabah Economic Development and Investment Authority Blueprint (SDC, 2011), 72% of Sabah's schools were located in rural areas. In terms of infrastructure and basic utilities, most rural primary and secondary schools in Sabah lack supplies of 24-hour electrical connection and clean water, access to good teaching and learning resources, computers, and science laboratories. It is apparent that these limited opportunities and facilities have somewhat created a gap in education attainment between rural and urban schools in Sabah and in Malaysia as a whole.

In its report about Malaysian rural schools, the World Bank (2010, p. 92) noted that: "Potentially as a result of less favourable conditions in rural schools, students from rural and remote schools perform significantly worse

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on tests than their peers in urban areas. Disparities within states between rural and urban areas are most prevalent in poorer states like Sabah". Specifically, the World Bank (2010) reports a disparity between urban and rural secondary schools' achievement in Mathematics among Malaysian students at Grade 9 (15 years of age). It is clear that many rural school students have lagged behind their peers from urban schools in academic performance due to inadequate infrastructures, utilities and learning resources.

As a consequence, despite many new initiatives aimed at transforming rural schools, it is a difficult task to achieve in the near future (Malaysian Digest, 2011). Similarly demanding is the revitalizing of Malaysian rural secondary schools in STEM education. Undeniably, information about the best practices from new initiatives or programs in rural secondary schools can be used as a reference to revitalize rural schools in the Malaysian context. As long as the right approach is put in place, the quality of Malaysian rural secondary schools can certainly be improved and in the intervening time, the gap between rural schools and their urban counterparts can be minimized or possibly closed.

In countries such as Colombia and the United States of America, an outreach program is usually designed to help and encourage disadvantaged students of rural schools to increase their science, technology, engineering, and mathematics literacy and enthusiasm. This afterschool program aims to improve the quality and reach of STEM education at all levels. These initiatives raise the questions, "How would an outreach program help less privileged students in Malaysian rural secondary schools learn about STEM?". Tackling questions like this, particularly in rural settings often requires innovative solutions. There is also a need to propose an integrated program which allows science teachers to seamlessly examine what rural school students would learn and difficulties faced during the outreach program.

Theoretical Background

Engineering Design Process and Problems

Many researchers propose engineering design process as a means of solving challenges in STEM fields (Farmer, Allen, Berland, Crawford, & Guerra, 2012; Householder & Hailey, 2012; Hynes, Portsmore, Dare, Milto, Rogers, & Hammer, 2011). The Massachusetts Department of Education (2006, p. 84) proposed eight steps of engineering design process which provide a guide for teachers and curriculum coordinators regarding learning, teaching, and assessment in science and technology/engineering specific content from Pre-Kindergarten to Grades 6-8 and throughout high school. Those eight steps of engineering design process include identifying the need or problem, research the need or problem, develop possible solution(s), select the best possible solution, construct a prototype, test and evaluate the solution, communicate the solution, and redesign. Wendell, Wright, and Paugh (2015) found evidence that specific instructional support built upon student resources could create more pathways to success and learning during the different phases of engineering design. Additionally, students could create and communicate design ideas to each other while engaging in practices. The use of the engineering design process as an instructional framework is intended to ensure that all pedagogical practices are contextualized within the engineering design process so that students research, calculate, test, brainstorm, build and perform activities to fulfil STEM-design challenges (Berland, Steingut & Ko, 2014; Farmer *et al.*, 2012).

Farmer *et al.* (2012), and Householder and Hailey (2012) have demonstrated how engineering design problems embedded in the context of an engineering design process in secondary school science classrooms could scaffold in building engineering skills and habits. As outlined by Khandani (2005), and Mentzer, Huffman and Thayer (2014), engineering design problems in practice tend to be structurally open-ended and highly complex. An open-ended problem may have various acceptable solution paths and be limited by rigid and negotiable constraints which are not always presented with the problem. Engineering design problems are also designed to be 'ill-defined'. Greenwald (2000) characterized an ill-defined problem as being: ''unclear and raises questions about what is known, what needs to be known, and how the answer can be found. Because the problem is unclear, there are many ways to solve it, and the solutions are influenced by one's vantage point and experience'' (p. 28). King and Kitchener (1994) claims that an effective technique for developing problem-solving and critical-thinking skills is to expose students to "ill-defined" problems in their field.

Many researchers claim that STEM curricula can be integrated in an engineering design process to provide a mechanism through which students learn relevant STEM content (Hmelo, Holton, & Kolodner, 2000; Mehalik, Doppelt, & Schunn, 2008; Schunn, 2009). This mechanism encourages students to make connections, helps connect design failure or next steps to real world engineering and technology (Lottero-Perdue, 2015). Students learn important scientific concepts and their application in engineering and technology, as well as their relationship and application in daily life or real world context. Students could look for connections by engaging with activities or material in 'real-world' contexts to establish relevance. This approach can attract students' interest in science lessons and provide them with a deep understanding of concepts and meaningful learning. A research by Neo, Neo and Tan (2012) found that activities that students carry out in the real world were effective in teaching and engaging students in the classroom as well as increasing their understanding of the subject matter.

Hynes *et al.* (2011) noted that engineering design process that focus on solutions and construction of prototypes impel students to encounter the process of creative and critical thinking as well as problem solving skills. Hence, engineering design process would offer an effective route as an instructional framework for teaching STEM subjects among rural secondary school students.

Purpose of Research

Relatively few organized efforts have been directed to the integration of secondary school STEM subjects in engineering design process experiences. This research was therefore undertaken to investigate the learning experience of rural secondary school students (16 years old) on the integration of STEM in an engineering design process (STEM-EDP) outreach challenge program. It was also conducted to address some of the concerns how and whether the students could benefit in the aspects of creative and critical thinking, problem solving skills and applying relevant STEM concepts. Implementing a STEM-EDP approach in an outreach challenge program may provide the platform to address the numerous challenges that are fundamental to the STEM education of rural school students.

Research Questions

The research questions guiding this research are:

1. What have students learned through engaging with the program?
3. How did STEM-EDP activities aid the students in their creative and critical thinking, and problem solving skills?
4. What difficulties did the students face as they engaged with the program? What suggestions would students offer to overcome those difficulties?

Methodology of Research

Research Design and Participants

A single group with intervening STEM-EDP challenge program design was used in this research. The outreach program was conducted in two secondary rural schools in April and May 2015. The two selected schools are located in a rural area on the West Coast of Sabah, Malaysia. School A was about 215 km whereas school B was 160 km from Kota Kinabalu. The participants consisted of 89 Grade Ten Science Stream students, with each 49 and 40 respectively from school A and school B. Participants comprised 53 females (59.6%) and 36 males (40.4%) aged 16 years old. In the Malaysian context, students from the age of 16 have the opportunity to pursue two years of study in the upper secondary upon completion of the lower secondary education. Students who are academically inclined can choose between two main streams: the Science or Arts Stream. Seemingly, the Science Stream students are perceived to be more adept at performing in mathematics and science related subjects. Thus, purposive sampling was employed in the selection of the participants. According to Fraenkel and Wallen (2000) purposive sampling minimizes experimental contamination. Selection of Grade Ten Science Stream students who possessed knowledge, ideas or experiences of STEM relevant to the research would best help the researcher understand the research question (Creswell, 2003).

Students gathered into heterogeneous groups of four to five members on the basis of random selection in accordance with gender and ethnicity (diversity). The groups were assigned by the teacher so that there would be inclusion of students of high-, medium- and low competency levels based on their individual scores achieved in the end-of-semester examination. To ensure active and equal participation within a group, each student was assigned to perform a specific role: a reporter, recorder, runner, checker, and sketcher. All groups were given identical materials. At the start of the program, students were presented a letter of consent detailing the nature of their involvement in the program and the need to give their consent on the sheet provided indicating their full understanding. Code names were used for the data to ensure the confidentiality of the schools and individual identities.

A total of 22 science teachers from School A and 19 science teachers from School B participated as assessors and facilitators. They were trained to carry out the facilitation and assessment prior to the program. They stood of qualified science teachers with degrees in Science Education. They obtained a passing grade in the Research Methodology course (qualitative and quantitative) in their Masters course which they were undertaking at the time. A total of 18 of them helped the researcher develop the STEM activities and testing procedures. The researcher guided the science teachers on how to facilitate students through the seven steps of engineering design process in order to ensure the consistency and reliability in the implementation of the STEM activities across students and schools.

Data Collection

Research Data were collected through qualitative means: participant's responses to open-ended questions; and teacher's field notes. Teachers wrote their field notes based on the observation made during the STEM activities, and the focus group interviews with students. A total of 19 semi-structured focus group interviews were carried out after the completion of each STEM activity. The questions of the interviews were open ended (Table 1) and the students were encouraged to draw explicitly from their learning experiences of working on the STEM activities. Each focus group interview was conducted in groups consisting of 4-5 students. Table 1 shows the tools that were being used to address the corresponding research questions.

Table 1. Data capturing tools.

Research Questions	**Data Capturing Tools**
What have students learned through engaging with the program?	Teacher's field notes based on focus group interview and observation.
Question: What were some of the things about this program that students learned?	Open-ended questions. *"Something new students have learned today was…"*
How did STEM-EDP activities aid the students in their creative and critical thinking, and problem solving skills?	Teacher's field notes based on focus group interviews and observation.
i. What difficulties did the students face as they engaged with the program? ii. What suggestions would students offer to overcome those difficulties?	Teacher's field notes based on focus group interviews and observation.

Data Analysis

The qualitative data were analysed through thematic analysis. Thematic analysis is a form of a pattern recognition technique by searching through the data for emerging themes (Fereday & Muir-Cochrane, 2006). Two researchers independently reviewed teachers' field notes and students' responses to open-ended questions. They read the data line by line and identified recurring patterns in the data. The patterns identified by each researcher were compared to ensure validity of the codes. They dealt with codes which had no consensus by sharing their perspectives and concerns to reach common codes. Through multiple reviews and an iterative process, categories and codes were refined and grouped into themes.

Learning through STEM-EDP Outreach Challenge Program

The STEM-EDP outreach challenge program was designed with a focus on encouraging rural school students to solve an ill-defined problem utilizing the engineering design process to design, build, and test their creations. In the challenge, students would be asked to consider the constraints of the materials and time, identify the problem, think about what they already know, design, plan, construct, test and evaluate a physical prototype of their design.

The STEM-EDP program consisted of Six STEM activities (Appendix A) lasting about three hours and 20 minutes each. Three activities were introduced in each school with specific context to enhance learning and understanding of the STEM concepts. Students also needed to answer the Higher-Order Thinking (HOT) questions that stood of questions that were not strictly in their curriculum. In a way, answering HOT questions inspired students to acquire new found competences. Anderson and Krathwohl (2001)'s Taxonomy was used as a guide to develop a blueprint for the HOT questions, which belonged to the Analysis and Evaluation category of the cognitive domain. Some samples of HOT questions used were: 'In your opinion, if buildings were constructed identical to this prototype, is it safe to be inhabited? If yes/no, please explain why?'(Evaluation); 'How can your prototype be modified in order to improve its results in the future?'(Analysis); and 'Explain why there is a difference of the submarines' speeds between the two bottles? (Analysis)'. The HOT questions were specially designed to evaluate students' analysis, evaluation and communication skills in connecting STEM activities with their daily life.

Previous research (Siew, Amir & Chong, 2015) found that science teachers noted several potential challenges while implementing a STEM-Project-based learning approach in their rural school classrooms. These included inadequate materials, limited facilities and limited allocation of classroom time. Accordingly, the engineering design process employed in this program (Figure 1) removed the 'redesign' step proposed by the Massachusetts Department of Education (2006, p. 84). This modification was made to ensure that students could produce workable prototypes that made best use of the materials and time provided.

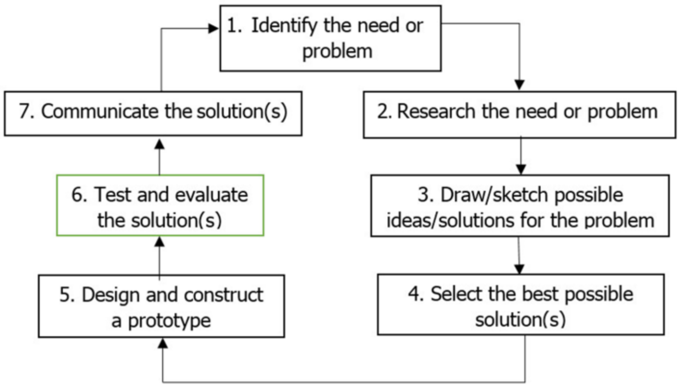

Figure 1. The seven steps of engineering design process (Adapted from Massachusetts Department of Education, 2006).

The advantages of the engineering design process in the teaching of STEM is that it focuses on solutions by constructing prototypes that drive students to encounter the process of creative and critical thinking, and problem solving skills. It allows students to realise that there are many ways to find solutions, as they engage in brainstorming to identify problems and propose solutions. The process of finding the optimal solution based on constraints requires participants to engage both in critical thinking and problem solving skills. Through the seven stages of engineering design process, learners are intended to develop creative and critical thinking, and problem solving skills while carrying out the STEM activities.

Prior to the program, students worked in teams to solve an ill-defined problem by designing and building workable solutions in forms of prototypes, which could be tested and fulfilled the criteria set in the problem. In this research an ill-defined problem was introduced to students within the context of their daily life. Thus, ill-defined problems become better defined and more contextualized as they were worked on and hence the solving and learning was through doing.

Students worked collaboratively to plan, design, construct, and test a prototype based on their prior and new knowledge; and demonstrated and tested their prototype to their peers and facilitators. The students were expected to be able to identify and discuss the science and mathematical concepts exhibited in their designs or prototypes. The STEM-EDP outreach challenge program promoted out-of-the-box creative thinking and discussions. Students were encouraged to find multiple, imaginative, intuitive and common sense solutions and not "one right answer" to a problem. The goal of this program was to enhance innovative and inventive thinking abilities of rural school students resulting in skills that can be applied in the Science, Mathematics, Engineering, and Technology fields.

Results of Research

Qualitative Analysis on Participants' Response

Science teachers' field notes and students' responses to open-ended questions were analysed using thematic analysis. A number of different themes in relation to STEM-EDP approach emerged from the data. The abbreviations used for the analysis are: "S" represents Student, "T represents Teacher, "SA" represents School A, "SB" represents School B and 'G' represents Group. The main findings are discussed below:

Students' acquisitions through engagement with the program

Application of Science, Technology, Engineering and Mathematics knowledge in solving daily life problems. Almost every participant (98%) noted that they benefitted from the STEM activities as they were exposed to real-life situations where Science, Technological, Engineering and Mathematical knowledge were applied for solving daily life problems. More importantly, STEM activities succeeded in providing a platform for them to apply scientific knowledge. Among the scientific concepts the students noted were related to water and air pressure, equilibrium of force, base area, balanced force, surface tension, stability, water density and the buoyancy force in a submarine. Students also pointed out that they were working like engineers. Related responses to open questions were:

"The activity integrates many of the STEM concepts such as water pressure (science), boat structure (engineering) and measuring length (mathematics)"(S39, S43);*"I could apply physics concepts in solving problems and thinking outside the box such as designing of floating needles and paper clips on the water's surface using the concept of water's surface tension"* (S31, S39); *and "We learned how to build balancing toys as if we were engineers"* (S78, S91).

T21, T30, and T36 (SB) confirmed that interviews with students revealed that they found the need to apply the concept of impulse in order to create an innovation to help absorb the impact of an egg being thrown from a high place. Furthermore, students were also able to explain that the concept of impulse was also applied in producing car air bags.

Application of scientific knowledge in designing and producing daily life products and answering HOT questions. A significant number of science teachers (88%) observed that a profound comprehension of scientific knowledge was needed in order for students to answer HOT questions every time a STEM session ended. Scientific knowledge did not only help participants answer high level questions but also helped them to be creative in reapplying knowledge learnt in the designing and producing of prototypes. For example, T5 and T10 (SA), and T6 and T19 (SB) observed that HOT questions gave students an opportunity to posit answers according to their thinking and make connections with scientific concepts they have learnt in class. Some of the evidences that showed students realised the importance of using scientific concepts in designing and producing daily life products include:

"I learnt that the Sink and Swim activity that involve the concept of weight and air pressure is very important in building a submarine" (S44); *"Scientific concept has always been applied in every creation"* (S7); *"It involves making daily life products through the applications of scientific concepts"* (S11, S37, S61).

T2 and T13 (SA) added that during the activity of creating a straw submarine, they observed that students discovered that the submarine needed to be designed with some air space inside it. When the plastic bottle was being pressed, it created pressure against the water in the bottle. Indirectly, the water in the bottle exerted pressure towards the air space in the submarine. Based on this understanding, students started to create different designs of submarines using straws. Students also discovered the different speeds of the submarine, moving up and down in two different solutions. Facilitators were even more satisfied that the students could answer the HOT questions correctly.

Connecting STEM activities with daily lives and scientific concepts learned. A large percentage (93%) of the science teachers noted in their field notes that participants learned how to make connection of the STEM activities with their daily life phenomenon. For example, T2, T18, T13 and T14 observed that students could relate how ships or boats function and why they could float on the surface of water by making comparisons with their boat models. Another example is when answering the HOT questions, participants could affiliate the floating needle and paper clip activity with the water strider bug, a floating log, water lilies, floating ants and others. T6 and T19 supported these claims by noting that "*Scientific knowledge is not only for answering exam papers but also useful in helping students create connections and explain situations faced in their daily lives. In* *this case, it is observed that students applied scientific concepts they learned during Physics lessons in problems given to them. Students not only applied the science principles and laws they learnt but also used them in practical forms*".

Designing and building something new and practical. A large percentage (96%) of the participants expressed in the open questions that STEM activities gave them an opportunity to create many new, interesting and practical science products using everyday materials. They stated that the balloon powered car made from plastic bottles was a new experience for them. They were fascinated with finding ways to make a highly powered car moved by air using ever ready materials such as glue, bottles, pencils and others. Another activity was making a boat. The students said they realised that play dough can float when shaped into a boat. Others noted that finding gravity centre through making the balancing toys was a new activity. Meanwhile, a few students commented that they discovered how to float the needles and paper clips while some noted their success in floating the objects.

According to T24 and T28, when participants were asked why they were excited with the STEM activity, they answered that: "*because we got the chance to design and build a new model which we only see in textbooks*". As for T20, T23, and T34, they observed that the students could design egg protection tools and that every group member worked together the whole time by contributing ideas and carrying out the projects as they had planned. Other than that, T13 and T14 also said that students showed interest in STEM 3 activity because they could become 'designers' of their own boat in the future. One of the members in the group shared her opinion by saying that, *"This activity gives me an idea of creating a modern boat that can give a great impact to the means of transportation"* (G6, S3). Thus, STEM activity, according to T13 and T14, seems to provide a very good start to stimulate the interest of students in learning Science.

Ways in which STEM activities have aided the students in their creative and critical thinking, and problem solving skills.

In their field notes, science teachers reported that all the participants agreed the activities they were engaged in had aided either in their creativity, critical thinking or problem solving skills through measures as discussed below.

HOT questions sparked critical thinking. A large percentage (93%) of the participants expressed through the open questions that they were challenged to think critically when answering the demanding questions in the STEM program. According to T4 and T11, students were capable of giving rational answers to the HOT questions. For example, one of the group members gave an excellent answer and showed that he/she understood the concept and was able to give a suggestion to improve the existing prototype if given the chance to design it with the aid of extra materials. From T4 and T11's observation, the HOT questions challenged the participants even in their groups. The sharing of answers added knowledge collectively to the group besides increasing their critical thinking skills.

Besides that, other teachers like T27, T31, and T39 (SB) also thought that the student's critical thinking was enhanced since each activity required students to answer HOT questions. The students felt that the HOT questions were difficult but they tried their best to answer and associate them with their prior knowledge. According to T24 and T28 (SB), two members from their group stated that STEM activities tested and challenged them to think outside the box using higher thinking skills.

Ill-defined problems inspired creativity and thinking. A significant number of science teachers (83%) reported that students faced complexities posed by ill-defined problems in the program. These ill-defined problems demanded from them effective response to the challenging tasks which in turn inspired creativity and thinking. For example, T26 and T33 stated that participants from groups Two and Seven admitted that STEM 3 activity was the most challenging because it demanded high thinking skills to solve problems and tested the students' creativity levels in creating a bottle car that was powered by a balloon. Participants had to figure out ways to move a car by using only air within a balloon. Participants also had to think of a method of reducing the car's weight and decrease its tire resistance. Besides that, T29 and T35 (SB) also declared that students found the STEM 2 activity challenging particularly when building a slide made of satay sticks tied together that needed high creativity skills.

T20, T23 and T34 (SB) also asserted that interview results showed that each student admitted that the problems posed in three activities were challenging. One of the male participants in their group admitted that he never knew that he could solve the challenge of building a slide using satay sticks in a short amount of time. On the other hand, participants in T25 and T40's group (SB) also claimed that STEM program encouraged them to think creatively as well as critically. This was because each activity had its own challenges.

For STEM 1 activity, which was the 'egg-astronaut', students were being hurried and struggled with having no ideas in using the materials given because *"slow to act as ideas came late*' (G4, S92). Nevertheless, discussions done from time to time enabled them to think creatively and they eventually made a sellotaped basket tied with three balloons. This idea came from their own group member and the inspiration for it came from their observation of the hot air balloon. Their own knowledge about hot air balloons helped them in this activity. Moreover, according to participants in T9 and T12's group (SA), *"The thing we like the most with this activity is that it challenges our mind to create something more creative that is to think of ways to produce balancing toys in a more stable way. This activity also tests patience"* (S3, G2).

Besides that, the problem of limited materials forced them to think creatively. Below is another example of an interview with student groups:

Students (SA; S4): I have to recombine other materials to make up a good raft.
Students (SA; S1): There is no glue, we need glue, teacher. No glue, so we have to think a bit critically to tie the straws together and minimize leakages.
Students (SA; S6): We redo the raft, well; it floats and still carries 18 marbles. I guess we managed to learn how to solve the problem. (Laughs)

Along with that, T5 and T10 noted that most respondents responded that STEM activities challenged them and their creativity for the sake of creating a working product that fulfilled the criteria needed in the specified rubric. As an example, the "Sink or Swim" activity needed students to identify methods or steps and design needed to make the paper clips and needles float on the surface of water.

Sketching, designing and constructing models fostered creative thinking and problem solving skills. A considerably large percentage (78%) of the science teachers noted in their field notes that participants stated that the activities of sketching, designing and constructing models helped to increase their creative thinking and problem solving skills. For example, T27, T31, and T39 (SB) noted that students expressed opinions that each activity encouraged creative thinking and also problem solving skills. This was because each activity needed students to sketch and design models according to the creativity of each group. Students noted that they had to think of a way to design models that worked and at the same time possessed creative elements. By observing the sketches in the three activities, T27, T31, and T39 (SB) found that there was improvement particularly in STEM activity 3. Besides that, students also said that their problem solving skills were highly stimulated because they had to solve problems in the stipulated time as well as create a working model out of the materials prepared.

Apart from that, T2 and T14 noted that participants became inventive when given the chance to design and produce their own functional straw submarine. One of them even stated that *"I liked this activity. Maybe, who knows, in the future, I can create my own submarine, because I already know the concepts of how to make it!" (G6, S2.).* T7, T15 and T17 (SA) also found that the 'Straw Submarine' activity challenged student's thinking skills as they noted: *"We can see that everybody was trying really hard to build the submarine. It can obviously be seen on their faces. All of them also stated that to build submarine is very hard compared to the previous activity".*

In addition, T2 and T14 stated that 'balancing toys' successfully induced creativity within students as almost every one of them were able to build a balancing toy with different designs. By using their creativity and imagination, students in group Six were able to create nine balancing toys with different designs. Furthermore, this activity also enhanced student's thinking skills. Students gained ideas on how to create their own toy design. Hence, it encouraged them to think more profoundly. What's more, from the interviews, students shared that this activity motivated their creative thinking. This was supported by observations made by T9 and T12 (SA) who noted that: *"Besides creating one 'balancing toy', students can think of ways to merge a few 'balancing toys' in a stable condition".* Moreover, T2 and T13 (SA) stated that the balancing toys activity successfully encouraged the creativity and imagination of the students as almost every one of them was able to build a balancing toy with different designs.

Another example was a boat making activity. From the provided materials, students designed two different kinds of boats, one from play dough and another from straws. This increased the number of marbles carried by the boat as long as the boat was stable enough to carry them. Brainstorming within the group produced new ideas and boosted the confidence of individuals, hence allowing them to do their best work in order to find optimal solutions.

Working cooperatively instilled thinking. In a statement by T4 and T11 (SA), students were in opinion that "Sink or Swim", the first STEM activity, challenged them to think of ideas and make many attempts without giving up in order for a needle and paper clip float. Suggestions from their friends in the groups helped them to increase their critical and creative thinking when making attempts to cooperate as a group to solve the problems. T6 and T19 (SA) also observed the mutual understanding shared among the group members while doing the activities and the cooperation in contributing ideas. T7, T15 and T17 (SA) reinforced that participants tried to solve and help each other to find the centre of gravity in order to create stable 'balancing toys'.

The challenge faced by the students during the program

Time Constraint. A major concern during the program was time constraint. T29 and T35 (SB) said that some students assented that it was tough to design the slide model in activity STEM 2. According to them, models built from sticks needed time but the time given was not enough. Time constraints caused them not to complete their model according to plan. Another pair who stated a similar problem was T26 and T33 of SB. They said that students in STEM 2 faced lack of time. T20, T23 and T34 (SB) also agreed that time was short and not enough for students to complete the STEM 2 activity. Similarly, T24 and T28 (SB) said that students from Group 1 complained that they did not have enough time to build a strong runway. Finally, T32 and T38 (SB) posited that participants from Group 3 found that the STEM 2 activity (slide invention) was the most arduous because the time given was too brief (S4, G3) and too many materials had to be assembled (S3, G3).

Students equipped with limited scientific concepts. T24 and T28 (SB) noted in their observation and interviews that students experienced difficulty in applying scientific concepts and knowledge in the implementation of the STEM-EDP program. The students were weak in mastering physics concepts, hence they needed to put in extra effort to relate physics principles in designing and building activities. For example, according to the students of group Four, their prior knowledge of scientific concepts was limited. This led them to be less creative in creating something unique for the STEM 1 activity. T7, T15 and T17 (SA) affirmed this:

"We found out that most of the students under our care cannot get the science concepts quickly, except the leader of group One. The main difficulty that the students faced was weak basic concepts in science. The next problem that we observed was, they did not know how to explain the concept, which can be seen in their answers for Higher Order Thinking (HOT) questions. For example, they only got one mark for question 2.3.2 because of insufficient explanation of the process involved when they pressed the bottle. This was the main reason why they got last placed in this program.

T6 and T19 (SA) noted that students encountered the difficulty of relating scientific concepts they have learnt in the classroom to the activity. For example in activity 1A, students were unable to link the scientific concepts such as buoyancy force and density to the design. Hence, a discussion among the students in determining the exact scientific concepts taught them to think using higher level thinking skills. They had to assess in detail the exact scientific concepts used to solve the problem in this activity. Additionally, T4 and T11 stated that students faced hardship in stating and explaining the concept of buoyancy connected with large ships made out of steel. In this matter, students could only give unfocused answers that did not match the suggested answers. This was seen when students tried to solve the problem of making boat models. Other facilitators responded:

"Students appeared to be unable to perform the activity, even after they understood what they have to do. This may be due to lack of ideas to create something that they are not accustomed to." (T1, SA).

"We have to give them hints such as 'force related to water' and giving them time to recall what they have learnt in the classroom. Fortunately, they remembered! Even though they knew the concept, they were not able to relate it with the activity." (T7, T15 & T17, SA).

Activities were too challenging. T20, T23, T24, T32, T34 and T38 (SB) remarked that participants experienced higher level thinking challenges in STEM activities As for T2 and T18's group, in the STEM 3 activity, students experienced obstacles in balancing the marbles on the raft. The dilemma was most felt when they had to choose a raft shape that could hold the most number of marbles. T7's group also found the same activity challenging. The interview finding was as follows:

: We faced so much problems with testing the raft on the water.
Students (SA; S1, S5) : ..... The leaks really cracked our brains. (Laughs)
: We tried many times to fix the raft but it was still leaking. Our brains are tired, (Smiles cheekily)

According to T2, T9, T12 and T18 (SA), students encountered hardship in balancing the 'balancing toys' even though there were several efforts done to tie them up. Students faced difficulty in finding the centre of gravity of the 'balancing toys' in order to create stable 'balancing toys. Even though the balance was the same, students found different designs had different centres of gravity. Nevertheless, after improvisation was done, each group was seen to be able to balance their 'balancing toys'.

T9, T12, T30, T21, and T36 reinforced that students were of the opinion that STEM activities were demanding especially when they tried to make a submarine float and sink. This was supported by their remarks: *"We found it extremely difficult to make the submarine float and sink. We tried many methods but we still could not manage. The activity undoubtedly tested our knowledge and skills*". This was also supported by the remarks made by T7, TT15 and T17:*"We found out that students were really engaged in 'Straw Submarine' compared to 'Sink or Swim' activity. This is because, according to students, 'Straw Submarine' is a more challenging and interesting activity because they must know the concept of buoyancy and how submarines work in order for them to build a straw submarine."*

Besides that, other teachers like T27, T31, and T39 (SB) revealed that all the students admitted that the STEM activities were challenging and that they needed to take high risks in making decisions in order for their models and designs to be built and function well using related scientific concepts and appropriate materials.

Students' suggestion for overcoming the identified source of problem

Extending the time. Time was a big issue in STEM 2 activity for school B in this program. According to T38 (SB), students suggested that time should be increased for STEM 2 activity which needed more time to construct the structure (G3, S1). T26 and T33 (SB) also noted the same suggestion for STEM 2 activities. Tuina, a student, stated that if time were increased, she and her friends would have been able to make better creations and do more trials so that weaknesses could be overcome. T24 and T28 repeated the same suggestion from participants for STEM 2 activity.

Discussion

The STEM subjects which were integrated into engineering design process provided a mechanism through which students learn to make connections by engaging in 'real-world' problems and contexts (Lottero-Perdue, 2015; Neo, Neo & Tan, 2012). In this present research, findings show that students were able to apply STEM knowledge in solving daily life problems, designing and producing daily life products and answering HOT questions. Students were also able to connect the STEM activities with daily lives and scientific concepts learned in the classroom, and to create new and practical products using everyday materials. This research makes clear that the execution of the proposed STEM-EDP program can help students in relating STEM knowledge to their real-world problems and contexts.

The STEM-EDP outreach challenge program not only allowed students to gain and integrate STEM knowledge but also provided an avenue to boost their creativity, critical thinking, and problem solving skills. Students' creative and critical thinking was sparked through solving HOT questions and ill-defined problems posed in the STEM activities. Students could respond effectively even with limited materials and time in organizing their thoughts to choose the best possible solution for their prototype using related scientific concepts. Lewis (2009) asserts that imposing some structure to open-ended design problems may assist in encouraging more creative thinking. Hynes *et al.* (2011) also noted that engineering design process provides students an opportunity to practice critical thinking skills as well as creative and outside-the-box thinking. King and Kitchener (1994) have also written about exposure to ill-defined problems that mimic those solved by real-world practitioners help students develop problem-solving and critical-thinking skills. This research demonstrates that STEM-EDP approach allows students to focus on solutions to ill-defined problems and construction of prototypes that could encounter them in the process of creative and critical thinking, and problem solving skills.

In addition, the research showed that activities such as sketching, designing and constructing a prototype have helped students to foster their creative thinking and problem solving skills. Students described how the engineering design process encouraged them to come up with sketches for possible solutions. The process also taught them how to solve the given problems in the stipulated time as well as design and create a working model out of the materials prepared. Students said that brainstorming within the group produced new ideas, and mutual understanding and cooperation boosted the confidence of each individual to do his/her best work in order to construct a functional prototype. For example, a group of five from group Six were able to create nine balancing toys with different designs.

A number of the earlier researches have noted that learning in cooperative learning groups fosters creativity and problem solving skills and social competences. For example, Siew, Chong and Lee (2015) reported that sketching science and sharing ideas in cooperative learning groups in problem-based learning fostered students' scientific creativity. Similarly, Stanford University Newsletter (2001) noted that students who brainstorm in a collaborative situations while solving a problem develop both domain knowledge and problem solving skills. Notably, the program had a significant impact on students' understanding about themselves as potential problem solvers, thinkers, creators, and collaborators. Students were made aware of their potential to become inventors. They also felt a sense of empowerment to make an impact to the world.

For most students, STEM-EDP outreach challenge program provided a fun and enjoyable learning experience, enabling them to incorporate their own ideas from daily life experiences and creative thinking to create new products. Overall, the program scaffold the students' critical thinking, problem solving, team work, creativity, and thinking. They learnt skills and competences that were otherwise tough to teach in a normal classroom setting.

While the students described many positive learning experiences gained in this program, they also pointed out several challenges. The two most commonly mentioned challenges were the limited amount of time needed to construct optimal prototypes, and limited knowledge of scientific concepts. Straw, MacLeod, and Hart (2012), and Siew, Amir and Chong (2015) also note that time is a critical constraint; this is especially obvious when the conducted STEM activities involved the use of a wide range of cognitive abilities. Siew *et al.* (2015) have also written about limited knowledge of scientific concepts being a challenge that influences success in STEM activities.

This research makes clear that reducing the time pressure by negotiating or extending the execution time would clearly help some students complete the activities. This research also highlighted that students who are equipped with sufficient knowledge of scientific concepts would be able to answer HOT questions elaborately, and thus adequate classroom opportunities to practice thinking skills are crucially needed. In addition, this research makes clear that consolidating students' understanding of scientific concepts would help them in adopting a STEM-EDP approach in their design and build activities. The research finding not only confirms the results of previous research studies reviewed, but also supports new research examining a number of potential ways to support STEM students with complex design tasks in time-limited situations.

Although the research findings suggest that rural secondary school students benefited from the learning experience through STEM-EDP outreach challenge program, its limitation must also be acknowledged. This research involved only 89 Grade Ten students, and may not be representative of the Malaysian rural secondary school students' population as a whole. This research is a one-day snapshot of students' learning experiences. Future research will therefore need to be carried out with a larger sample size and longer period with extra ill-defined problems compared to the current research to assess extensively the learning effects of integrating STEM in an engineering design process. Further comparison between rural and urban schools would shed light on the extent to which locality influences students' learning experiences in the STEM-EDP program.

Conclusions

This research investigated and elaborated how Grade Ten rural school students (16 years old) benefited from a day long implementation of the STEM-EDP outreach challenge program. It concludes that the proposed program is an extremely rewarding and influential process of teaching and learning both for the educators and the students. Vis-à-vis the program, students were able to expand their boundaries of knowledge and competencies to become problem solvers, innovators, creators, and collaborators even though they experienced difficulties in tackling challenges associated with STEM activities. The STEM-EDP outreach challenge program opened the eyes of many rural secondary school students of their potential to fill in the critical pipeline of engineers, scientists, and innovators so essential to the future of Malaysia. Findings suggest that the STEM-EDP outreach challenge program offered a means for developing creativity, problem solving skills, and thinking skills among rural secondary school students. This research has therefore highlighted the pivotal role of applying integrated approaches such as STEM-EDP to the teaching and learning process of science related subjects which cater to the needs and challenges faced by rural school children in the country.

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Appendix A

STEM activities in School A and School B

	SCHOOL A	SCHOOL B
STEM 1	1 (a) How would you produce an object using paper clips and needles that can float on the water surface? 1 (b) How would you produce a submarine that may arise and submerge in a closed water bottle?	How would you produce a protective egg device in order to protect a raw egg as it falls to the ground from a height of a 2-storey building?
STEM 2	How would you produce a balancing toy that can stand upright and stable on your finger, like a bird perched on a tree branch?	How would you produce a sliding model that is able to withstand the load of and encourage the acceleration of a tennis ball?
STEM 3	How would you design and build a model boat that can accommodate as many boxes of biscuits for your company to be transported from Labuan to Kota Kinabalu? Suppose that marbles are the boxes of biscuits that need to be brought to Kota Kinabalu.	How would you produce a balloon-powered car that can go the fastest and furthest away from the starting line?