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EXPLORING STUDENTS' STEM IMAGINATION PROCESS THROUGH AN ENGINEERING DESIGN PROCESS

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Abstract: This research was conducted to explore the STEM imagination of Grade 10 students from one Malaysian rural secondary school that adopted the integration of the imagination process in an Engineering Design Process (EDP) through an outreach program in STEM. Four stages of the STEM imagination process were examined: initiation, dynamic adjustment, virtual implementation and implementation. A total of 50 students aged 16 participated in a 10-hour program which engaged them in designing and building two different prototypes. Data on students' STEM imagination were captured through teachers' field notes based on focus group interviews and observations. The findings reveal that students needed to draw from their lived experiences to brainstorm problems and solutions around a given scenario, and to arrive at a workable solution in order to move from the initiation to the implementation stage. The findings also suggested that the EDP approach is able to create a supportive environment for nurturing STEM imagination among rural secondary school students.

Keywords: engineering design process, outreach program, STEM imagination

Imagination has been regarded as one of the key components of creativity and innovation, and the source of every form of human achievement (Robinson, 2011). A number of scholars (Pelaprat & Cole, 2011; White, 1990) have claimed that individuals who demonstrate a certain degree of imaginative capabilities are considered to be more capable of thinking of lots of possibilities and generating ideas or prototypes that can solve current problems in life. It has been argued that imagination and creativity should be emphasized as important outcomes of science education (Kind & Kind, 2007). McCormack (2010) voiced support for science education as a good way to cultivate talented individuals with rich imaginations and creativity. McCormack further asserted that fostering imagination in school science lessons can contribute to students' talent development.

Recently, the integration of science subjects (physics, chemistry, biology) and mathematics with technology and engineering (STEM) has gained academic as well as national attention in Malaysia for the purpose of preparing students with the skills to meet future scientific and technological challenges and to ensure that Malaysia acquires enough talented workforce in STEM (Ministry of Education Malaysia [MoE], 2014a). Talented STEM individuals have the aptitude to approach and solve problems using their insight, imagination, and ingenuity to create new products. Undeniably the supply of a talented STEM workforce is highly dependent on new entrants into STEM related programs in upper secondary schools as well as at tertiary levels. However, a report has shown that only 22.5% of Malaysian students enrolled in the science stream, and technical and vocational secondary school classes in 2017, which is far from the ideal ratio of 60:40 (Science/Technical: Arts) policy set in 1970 (Academy of Sciences Malaysia, 2015). A shortage of talent in areas related to

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STEM would be a hindrance in gearing Malaysia up to become a developed nation by 2030. Students need exposure to the methods employed by those who are already seasoned STEM individuals, who are adept at solving problems by using their imagination to generate ideas to solve everyday problems.

Despite the increased emphasis on fostering children's creativity and imagination in recently introduced Malaysian Primary School Standard Curriculum (MoE, 2014b) and Secondary School Standard Curriculum (MoE, 2016), there is little research evidence on imagination among students. Sanders and Budnik (2009) elaborated the success of camp invention programs in encouraging imagination among elementary students in the STEM disciplines. Liang et al. (2012) examined a learning environment that stimulate imagination among university students. However, no details were given by those researchers as to which learning process might have contributed to the students' imagination. Gajdamaschko (2005) and Porter and Brophy (1988) asserted that hardly any research has been conducted to examine whether imagination can be nurtured through science disciplines. Furthermore, there are very few guidelines provided for Malaysian science teachers regarding methods of nurturing imagination in STEM education, hereafter referred to as "STEM imagination." In contrast, academic research has been extensively conducted on drawing and writing based on the imaginations of artists and novelists (Abdul Majid et al., 2015; Salleh & Sailin, 2014). Hence, this study was undertaken to explore the learning process that could nurture STEM imagination.

Theoretical Framework

Imagination

Imagination is an innate ability in human beings. Scientists use imagination to construct scientific theories and create new inventions to improve life through the process of constant thinking and trial and error (Ho et al., 2013). Thus, great inventions were originated from human imagination. Lindqvist (2003) and Vygotsky (2004) asserted that imagination operates based on daily life experiences that inspire creative activities. Likewise, Pelaprat and Cole (2011) regarded imagination as a mental activity that links daily life experiences and generates novel ideas. Ho et al. (2013) elaborated this further by stating that imagination is an ability to construct images in the brain that are further concretized and visualized to generate ideas that can solve current problems in life. In tandem, Policastro and Gardner (1999) posited that imagination is an ability that links previous experiences in a unique way to generate thoughts with new meanings and to produce potentially creative thinking. White (1990) similarly opineed that to "imagine something is to think of it as possibly being so" (p. 184), and that an "imaginative person is one with the ability to think of lots of possibilities, usually with some richness of detail" (p. 185). He elaborated that imagination "is linked to discovery, invention and originality because it is thought about the possible rather than the actual" (p. 186). Likewise, McCrae (1987) associated imagination with divergent creative thinking. McCrae posited that individuals capable of divergent creative thinking would generate multiple possible solutions to a given situation or problem.

According to Wang et al. (2015), scientific imagination is a mental activity involving the creation of new ideas that are consistent with scientific principles linked to daily life experiences. Wang et al. classified the process of scientific imagination into three stages: initiation, dynamic adjustment, and virtual implementation (see Table 1). Different key components operate during each stage.

Table 1
Stages and components of scientific imagination (Wang et al., 2015)

Stages	Components
Initiation	Brainstorming and Association (problems)
Dynamic Adjustment	Transformation and Elaboration (solutions)
Virtual Implementation	Conceptualization, Organization, and Formation

The initiation stage involves students in brainstorming to identify as many problems as possible. Likewise, students are supposed to find as many associations of ideas as possible to their daily life. Brainstorming is the process involved in generating an abundance of ideas. Through brainstorming, students can break through any limitations and come up with many problems linked to daily life experiences. The components of brainstorming and association also work in the dynamic adjustment stage in a different way.

During the dynamic adjustment stage, students brainstorm to explore as many possible solutions to the problem and identify relationships among their ideas in order to formulate new ideas for solving problems. This involves the transformation and elaboration component in illustrating the appearance of physical features and functions of their creations through rough sketches. The virtual implementation stage involves students formalizing the idea through a detailed sketch. This stage focuses on conceptualization, organization and formation in refining particular ideas and honing students' problem-solving abilities by having them sketch detailed designs, diagrams, and models in order to formulate a prototype to be realized in the future. This includes issues related to the choice of materials, techniques for assembling parts, and the means of creating design diagrams and final drafts from the initial diagrams. However, scientific imagination as proposed by Wang et al. (2015) focused on potential design solutions without considering the construction and testing a physical prototype. According to Brown et al. (1989), the necessary experiences for effective learning are, "Engineering and technology provide a context in which students can test their own developing scientific knowledge and apply it to practical problems; doing so enhances their understanding of science" (p. 12). Hence, imagination should engage students in the construction and testing of the prototype in order to generate a workable solution to a problem, what the author hereafter refers to as "STEM imagination."

Joh et al. (2011) stated that, "The 'imagine' instructions appear to have provided children with a mental problem-solving strategy that was more effective than visual feedback" (p. 749). Weick (2006) asserted that imagination is an ability which can be further developed. The literature review thus raises crucial questions: Can STEM imagination be developed among students? What is the best learning process that encourages the development of STEM imagination among students? Children naturally enjoy using their imagination to solve problems that arise. A lack of attention to STEM imagination in the design of effective instruction can lead to failure in inspiring creative activities among young school students. Undeniably, the need to fulfil this gap in the learning process is crucial in order for science teachers to explore its effects on students' STEM imagination. The present study addressed this concern by proposing a learning process for Grade 10 students which could develop their STEM imagination.

Engineering Design Process

A number of researchers (Farmer et al., 2012; Householder & Hailey, 2012; Hynes et al., 2011) have proposed the engineering design process (EDP) as a means of solving challenges in STEM fields. The Massachusetts Department of Education (2006, p. 84) designed eight steps of EDP which provides a guide for teachers and curriculum coordinators regarding learning, teaching, and assessment in science and technology subjects or engineering specific content from pre-kindergarten to grades 6-8 and throughout high school. Those eight steps of EDP are: (1) identifying the need or problem; (2) research on the need or the problem; (3) develop possible solution(s); (4) select the best possible solution; (5) construct a prototype; (6) test and evaluate the solution; (7) communicate the solution; and (8) redesign. Hynes et al. (2011) noted that the EDP focuses on solutions and construction of prototypes which impel students to encounter the process of creative and critical thinking as well as problem-solving skills. An affiliated research conducted in Malaysia showed improvement in creativity, problem solving skills, and thinking skills among rural secondary school students in the EDP outreach challenge program (Siew et al., 2016). This finding raises questions such as, “Would students’ STEM imagination be developed as a result of their participation in an EDP outreach program?”; and, “What are the students’ thoughts or issues raised on their learning experiences in an EDP outreach program?” There is very little evidence to show that this EDP process has been or is being used to explore students’ STEM imagination. Therefore, this study was undertaken to examine whether the EDP can contribute to the development of learners’ STEM imagination through an outreach program.

This study attempts to investigate whether STEM imagination can be developed among Grade 10 Science Stream students using a proposed engineering design process with imagination (EDPI) model (Figure 1). The scientific imagination process as proposed by Wang et al. (2015) is integrated into the EDP model in order to accommodate the development of STEM imagination among students. Some minor changes were made to the last three stages of the original EDP model proposed by the Massachusetts Department of Education (2006). This was done to ensure that students could produce physical prototypes that make the best use of their STEM imagination, materials, and time provided.

As illustrated in Figure 1, the brainstorming and association in identifying and researching of problems and solutions drive students to encounter the process of initiation. It allows students to become aware of the many possible solutions as they engage in sketching to propose solutions. The process of finding the optimal solution by designing a prototype based on appropriate choice of materials and techniques for assembling parts requires participants to engage in transformation and elaboration. Students are required to communicate their solutions to facilitators and peers on how to formalize the idea to be realized in future, thus driving them into the conceptualization, organization, and formation. The advantages of the proposed seven steps of the EDPI is that it focuses on construction, testing and evaluation of a prototype, hereafter referred to as “implementation.” By going through the seven stages in this process, learners are intended to develop STEM imagination (Table 2) while carrying out the STEM activities.

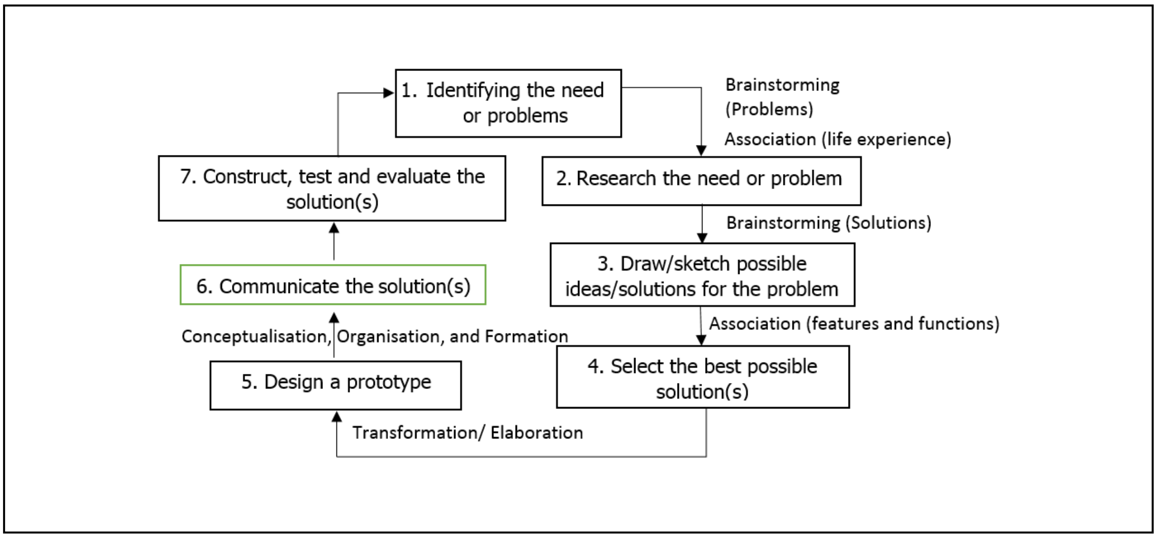

Figure 1. The proposed engineering design process with imagination (EDPI) model

Table 2
Stages and components of STEM imagination

Stages	Components
Initiation	Brainstorming and Association (problems)
Dynamic Adjustment	Transformation and Elaboration (solutions)
Virtual Implementation	Conceptualization, Organization, and Formation
Implementation	Construction, testing and evaluation

Research Purpose and Research Questions

Relatively few studies have been conducted on the development of secondary students' STEM imagination through the employment of the engineering design process. This research was therefore undertaken to explore the STEM imagination process that students encounter while engaging in EDPI activities. Additionally, this study also aimed to examine some of the students' thoughts or issues on their EDPI experiences. Accordingly, the research questions guiding this research were:

1. What are the STEM imagination processes that students encounter while engaging in EDPI activities?

2. What are the students' thoughts or issues raised on their EDPI experiences?

Method

Research Design and Participants

A one-group post-test only design with intervening EDPI outreach program was carried out in this research. A qualitative research design was used for data collection and interpretation. The outreach program was conducted in one of 54 secondary rural schools located within the Interior Division of Sabah, Malaysia. The school is located about 130 kilometers from Kota Kinabalu. The participants consisted of 50 Grade 10 Science Stream students with 37 females (74%) and 13 males (26%) aged 16 years old. In the Malaysian schooling system, 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: Science or Arts. 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 10 Science Stream students from one school who possessed about the same level of knowledge, ideas, lived experience, or experiences of STEM would best help the researcher understand the research question (Creswell, 2003).

Students were gathered into heterogeneous groups of four to five members. The groups were assigned by the participating secondary school teacher so that there would be an inclusion of students of high-, medium- and low-competency levels based on their individual scores achieved in the end-of-semester examination. A total of 33 science teachers participated as assessors and facilitators in the EDPI outreach program. They were trained to carry out the facilitation and assessment prior to the program. They were in-service teachers with degrees in Science Education and obtained passing grades in the Research Methodology course (qualitative and quantitative) in their Master's degree course which was simultaneous to the study. Nine of these teachers helped the researcher develop the STEM activities and testing procedures. The researcher guided the science teachers on how to facilitate students according to the seven steps of the EDPI in order to ensure the consistency and reliability in the implementation of the EDPI activities across students. The science teachers also helped the researcher to collect data.

Learning Through EDPI Outreach Program

The EDPI outreach program was designed with a focus to encourage rural school students to solve a situation-based problem by utilizing the EDPI model (see Figure 1). Through this endeavor, students were conditioned to engage in a myriad of brain-stimulating and integrative activities: to identify problems, to think about solutions, to design, to sketch, to communicate, and to construct a physical prototype of their design.

The EDPI program consisted of two STEM activities, lasting about five hours each. The STEM Activity 1 dealt with the El Niño phenomenon and its effects on crops, the environment, and humanity. In context, Malaysia was first hit by El Niño in 1998 and was recently impacted by the phenomenon again. The scenario is described as below.

> From the end of 2015 to this present day, agricultural activities in the Tambunan district has suffered adverse effects caused by El Niño. The prolonged drought has troubled farmers as well as students.

The STEM Activity 2 dealt with poor irrigation in paddy plantations as well as low rice produced in a rural area in Sabah. The purpose in exposing this activity was to engage students in making use of alternative energy and technology to improve the irrigation and output of farming activities. The scenario is described as below.

> The Tambunan district is a high ground area in the interior of Sabah and its paddy fields comprise 1,445 hectares of the district. There are two main rivers that give the paddy fields their main source of water; they are the Tondulu and Tambatu Rivers. Nevertheless, farmers are increasingly facing the problem of water supply and increasing their crops for commercial and personal use.

These STEM activities were introduced to accommodate the specific context of the students' daily lives in order for them to develop their imagination and understanding of STEM concepts. The students carried out the seven steps of the EDPI model (Figure 1) which are described as below.

Step 1: Identified the need or problems

- Students brainstormed together as many problems that were likely to arise by deriving them from the given scenario.
- Students associated or correlated as many problems as possible with their life experiences.

Step 2: Researched the main need or problem

- Students then identified the main problem encountered in their daily lives.

Step 3: Developed possible solutions for the problem

- Students brainstormed in groups using their imagination to propose as many possible solutions to the main problem.
- Students deliberated the possible physical features and functions of a creation in sketches to solve the pressing problem.

Step 4: Selected the best solutions

- Students selected the most suitable physical features and functions of a creation.

Step 5: Designed a prototype

Students drew sketches of their prototypes with greater detail of physical features, functions, choice of material, and techniques for assembling parts.

Step 6: Communicated the solutions

- Students communicated the physical features and functions of their prototypes to their facilitators and peers. The students were expected to showcase the science and mathematical concepts exhibited in their designs or prototypes.
- From the facilitator's comments, students reorganized and refined their previous prototypes by including the details of improved choice of material, techniques for assembling parts, and the means to create their prototypes. Students gave a name to their creations.

Step 7: Constructed, tested and evaluated the solutions

-Students then construct a physical prototype based on the final drafts of their design. Finally, they demonstrated and explained their final physical prototype to their peers and facilitators for feedback.

The role of the facilitators was to guide their students to come up with their own solutions. Facilitators offered assistance when the students became dispirited but did not suggest solutions for them. Through guided discussions and the engineering design process, it was intended for the students to develop STEM imagination that can be applied in the STEM fields.

Ethical Considerations

Permission to do the research was obtained from the school principal and teachers. At the beginning of the program, participants were presented with a letter of consent detailing the nature of their involvement in the program and the need to provide their consent on the sheet indicating their full understanding. The purpose of the research was explained in detail and all the participants were assured of the confidentiality of their response and of complete anonymity. Therefore, no names of the participating students were used in reporting the findings. All participants were informed that anyone could withdraw from the program and the interview without penalty. Code names were used for the data to ensure the confidentiality of the schools and individual identities.

Data Collection

The research data were collected through science teachers' field notes. Teachers made field notes based on their observations during the STEM activities and the focus group interviews with students. A total of 10 semi-structured focus group interviews were carried out after the completion of each STEM activity. The interview questions were open-ended (see Table 3) and the students were encouraged explicitly to draw their answers from their learning experiences during the EDPI activities. Each focus group interview was conducted in groups consisting of 4-5 students. Table 3 shows the tools that were used to address the corresponding research questions. Likewise, focus group observations were collected using an observation form adopted from scoring guides developed by Wang et al. (2015).

Table 3
Data capturing tools

Research Questions	Data Capturing Tools
What are the STEM imagination processes that students encounter while engaging in the EDPI activities?	Teachers' field notes based on focus group observations and interviews
2. What are the students' thoughts or issues raised on their on their EDPI experiences? a) How do students think of ideas for the problems/solutions? b) What kinds of difficulties did students encounter during the process of thinking for ideas? How did students overcome these difficulties?	Teachers' field notes based on focus group interviews

This scheme enabled the researcher to identify and gain knowledge about STEM imagination which students encountered during the STEM activity.

Data Analysis

The qualitative data was analyzed 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 the teachers' field notes by reading the data line by line and identified recurring patterns in the data. The patterns identified by each researcher were compared to ensure the validity of the codes. The researchers dealt with codes which had no consensus by comparing and contrasting perspectives and concerns in order to create common codes. Through multiple reviews and an iterative process, categories and codes were refined and grouped into themes.

Results

Qualitative Analysis on Participants' Response – Part 1

The science teachers' field notes which were based on focus group observations and focus group interviews were analyzed using thematic analysis. The abbreviations used for the analysis were "S" represents Student, and "G" represents Group. The STEM imagination process which students encountered while engaging in STEM activities is described as below.

Specifying the problems based on real life situations. The facilitators expressed that all 10 groups could brainstorm and specify many problems inflicted by El Niño and poor irrigation in the paddy field. There were seven groups that used mind maps to brainstorm the problems. The problems suggested by the students were the decreased production of rice, water shortage in paddy fields, infertile crops, limited outdoor activities, risk of diseases, arid ground, affected emotions, fire outbreaks, and heat stroke. There were five groups that even expressed their concerns about the level of water in the rivers due to over-vaporization.

Specifying problems which correlate with lived experiences. The facilitators expressed that students in 10 groups could make links to their own personal daily experiences. Additionally, they had hands-on experience seeing and handling the planting of paddy. Students also shared real life encounters where their families faced farming issues such as lack of rain water which causes low rice and ginger produce, dehydration during sports activities, health maladies such as headaches and migraines, increase of electrical bills, and forest fires causing haze. Students added that the extreme hot weather caused fatigue and disrupted their daily work.

Proposing solutions to the problem. Overall, all 10 groups managed to generate many solutions to overcome the problem specified by group members. The students in five groups decided to create windmills, water mills or water pumps to solve the problem of water shortage in paddy fields. The idea of making a windmill was for the purpose of producing electricity as an energy source while the water pump idea was to enable water to flow systematically in large quantities. Water mills function by creating a strong force that pushes water to flow in bigger quantities to enter into paddy fields. The prototypes were proposed based on the students' observations of paddy fields in their surroundings. To illustrate, S3 and S4 in Group 2 stated:, "We created this model based on our observation in several places that have windmills. We tried to manipulate that idea into something new with more functions that can positively impact the community" (S3, S4, G2).

The participants explained that adding windmills could help generate electricity because the villages were located far from any source of electricity. This showed that the students took the welfare into account since they were able to envision the villagers and families enjoying the use of electricity without worrying about bills. Collectively, the students considered their families and the villagers when deciding on a solution for the problems they faced caused by El Niño.

The most common examples used by another three groups to battle the extreme heat caused by El Niño was the use of green technology which incorporates the use of solar panels to generate electricity as well as a water tank to collect rain water that circulates it to the whole house. Another solution propounded by another two groups was a water sprinkler to help water plants which could save villagers energy as well as cost, since it is built using only recycled materials.

Illustrating the physical features and functions of their creations. From the science teachers' observation, 80% of the groups could illustrate the physical features and functions of their creations per suitable science and technology concepts through Sketch 1 and Sketch 2, while two groups expressed problems, they faced concerning materials and technical issues. For example, Group 5 facilitators stated that their students initially had difficulty and took some time to illustrate ways to combine the function of the windmill with the water pump. Nonetheless, students eventually managed to assemble their creation through Sketch 1 and Sketch 2, after the facilitator guided them through relevant questions such as, "What alternative energy can generate electricity?" and, "How can the wind mill power up the water pump?"

Group 10 was a shining example in the activity. They unanimously decided to create a water mill because they had witnessed farmers using this contraption in the process of planting paddy. This group truly impressed their facilitators and showed great enthusiasm in the activity. Comparatively, Group 8 students had to receive lots of encouragement and feedback from their facilitators to illustrate their models. They had never seen a water pump before, so this made it difficult for them to envision and draw one. The facilitator described how to make a water pump by relating it with the functions of the human respiratory organs such as the diaphragm and heart. Consequently, this group realized that the creation of the pump corresponded with the observation of the way those human organs work. This group could illustrate their model by applying the use of valves to create a singular flow and observing low-pressured spaces to contain water using the concept of breathing.

Group 9 subsequently illustrated their idea by proposing a prototype named "El Niño Water Fountain" that used the vaporization technique and an air filter tool. They also stated that the creation could collect water from plant sources such as bamboo.

Reorganize or refine the physical features and functions of the creations to solve the problem given. Facilitators stated that 80% of the groups could reorganize or refine their models as they progressed from Sketch 1 to Sketch 3. More elaboration on physical features and functions were observed in students' sketches. There were two groups that retained 20% of their original ideas from the first sketch while seven groups transformed the specifications of their sketches from the ground up. Sketches from one group had only slight changes in the three sketches they were asked to do.

One example of a good sketch was created by Group 7. At first, they drew a simple sketch that matched the real prototype they had wished to create. They drew a newer sketch that was more detailed through their own effort and good planning and creatively named their creation the "Non Stop Water Resources System." Other groups, such as Group 4, managed to include the process of creating their models in their sketches.

Initially, Group 9 presented very simple and basic sketches of their models. They were very much influenced by their childhood experiences. They explained that they used to eat chocolates that had fan blades to play with. Others shared that they had seen windmills in paddy fields that had whistles attached to them to scare off birds. After discussing and drawing a few sketches, they drew a more sophisticated model together with the specifications of its parts.

Participants from Groups 5 and 6 underwent a different experience compared to the other groups. They were reported to have made unclear and weak sketches especially in arranging the physical characteristics to create their model. The students were simply perplexed with the use of recycled materials The facilitators reported that while presenting their creation, the students showed poor knowledge about scientific concepts such as the greenhouse effect, renewable energy, and heat convection. Nevertheless, they could explain two physical traits that influenced the windmill's ability to spin well which were the size and number of blades on the windmill. The facilitators took note that the students did not create a windmill that could generate a large amount of electrical current. So the facilitators gave them guidance by directing them to questions about green technology which eventually set the path for their creation.

Conceptualize, organize, formalize and communicate the idea through a detailed sketch. Facilitators stated that all of the groups could draw their final sketches but they varied in details, focus, characteristics, choice of material, and techniques for assembling parts. Some sketches were elaborated and clearly demonstrated the functions of the models while others were too simplistic and lacking in detail and sophistication. Overall, the groups made improvisations to the ideas for the model from the materials they used while assembling their sketches.

It was difficult for two groups to determine an idea to draw for their best sketches. This involved the process of choosing the right material, assembly techniques for the parts of the prototype and the steps to create the final draft of their sketches. These groups needed time to conceptualize their ideas into the sketch through the process of constant thinking and trial and error. A student stated about drawing sketches, "This activity stimulated me to think far and I got to think of many ideas and sketches. We used the trial-error method to draw the most suitable sketches" (S2, G6).

There were eight groups that were able to create organized and precise second sketches compared to their first ones. The participants could draw well by labelling the parts of their creation. Improvisations were done in group sketches particularly in rearranging and adding to the physical characteristics and functions of the parts of their creation. Other sketches showed the combination of materials, assembly techniques and steps to create the prototype. The facilitators often played a role in improving the students' sketches. They would challenge their students with questions in order to get the participants to create better and more effective creations.

Group 10 did not initially sketch a water tank and irrigation pump but after testing the prototype and establishing its weakness, they felt the need to add a water tank and irrigation pump to enable the model to function better. They also improvised the water mill so that it would not only increase irrigation but also generate electricity.

On the other hand, Group 3, 4, 7, and 10 facilitators were satisfied with their students' efforts to refine their creations. They commented that their groups had drawn detailed sketches which showed the good combination of various materials, installation techniques, and methods of creating their model. The students drew their sketches along with the physical traits of their creation such as the fan, wires, and motor. A Group 7 student remarked that,

> The new thing we have learned is the combination of windmill and the water pump. Before this, we know that the windmill functions to generate electricity only, but now we know that the windmill can be connected to the water pump. The electricity produced by windmill is used to power up water pump, thus can overcome the problem of water shortage (S3, G7).

An example of the students' efforts to create a physical prototype was by creating more than one possible model using different materials. Group 1 did a good job by sketching two designs for their model. They described the use of a drink can, 1.5ml plastic bottles, bottle caps, DC-motors, electrical wires, and a hot glue gun. The students created two physical windmills each from a 500ml bottle and a drink can. They realized that the aluminum windmill could generate more energy so they made more adjustments to this creation to increase its energy flow. Group 9 created very basic and simple drawings of their creation in the beginning; but after brainstorming, they took stability into account to create a physical windmill that had a bigger base to increase its stability. The students improvised their ideas and sketches as they went along this process. A student remarked,

> There were many differences. Among them, from our first idea until the end product. We identified the weaknesses from the beginning and we improved it along the process till we got a model like this that has many functions. We combined many elements, for example, using water and also solar (S4, G9).

Statements such as the above demonstrate that the students constantly made improvisations in the choice of material and assembly technique to create a stable prototype with more functions.

Construction, testing and evaluation of the final prototype (Implementation). The students mainly assembled their ideas by examining the most suitable and best idea among them. Through discussions, students integrated their original idea with the final sketch to create the prototype. They tested their physical prototypes through many attempts, improved or modified their original idea through the process of constant thinking and trial and error. Students in four groups stated that their ideas were gained during the sketching process and creating the physical prototype. On the contrary, two groups said that by just observing their materials they were able to come up with new ideas. Eight groups admitted that their final product and original idea were very different from one another while two groups said there were slight differences between their initial idea and final product. This was due to the fact that students had combined many elements together.

Conclusively, the big ideas about student engagement in STEM imaginative processes are presented in the Appendix.

Qualitative Analysis on Participants' Responses – Part II

The science teachers' field notes, which were based on focus group interviews, were analyzed using thematic analysis. The students' analyzed responses were about their thoughts or issues they faced while engaging in the STEM imagination process. The main findings in relation to the sources of generating ideas, difficulties encountered, and ways to overcome these difficulties are discussed as below.

The sources of generating ideas. A majority of the students from almost all of the 10 groups stated that their own past daily life experiences inspired them in generating ideas to solve the problem. This was gained via their observations and experiences of their surroundings and the environment in the paddy fields and during El Niño. A significant number of students said that their ideas derived from television shows, internet videos, blogs, social media platforms or previous school experiments. Besides that, seven groups expressed that group discussions were the catalyst for their ideas while three groups stated that they had thought of ideas based on their own knowledge or views. Even the facilitators' questions helped the students to think of ideas. Other ways which students thought of new ideas were through the combination of their ideas as well as through the trial and error method. Two groups said that ideas were derived from their own imagination while six groups said they improvised ideas that had already existed.

Difficulties the students encountered during the process of thinking of ideas and ways they overcame these difficulties. There were six groups who revealed that participating in the STEM activities was a new experience and that they had insufficient scientific and technical knowledge to think of novel ideas. This was evident in their group sketches where they used irrelevant scientific concepts to elaborate the mechanism of their inventions. It was also noted that students in these groups chose irrelevant materials and assembly techniques for the prototypes' parts. There were four groups who commented that the time given to think of new ideas was insufficient; students stated that they overcame these difficulties by seeking help from their own group members. Group members combined and refined their group members' ideas in order to reach the best solution. They used the provided materials to explain their ideas to one another, while others received guidance, support or inspiration to voice ideas.

There were three groups who revealed that they sought help from the facilitators. The most notable assistance provided by the facilitators, according to them, was in the form of clues, ideas or tips, and encouragement to boost their morale. Students independently solved the problem by employing their skills learned in the science process and experimenting with methods or derived solutions from scientific investigation they had learned in school.

Discussion

Research findings showed that students were inclined to associate their lived experiences with the environmental and agricultural problems presented in the STEM activities. Conclusively, the findings reinforced previous studies (Lottero-Perdue, 2015; Neo et al., 2012) which claim that the engineering design process provided a mechanism through which students learn to make connections by engaging in "real-world" contexts. This research demonstrates that the EDPI approach, which allows students to make connections and associate their lived experiences with the environment, could enrich their STEM imagination beginning from the stage of association.

The EDPI outreach program not only enabled students to specify problems correlating with lived experiences but also provided an avenue for them to propose solutions to a universal problem. Notably, the students showed their STEM imagination and enthusiasm to create prototypes that could become solutions to a problem they faced. Students could illustrate the physical features and functions of their creations in forms of windmills, water mills, water pumps, or water sprinklers etc. Students expressed that the sketching process for ideas or solutions enabled them to elaborate and organize the physical features and functions of their creations. This process has helped students to foster the dynamic adjustment process of their STEM imagination.

This program tailored according to the engineering design process also managed to cultivate an environment that encouraged students to engage in sketching detailed drafts of their creations and illustrating details for their choice of material and techniques for assembling parts. Students conceptualized, organized, and formulated their final drafts, even if they varied in detail, focus, characteristics, choice of material, and assembly techniques for assembling parts. New ideas were generated by improving their sketches through the process of trial and error. Ho et al. (2013) similarly highlighted one's ability to make use of the process of trial and error in imaginative activities. Despite several difficulties encountered during the activities, students were able to make improvisations towards their sketches and formulate better prototypes through group effort and guidance from facilitators. This study demonstrated that the virtual implementation process in the STEM imagination of the students was inculcated among them by consolidating students' conceptualization, organization, and formulation of ideas via group members and facilitators' guidance, and the process of trial and error.

The final prototypes produced by the student groups were mostly different from the original ideas. This was a direct result of the students' efforts to combine and refine their creations through the iterative thinking process and trial and error. Ho et al. (2013) similarly believed that individuals use imagination to create new inventions to improve life through the process of constant thinking and trial and error. In tandem, a previous study by Siew et al. (2016) affirmed that the integration of STEM in an engineering design process enabled students to organize their thoughts to choose the best possible solution for their prototype using related STEM concepts.

The sources of students' STEM imagination, according to the findings, is mainly based upon their own observations and experiences about events in their daily surroundings and environment. The most common source for ideas presented by the students originated from their realization of the need to solve real life personal and familial encounters with irrigation problems in their paddy fields and the adverse effects of El Niño. Previous research (Lindqvist, 2003; Pelaprat & Cole, 2011; Vygotsky, 2004) also confirms that an individual's daily life experience is the source of imagination. Besides that, social experiences derived from interactions with information-based technology, internet-based information, and group discussions were also needed for students to generate novel ideas. Vygotsky (2004) similarly opined that an imaginative creation draws upon and combines different elements of prior experiences and social experiences with other people.

While the students described many sources as the catalyst for their imagination, they also voiced several issues during the process of thinking for new ideas. The most mentioned challenging aspect in the program was insufficient scientific and technical knowledge, which was evident from some irrelevant materials and assembly techniques given in the sketches. Students overcame this deficiency by combining or comparing group members' ideas and getting help from the facilitators in the form of clues, ideas or tips. A previous study (Siew et al., 2015) also asserted that sufficient scientific knowledge was an aspect that determined success in STEM activities. This study highlighted that students who are equipped with sufficient scientific and technical knowledge would be able to think of lots of possible practical and relevant creations in the real world. Thus, adequate classroom opportunities to strengthen students' scientific and technical knowledge is a critical matter and should be facilitated by educators.

Conclusions

The findings reveal that students needed to draw from their lived experiences to brainstorm problems and solutions around a given scenario and to arrive at a workable solution in order to progress from the initiation to the implementation stage of STEM imagination. Individuals' lived experience was mainly derived from the living environment, while social experiences were from interactions with other people and information-based technology. Under the facilitation of the EDPI approach, students were able to formulate concise ideas capable of solving problems associated with daily lives, in spite of insufficient scientific and technical knowledge. The EDPI approach can create a supportive environment for nurturing STEM imagination among rural secondary school students. By nurturing students' STEM imagination, science educators can prepare students to become better creative thinkers and problem-solvers who have the necessary abilities and skills to address problems and issues faced on an everyday level in new and innovative ways. This study has therefore highlighted the pivotal role of applying integrated approaches such as the EDPI approach to propel students' STEM imagination to greater heights in line with the needs of the country in this 21st century.

This study embraces the usability of an EDPI approach as a reference model for scholars, academicians and educators who are driven to develop a similar learning process for developing STEM imagination. This study also proposes that the approach can be further improved for maximum effectiveness in the future. Future research may need to address two issues highlighted in this study. First, while students' scientific and technical knowledge is helpful to the imagination processes, this may benefit students who can draw from their lived experiences and use these experiences to arrive at a workable solution. However, some students may not have as much of a chance to relate if they have had different or limited experiences. Thus, a class session about basic scientific and technical knowledge needed in the program is therefore suggested to be provided to students prior to their engagement in the EDPI approach. The second issue is that facilitators were not the science teachers from the participating school, which may influence the way in which participants shared their ideas during the focus groups interviews. In future research, the facilitators may need to be trained on how to help groups to build rapport and trust.

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Appendix

The big ideas about student engagement in STEM imaginative processes

Student engagement in STEM imaginative processes	
1	Specifying the problems based on real life situations. Example: decrease produce of rice water shortage in paddy fields infertile crops
2	Specifying the main problems correlated with lived experiences Example: dehydration during sports activities health maladies (e.g. headaches and migraines) increase of electrical bills forest fires causing haze
3	Proposing and selecting the best solutions to the problem Example: wind mills, water mills and water pumps solar panels and water tank water sprinkler
4	Illustrating the physical features and functions of their creations Example: drawing sketch 1 and sketch 2 relating to organs of human respiratory system applying the vaporization technique
5 (i)	Designing a prototype (Part 1) Reorganize or refine the physical features and functions of the creations to solve the problem given Example: transforming the specifications of sketches from the ground up drawing and assessing a few sketches retaining the 20% of original ideas
5(ii)	Designing a prototype (Part 2) Conceptualize, organize, formalize and communicate the idea through a detailed sketch Example: examining the most suitable and best idea choosing the right material and steps, and assembly /installation techniques and methods rearranging and adding to physical characteristics and functions of the parts of creation communicating the detailed sketch to facilitators
6	Constructing, testing and evaluating the solutions Example: creating more than one possible model using different materials testing the prototype out and establishing its weakness testing the physical prototypes through many attempts going through the process of constant thinking and trial and error.