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A STEM Robotics Workshop to Promote Computational Thinking Process of Pre-Engineering Students in Thailand: STEMRobot

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Abstract: Engineering becomes significant in every aspect of our daily lives. To understand and learn engineering effectively, its foundation derives from the integration of multiple content subjects of science, technology, and mathematics. In Thailand, these topics are taught independently, making young students do not understand and apply the knowledge further. Furthermore, engineering education requires computational thinking skill to solve problems and create products logically. Therefore, this paper proposes a robotics training workshop to promote computational thinking process for pre-engineering students. The workshop activities, including labs, tasks, and competition are developed based on STEM strategy to provide meaningful, engaging learning environment bonding relevant knowledge in robotics performance. After analyzing collected data from questionnaires and interview, it was found that the pre-engineering students could enhance robotics performance, where their computational thinking process was promoted through its component of logical thinking, problem-solving and creative thinking. Interestingly, the high-robotics performance students could solve robotics problems more logically with creativity than the other group.

Keywords: Robotics, STEM, engineering education, computational thinking, collaborative knowledge construction, training workshop

1. Background and Rationale

Since the second industrial revolution era in the late 20th century, the term engineering has become prominent to focus on around the world. Most of the products and services used in various industries have been invented to maximize the productivity (Clark, 2007), ranging from conveyor lines to move many products at a faster rate to autonomous arms to grab tiny parts in the automobile industry. Especially in the past decades, engineering plays a crucial role in everyone's daily life (Pasman & Mulder, 2010), starting a day with small alarm clock with a thousand of mechanics, check the news on mobile devices, get an instant coffee flavored for most people, till ending a day with watching a favorite drama series on the internet-connected TV. This illustrates how engineering is significant to everyone. In this perspective, engineering education is important.

Engineering education focuses on the teaching and learning relating knowledge and principles to the professional practice of engineering. Engineering education must be strengthened to teach and provide training in critical and creative thinking skills and problem-solving methods (Felder et al., 2000). In Thailand and many countries, young students learn many subjects at school independently (Chesloff, 2013). Most of those subjects are the foundation of engineering education at the higher level, e.g. Mathematics, Physics, Science, and Technology. This disables students to see and understand how the knowledge of multi disciplines integrate together to perform or operate certain tasks/functions of the engineering process. Furthermore, the students lack essential skills which are significantly required for an engineer; that is computational thinking process (National Academy of Engineering, 2009; Swaid, 2015).

Computational thinking was firstly introduced by Papert in 1996 as the value of applying human cognitive primitives to object oriented problems by noticing the relationships between the components of a complex system based on students' thinking. After that, Wing (2006) proposed the computational thinking that is a kind of analytical thinking. It shares with engineering thinking in the general ways in which we might approach designing and evaluating a large, complex system that operates within the constraints of the real world that approach to solving problems, designing systems and understanding human behavior that draws on concepts fundamental to computing (Wing, 2006; Wing, 2008). To enhance the computational thinking process, three major components are required, i.e. logical thinking, problem-solving skill and creative thinking (Bocconi, Chioccariello, Dettori, Ferrari, & Engelhardt, 2016). Especially for engineering education, young students should get ready and trained with carefully designed learning activities. Many research attempts to study the element of preparing high school students into engineering education such as engaging in design thinking with a little understanding of the problem of high school students (Mentzer, Becker & Sutton, 2015). In addition, the integration of science, mathematics, and engineering is a benefit of students in high school engineering they can design work without teacher prompting when the concepts were familiar (Valtorta, and Berland, 2015).

The current research interest in science, technology, engineering, and mathematics (STEM) has been emphasized in high schools and higher education (Eguchi, 2015; Thomas & Watters, 2015; Mosley, Ardito & Scollins, 2016; Master et al., 2017). In the past decade marked the beginning of a transformative time for engineering education, many research has interested the challenge in engineering education is the ability to promote students' learning by thinking and working in pursuing careers in STEM. Moreover, several researchers' interesting design and implement STEM using robotics (Kim et al., 2015; Master et al., 2017). Educational robots enable the students to integrate different fields of knowledge, from basic mechanical devices, electrical peripherals, sensors, computer programming, to operate the robots. Meanwhile, the students have to perform systematical, logical, critical, and computational thinking to analyze the robotics environments, assemble the parts, configure to meet the surrounding conditions. These processes require hands-on exercises with trial-error basis to achieve the goals (Leonard et al., 2016).

Presently, many research used the advantage of robotics that offers opportunities for students to engage computational thinking skills (Atmatzidou & Demetriadis, 2015). Computational thinking tries to strengthen the development of students' learning achievement. Computer programming has become an important skill to express ideas, inspiring student's originality while helping develop logical thinking. Many studies attempt to use robotics technologies in education is increasingly common and has the potential to impact students' learning (Kucuk & Sisman, 2017).

Using robotic programming software has become an increasingly popular, and the use of tools is regulated in education. The graphic programming environments play an essential role to enhance computational thinking in the learning process (Basogain et al., 2017). Thus, finding ways to foster computational thinking and to incorporate computer programming in many research, such as Chen, et al. (2017) proposed framework of computational thinking for elementary school where a new humanoid robotics curriculum has good psychometric properties and has the potential to reveal student learning challenges and growth in terms of computational thinking.

Based on this significant perspectives, therefore, this study aims to propose a STEM-based robotics workshop to enhance pre-engineering students in Thailand. mBot educational robot kit was used in a series of workshop tasks and activities, which were developed accordingly to promote students' computational thinking process. To direct this study, several research questions were formulated: 1) how is the computational thinking process of the students who participate in the proposed workshop, and 2) what are their engagements towards the STEM-based activities in the proposed workshop?

2. A Proposed STEM-based Robotics Workshop

In this study, the researchers adopted the idea of STEM education to help prepare pre-engineering students to understand the mechanism and phenomena of basic engineering. With the availability of time, resources and environment, a robotics workshop was hosted for students as it enables the real-world applications of the concepts of engineering and technology and helps to improvements in science, technology, engineering, and mathematics learning (Kim et al., 2015). Therefore, a STEM-based robotics workshop was presented in a training workshop format, hereinafter called, STEMRobot. This study mainly focuses on the computational thinking process as a result of this workshop.

2.1. Overall Structure

The structure of STEMRobot mainly comprises of how the elements of STEM integrate together as a workshop, what activities are carried out in order to enhance the computational thinking process (CTP) of the participants, as presented in Figure 1.

In the workshop, each STEM element is account for certain concepts: S (Science) covering condition, iteration, variable and parameter in computer programming, T (Technology) used in this study: an educational robot kit (mBot) with graphical programming software (mBlock), sensors and Bluetooth connection, E (Engineering) covering construction, mechanical, electrical, precision and stabilization, M (Mathematics) covering number, measurement and estimation, transition and rotation. While, CTP in this study considered from logical thinking, problem-solving skill and creative thinking. Therefore, a series of learning activities, labs and competition were carefully designed in this training workshop.

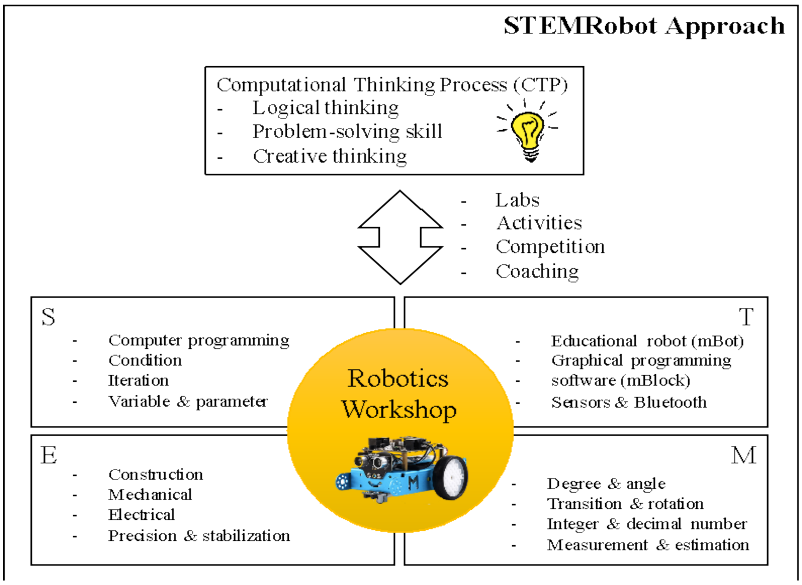

Figure 1. An Overall Structure of STEMRobot.

2.2. mBot and mBlock

mBot is an affordable educational robot kit designed for learners to enjoy the learning experience of programming, electronics, and robotics (Merino et al., 2016). As shown in Figure 2 (left), mBot is a detachable robot operating under the integration of core body, main board, wheels with motors, light sensors, mechanics and electrical components, etc. Apart from the assembly process, the robot is controlled by the programmable computer code structured in the graphical programming software companion, called mBlock.

mBlock programming software is made up of colorful and modularized drag-and-drop graphical blocks for writing Scratch 2.0 language, presented in Figure 2 (right). Unlike traditional programming environment, mBlock came in graphical interfaces allowing to learners to easily program the robot without writing difficult codes. Note that the code can be wirelessly transmitted to the robot's main board via Bluetooth.

With this educational robot kit, there is a number of challenges for students to enable opportunities of different robotics experience. The students have to consider relevant contexts both physically in the robot and virtually in the programming, such as what happened with the robot, why it moved out of the direction, what to reassemble the robot, how to make it better, how to adjust the code blocks accordingly to achieve the goals.

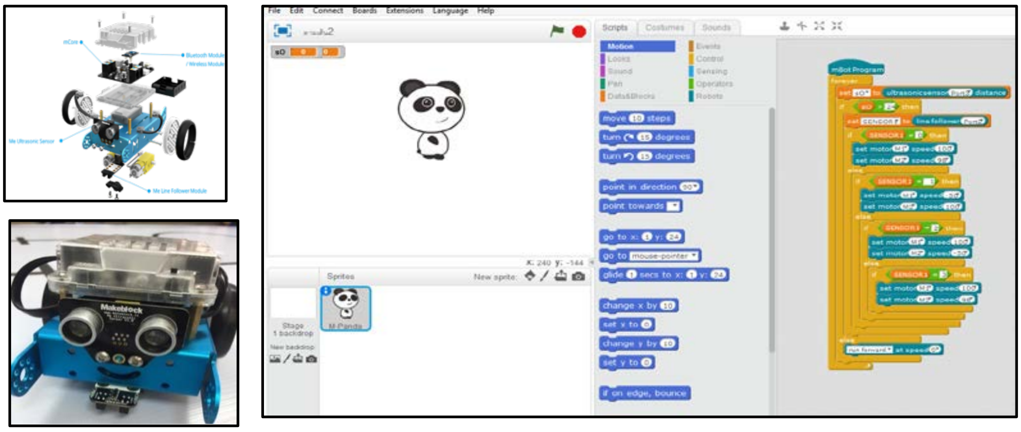

Figure 2. mBot Structure (left) and mBlock Graphical Environment (right).

2.3. Workshop Activities

In STEMRobot, a three-day training workshop is provided for higher-secondary school' students. The workshop run by the organizing team which comprises of a teacher who has expertise in mechanical engineering education and robotics as a workshop host, and vocational pre-service teachers in mechanical engineering education as teaching assistants (TAs). They all have been trained to not only facilitate the robotics workshop but also provide the meaningful guidelines for workshop participants. Students participate the workshop in groups of 2-5 members upon the availability and convenience. Note that the organizing team arrange the workshop environment and prepare one robot kit and one computer laptop for each group of students. The workshop activities are scheduled as follows.

Day 1: the students get acquainted with the mBot components through several mini labs: control board, sensor, speaker, battery, and motor. After that, they begin to design and assemble the robot step-by-step, and learn how to program the robot, such as turn life and turn right, move forward and backward. At the end of this day, the students should be able to understand how the robot functions and how to operate the robot.

Day 2: the students in each group work together on the given tasks ranging from testing the robot on the field to moving robot following symmetrical and unsymmetrical tracks. At this moment, each group is faced with different problems upon their robot's settings and programming. They learned to analyze and solve the problems in a logical way by taking the knowledge integration of STEM.

Day 3: it is a final day in which each group is encouraged to apply what they have learned to accomplish the goal effectively on the robot competition. As in the preparation, they are expected to work in cooperation with peers for planning, analyzing, solving the problems, and finally showing the best performance in the competition.

Through three-day training workshop of STEMRobot, the students could encounter trial and error process and learn from the mistakes to not only better understand the engineering process, but also develop their computational thinking process. However, the activities in the proposed workshop have been tested for the collaborative knowledge construction, robotics and engineering understanding and STEM workshop before the implementation. Figure 3 shows parts of the workshop activities.

Figure 3. Workshop Activities.

3. Methods

To examine the results of this proposed STEMRobot approach, a three-day workshop has been conducted with 31 higher-secondary school students from a school in the upper central area of Thailand (21 males, 10 females). Participants, who are studying the science and mathematics program and have had a basic understanding of computer programming, spent three days in ten groups for this workshop at their school.

In order to investigate and understand the effects of the proposed workshop, two research instruments were used in this study. First, a questionnaire for assessing STEM robotics workshop engagements and for evaluating the perception towards the workshop; the former adopted from Kim et al., 2015 has 13 items to assess behavioral engagement, cognitive engagement, and emotional engagement, while the latter examine students' satisfaction on 5-point Likert scale items on two dimensions of workshop activities and usefulness. Second, nine semi-structure interview questions (five scores for each question) to investigate students' computational thinking process through following components: logical thinking, problem-solving skill, and creative thinking. Both instruments were cross-validated for item discrimination and reliability with four experts in technology/computer education, mechanical engineering, and robotics. In addition, the results from labs, activities, and competition from the workshop were also collected from the activity sheet and observations done by TAs.

This research study adopted a one-shot case study design with one group of the participants. The participants received a three-day workshop based on the proposed STEMRobot approach. Then, they were required to provide the answers on the questionnaire individually for ten minutes and interviewed for another ten minutes.

4. Results

4.1. Computational Thinking and Robotics Performance

In this study, the participants were separated into ten groups completing six workshop labs/activities (30 points) and one final competition (70 points) covering robot assembly/structure (10 points), logics and coding (10 points) and competition result (50 points), in a total of 100 points. The robotics performance results can be ranked by each group's collected points. To better understand the effects of the proposed workshop, the difference between a high robotics performance group (HIRP) for top three groups and a low robotics performance group (LORP) for bottom three groups were contrasted.

From the interview scoring results shown in Table 1, it was found that the students in HIRP group (high level) hold better computational thinking process than LORP group (medium level) on the problem-solving component. While both groups gain the same results on logical thinking (high level) and creative thinking (medium level) components.

To further understand this phenomenon, the correlation between each two component was analyzed as presented in Table 2. It was found that there were significant correlations between PBS and LOG, and CRT and PBS on HIRP group, and between PBS and LOG on LORP group.

Table 1: Descriptive results of computational thinking components between high- and low- robotics performance groups.

Component	HIRP Group		LORP Group	
	M ± SD	Interpretation	M ± SD	Interpretation
Logical thinking	4.22 ± 0.38	High	4.05 ± 0.16	High
Problem-solving	4.16 ± 0.94	High	3.58 ± 0.58	Medium
Creative thinking	3.91 ± 0.82	Medium	3.50 ± 1.23	Medium

Therefore, it can be implied that the proposed workshop approach better helped promote computational thinking process in those who gain higher robotics performance. Moreover, those who better performed on robotics tended to have creative thinking to solve the problems logically, while those who lower performed could solve the problems logically but lack of creative ideas.

Table 2: Pearson correlation coefficients results among computational thinking components.

Component	HIRP Group			LORP Group		
	LOG	PBS	CRT	LOG	PBS	CRT
Logical thinking (LOG)	1	0.87***	0.63	1	0.50*	0.49
Problem-solving (PBS)	0.87***	1	0.86*	0.50*	1	0.52
Creative thinking (CRT)	0.63	0.86*	1	0.49	0.52	1

*$p < 0.05$; ***$p < 0.001$

4.2. STEM Engagement and Perceptions

Owing to the data collection procedure, it was found that most of the students' responses were inadequate for numerical analysis. Therefore, the results of students' engagements in the proposed STEMRobot approach were presented qualitatively on three different aspects in Table 3. For behavioral engagement, the high-robotics students revealed that they could perform well individually and prefer no distraction environment, while those with low-robotics performance enjoy learning in a group with friends to support and make a decision. Both groups agreed that three persons in the group are best for cooperation and united. For cognitive engagement, the better robotics students can reflect higher thinking skill on applications on their daily lives, while those in another group just reflect what they have experienced from the workshop by putting more efforts before the success. Moreover, the students in LORP group revealed their emotions towards the assistance of peer members in the group that could encourage them to proceed on the workshop.

Table 3: Qualitative results of individual students' STEM engagement towards STEMRobot.

<table>
<tr><th>Engagement</th><th>HIRP Group</th><th>LORP Group</th></tr>
<tr><td rowspan="2">Behavioral</td><td>- I prefer to run the project individually.
- I think classroom is the best learning environment with less distraction.
- Regular classroom is best with A/C.</td><td>- Work in team can make a better decision when needed.
- Lecture hall is the best learning environment as we can meet friends.</td></tr>
<tr><td colspan="2">- Team of three members are suitable for the project.
- I think working in group can produce a better work and performance.
- Discuss with peers in group makes us united.</td></tr>
<tr><td rowspan="2">Cognitive</td><td>- I can apply what I have learned from this workshop in my everyday life.
- The workshop helps my cognitive development.
- Planning is the key for any process.</td><td>- I have learned and experienced new things.
- Time is too short to complete the project.
- It took me many mistakes before seeing the successful results.</td></tr>
<tr><td colspan="2">- TAs are very helpful for learning in this workshop.</td></tr>
</table>

Emotional	- Watering the plants and fixing the light bulbs are my very first plan to do after the workshop.	- I cannot apply this knowledge in my life. - I gave up sometimes in workshop activities but friends helped.
	- I very enjoyed the activities in the workshop. - It's really worth joining this activity.	

In addition to that, the students' perceptions towards the STEMRobot approach were examined on two dimensions, as presented in Table 4. It was found that students in HIRP group were more satisfied than those on LORP group on workshop activities and workshop usefulness. This result confirmed that those who better improve robotics performance could perceive the benefits of learning activities arranged by the organizing team and perceive its usefulness of integrating difference knowledge domains of science, technology, engineering and mathematics in their daily-life applications.

Table 4: Perception results towards STEMRobot

Items	HIRP Group		LORP Group	
	M ± SD	Interpretation	M ± SD	Interpretation
Activities	*4.76 ± 0.31*	*Highest*	*4.45 ± 0.58*	*High*
The learning environment is engaging with enjoyment.	5.00 ± 0.00	Highest*	4.35 ± 0.74	High
The facilitator provides a meaningful learning guideline	4.70 ± 0.48	Highest	4.37 ± 0.74	High
The learning materials are given for learning enhancement.	4.60 ± 0.51	Highest	4.62 ± 0.51	Highest
Usefulness	*4.50 ± 0.70*	*Highest*	*4.35 ± 0.53*	*High*
The knowledge gained from this workshop can be applied in other projects.	4.50 ± 0.75	Highest	4.40 ± 0.51	High
The workshop illustrates the real applications of regular school contents.	4.50 ± 0.75	Highest	4.30 ± 0.65	High

* Maximum level

5. Conclusions and Discussion

Owing to the importance of engineering and the flaws of learning subjects independently in the regular school context, this paper presented an approach for conducting robotics workshop based on STEM strategy for pre-engineering students in Thailand, called STEMRobot. The educational robot kit, mBot, and its accompanied graphical programming software, mBlock, were used as a major tool in this workshop. With this robot kit, the students can learn and experience different robotics situations in which they are required to tackle on to accomplish the goals. A series of workshop activities, tasks and competition were developed accordingly by focusing on the integration of science, technology, engineering, and mathematics. In this study, this proposed STEMRobot aims to promote the students' computational thinking process from a three-day robotics training workshop.

By collecting data from the activities results and observations, their robotics performance can be collected. Moreover, the participants also took a questionnaire and interview questions for further analysis. It was found that the students in higher robotics performance revealed better computational thinking process than those who are in the lower robotics performance. Moreover, the former tended to solve the problems with better logics and creativity. Furthermore, the former group provided more advanced responses towards the STEM engagement questions than the latter group, meaning that they were higher engaged in the STEM strategy. Both groups were satisfied with the workshop activities and perceived the usefulness of this workshop.

The findings of this research study shed light the essence of STEM activities with robots which not only help better understand the engineering process and robotics but also help promote the significance of computational thinking process from different aspects. However, the results of this study could not generalize to bigger population due to the limited number of participants (Polit & Beck, 2010). The finding was aligned with Eguchi (2016) and Leonard et al. (2016) that the high robotics achievers can better handle different robotics tasks logically.

Based on the existing results, we would suggest the educators on STEM, robotics, engineering to be aware of applying the proposed approach to your actual contexts with following recommendations. First, the grouping process of workshop participants is important to the success of their learning. Second, the materials and robots setup should be carefully tested at the workshop location in advance. Additionally, a series of follow-up studies can be performed upon the future implementation of the proposed approach, such as the behavioral pattern of participants, the effects of peer collaboration, and the use of digital tools to track the participants' ongoing robotics performance.

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