Enhancing High-School Students' Computational Thinking with Educational Robotics Learning

An investigation of three-day workshop activities based on STEM education

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***Abstract*— In recent years, engineering education has become one of the challenging issues in Thailand education. By teaching and learning subjects independently, students are limited to subject-oriented problems, which are not in reality. To address these flaws, integrating knowledge across disciplines becomes significantly necessary. In the past years, STEM has been accepted as one of the effective strategies to bridge the difference in nature of each field to construct more practical projects and innovations. Moreover, the educational robot can be employed as a learning tool in that strategy since it not only provides challenging learning missions but also promotes computational thinking for the students. Therefore, this research study proposed STEM learning activities on three-day workshop to lay out the foundation to the high-school science-and-technology students who are becoming the engineering students. The workshop comprises of eight phases to facilitate their learning inquiry process with hands-on experience; moreover, the activities were designed in consideration of promoting computational thinking with challenging learning missions. The findings of this study showed that the proposed workshop activities are beneficial for the students who outperformed on robotics with higher computational thinking; meanwhile, they could provide more relevant responses regarding the proposed learning activities.**

***Keywords*— STEM; computational thinking; educational robot; engineering education**

I. Introduction

In the past decade, engineering education has been accepted as an important field in developing engineers. They need to be mastery in scientific knowledge to design, construct, and maintain engines and machines. Moreover, engineers play a vital role in developing innovative solutions to improve the quality of lives. Regarding this significance, therefore, many educators have endeavored to improve the activities of teaching and learning to strengthen the knowledge and principles of engineer students with more professional practices based on the real-world applications [1].

In Thailand, high-school students learn many subjects independently such as General Science, Physics, Mathematics, Materials Science and Computer Programming. Subsequently, students could not understand and appreciate how the knowledge of multi-disciplines integrate together to perform or operate certain tasks/functions of the engineering process [2].

Owing to such instructional limitations, many research studies have found STEM strategy could help enhance engineering students' learning performance. With the integrated knowledge of Science, Technology, Engineering, and Mathematics, it facilitates students' thinking and working with the real-world challenges and problems. In the meantime, this strategy serves as a gateway to improve their computational thinking, which is important in the process of engineering education [3, 4].

With the rapid development of robotics field, it was repeatedly reported that robotics not only provide engaging learning environments but also develop computational thinking knowledge and skills for students [5]. In other words, it enables real-world applications of the concepts of engineering and technology; besides it helps to displace the abstractness of science and mathematics [6]. In addition, robotics has been used to promote the efficiency of STEM through many educational robotics competitions [7].

Therefore, this study has integrated the benefits of STEM education with robotics-based learning activities to promote students' computational thinking and learning engagement. The activities are presented in the 3-day training workshop for

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high-school students. The details and rationales of each learning activities are described in this paper. With the workshop activities, the data were simultaneously collected. To direct the scope of this research study, following research questions have been formulated: 1) how is the computational thinking process of the students, and 2) what are their engagements towards the proposed workshop activities?

II. Related Study

A. Robotics and STEM Education

Robotics technologies can be an effective tool to get teachers to design teaching and learning using STEM robotics in many topics such as science concepts [8] or computer programming concepts [9] because that important skill to express ideas, inspiring student's originality while helping develop logical thinking and solving problems.

Using robotics for teaching to promote teacher knowledge of science concepts and computational thinking developed after participating in activities [10]. Also, robotics has been used in many workshops for promoting student creativity and teamwork and communication among students [11]. Furthermore, it is a valuable tool for developing students' cognitive and social skills and can be a powerful tool for developing creativity because the robotics design process requires creative thinking in during the robotics instruction process [12]. In addition to that, it helps motivate student learning with the robot's programming [13].

B. Computational Thinking

Papert (1996) proposed 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 [14]. While, Wing (2006) proposed computational thinking is a kind of analytical thinking to solve problems, designing systems, understanding human behavior, and fundamental to computing that shares mathematical, scientific, and engineering thinking in the general ways understanding computability, intelligence, the mind and human behavior [15, 16]

Following this point of view, Chen et al. (2017) proposed the framework of computational thinking for the elementary school where a robotics curriculum has good psychometric properties and has the potential to reveal student learning challenges and growth concerning computational thinking [9]. Best of all, robotics-based can be used as an instrument that offers opportunities for students to engage and develop computational thinking skills [17]

Based on this perspective, this research study employs the capabilities of robotics to promote students' computational thinking based on STEM strategy through the process of workshop activities.

III. Robotics Learning with Three-Day Workshop

mBot is an affordable educational robot kit designed for students to enjoy the learning experience of programming, electronics, and robotics [11]. The mBot parts include body, control board, sensors, connectivity (Bluetooth), and power supply (battery). The mBot kit is accompanied by mBlock programming software which supports colorful and modularized drag and drop graphical blocks. Note that mBot comes with three pre-set control modes: obstacle avoidance mode, line-follow mode, and manual control mode.

The students could feel accomplished when they can easily program the mBot without writing difficult codes and language. Also, the graphic programming environments play an essential role to enhance computational thinking in learning process [12]. However, students could learn and practice by following the proposed workshop activities.

The structure of three-day workshop comprises of how the elements of STEM integrate together as a workshop, what activities are carried out to enhance the computational thinking process (CTP) of the participants, as shown in Fig. 1.

In this study, the three-day workshop consists of eight phases (six hours/day, 18 hours in total). In each phase, certain activities were run by ten assistant teachers, hereinafter called workshop trainers (WT). They are pre-service teachers in Mechatronic education program.

First-day activity, WTs provided a fundamental for students. They learn about the mBot in a stepwise manner. WTs described its components such as electronic module, programming software, and functionality. Then, the students were separated into 17 groups while each group had 3-4 members, as shown in Table 1.

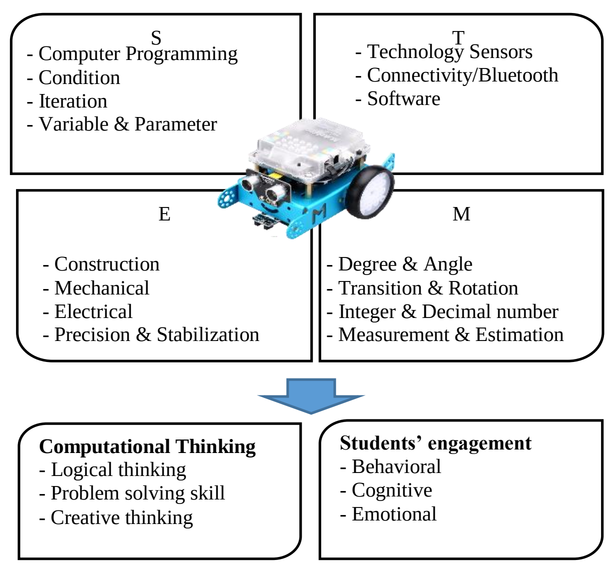
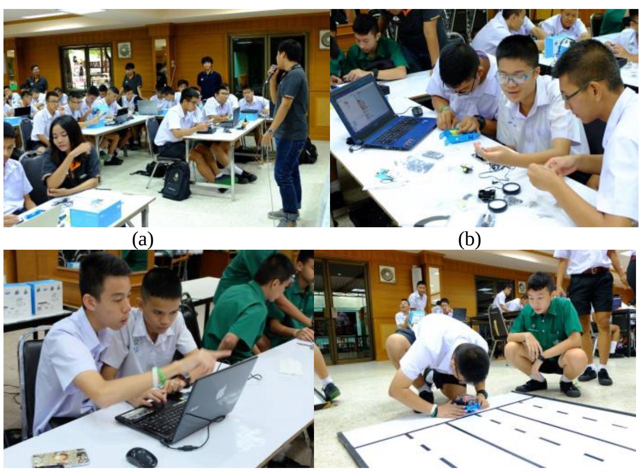


Fig. 1. Overall structure of STEM robotics learning

TABLE 1: DAY 1 ACTIVITIES

Activity	Descriptions
Phase 1: Robot introduction	WTs presented the mBot components based on the engineering design process. After that the students get acquainted with the mBot components through several mini labs: main control board, sensors, connectivity (Bluetooth), and power supply (battery), see Fig. 2(a).
Phase 2: Robot assembly	The students were separated into groups, then members of each group worked together. They began design and assemble the mBot step-by-step following the given task, see Fig. 2(b). This phase required students to get acquaint with each parts and start to join each part together by robot function.
Phase 3: Primary programming	The students learn how to program the mBot, such as turn life and turn right, move forward and backward. They used mBlock based on Scratch 2.0 that is a graphical programming software for writing on laptop/PC, see Fig. 2(c). During this phase, students in each group have to analyze the facing proposition and situation in which they require test-run-revise the code in a stepwise manner. The result of this phase acts as a fundamental to the next phase, in the meantime, this marks the robot functioning.
Phase 4: Robot in the field	The members of each group work together on the given tasks ranging from testing the robot on the field to moving robot following symmetrical and unsymmetrical tracks, see Fig. 2(d). In this phase, each group has to adapt the physical robot as well as the programming instructions to overcome different challenges on the field.



(a) (b) (c) (d)

Fig. 2. Workshop activities of Day 1

The second day, the goal of this phase is to the students in each group learned and worked together. They received the tasks for learning the obstacle avoidance and line-follow. Each group solved the problems in a logical way by taking. They find the solution and strategy for solving the problem (as shown in Table 2).

Last day, the goal of this phase is to apply the knowledge for a robot competition. The Balloon Battle Game was used to activities on a final day. To start this game, each robot was attached with a needle and a balloon at the front and back of its body. Then each group's robot goes stab balloon's competitor while maintaining their attached balloon. The groups with their balloons available are qualified for the final stage. In the final game, each qualified team has ten minutes to come up with a better strategy of controlling the robot in a battle while maintaining their balloons. It is quite challenging and interesting to see who the survivor of this robot battle is (as shown in Table 3).

TABLE 2: DAY 2 ACTIVITIES

Activity	Descriptions
Phase 5: mBot Tasks	The students in each group solved the problems in a logical way by taking. At this moment, each group is faced with different problems upon their robot's settings and programming. For example, the coming challenge is on the opposite direction of the previous ones. They learned to analyze and solve the problems in a logical way by taking the knowledge integration of STEM, see Fig. 3(a). The adjustment of one point will affect the relate points.
Phase 6: Sharing	The representative student present ideas and methods about control the mBot in order to carry out the mission. The students each group helped to justify the approach to solving the problem, see Fig. 3(b).

(a) (b)

Fig. 3. Workshop activities of Day 2

TABLE 3: DAY 3 ACTIVITIES

Activity	Descriptions
Phase 7: Practice before the battle	The members in each group analysis and discuss for preparing competition. They had rehearsal before competition, see Fig. 4(a). This will increase their team's confidence on the final robot, while final configuration may be needed.
Phase 8: The competition	The members in each group is encouraged to apply knowledge what they have learned to accomplish the goal effectively on the robot competition on the Balloon Battle, see Fig. 4(b). This phase is vital to each team since the great robot's performance during rehearsal may be ineffective when compete with the others.

(a) (b)

Fig. 4. Workshop activities of Day 3

To achieve the final stage of this workshop, students are encouraged to apply knowledge, skills and experience from three-day workshop. In the meantime, each team has to come up with the better solutions by integrating the knowledge of STEM and robotics, while their computational thinking was promoted accordingly.

IV. Method

A. Participants

Participants of this study were 60 high-school students from a public school in Thailand (60 males). They all study in science and mathematics programs and expect to be scientist or engineer students in higher education level.

B. Instruments

In order to investigate the effects of the proposed three-day workshop, the following instruments were used to collect the data:

- Scores from six workshop labs/activities (30 points) and one final competition (70 points) covering robot assembly/structure (10 points), logic and coding (10 points) and competition result (50 points), in a total of 100 points. This will be used to analyze the robotics performance of each group.
- A semi-structured interview was used to elicit qualitative responses. It was used at the end of the workshop. The questionnaire was mainly qualitative in nature and involved a series of ten open-ended response questions, including problem solving (PBS), logical thinking (LOT), and creating thinking (CRT). This data is to used in categorizing robotics performance in respect of computational thinking.
- A questionnaire for assessing STEM robotics workshop engagements and for evaluating the perception towards the workshop; the former adopted from Kim et al. has 13 items to assess behavioral engagement, cognitive engagement, and emotional engagement [4], while the latter examine students' satisfaction on 5-point Likert scale items on two dimensions of workshop activities and usefulness. The results from this data would give the insights of participants on this proposed robotics learning approach.

This study utilizes the mBot platform to operate and enjoy learning experience of programming, electronics, and robotics.

V. Result

The results were analyzed based on computational thinking components: Problem-solving (PBS), Logical thinking (LOT), and Creating thinking (CRT), as presented in Table 4. To better understand the effects of the proposed three-day workshop, the difference between a high robotics performance group (HIRP) for top four groups and a low robotics performance group (LORP) for bottom four groups were elaborated. Moreover, their activity points are presented in Table 5.

Based on this result, it can be implied that the proposed three-day workshop activities better helped develop computational thinking process for 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 4: Descriptive Results of Computational Thinking Components between High- and Low- Robotics Performance Groups

Component	LORP		HIRP	
	M ± SD	***Remark***	***M ± SD***	***Remark***
PBS	4.00 ± 0.71	High	4.13 ± 0.22	High
LOT	2.88 ± 0.74	Medium	4.75 ± 0.43	High
CRT	3.25 ± 0.83	Medium	4.13 ± 0.54	High

TABLE 5: Descriptive Results of Activity Points

Activity Points	LORP (M ± SD)	HIRP (M ± SD)
Six workshops (30 points)	11.75 ± 3.03	21.75 ± 4.92
Final game (70 points)	17.75 ± 2.77	57.25 ± 9.20
Total (100 points)	29.50 ± 2.69	79.00 ± 12.10

On account of 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 STEM integrated robotics learning were presented qualitatively on three different aspects in Table 6. In behavioral engagement, the high-robotics performance students revealed that they could manage the function of members and have the confidence of learning while those with low-robotics performance not enjoy learning in a group with members too much and they have less time. For cognitive engagement, the high-robotics performance 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 low-robotics performance revealed their emotions towards the assistance of peer members in the group that could encourage them to proceed with the workshop. In the dimension of emotional engagement, the high-robotics performance students enjoyed the activities in the workshop while low robotics performance students did not concentrate on some activities.

TABLE 6: Qualitative Results of Individual Students' STEM Robotics Engagement towards Workshop Activities

Engagement	Responses
Behavioral	*High robotics performance* - In this works, we helped in my group about coding program and explained each other. - It is wonderful to have this experience and I can construct robot by myself.
	Low robotics performance - I have less time to work on many tasks - In my group, we have many members so somebody does not involve in some activities.

Cognitive	*High robotics performance* - I apply multiple tasking skill and I can try when not sure. - I play it again when I come back home.
	Low robotics performance - I am upset about how to complete work. - I do not plan in advance, it's not success but I reattempted.
Emotional	*High robotics performance* - I like to control robot, it can follow my instructions. - I very enjoyed the activities in the workshop.
	Low robotics performance - I think robot cannot be used because it is unaffordable. - This workshop was held during semester, I have many homework so I do not much concentrate on some activities.

VI. CONCLUSION AND DISCUSSION

With the significance of engineering education in Thailand, this study attempted to enhance its learning process by integrating multi-disciplinary knowledge of STEM to promote students' computational thinking. The educational robot was used as a learning tool. The proposed learning activities are held in the form of 3-day robotics workshop for higher-school students, including eight phases in total, from robot introduction, assembly, programming, test on the field, to the two rounds of robot competition with an interesting mission. Students constructed their robotics knowledge with hands-on experience based on STEM strategy by following the step-by-step workshop activities run by pre-service engineering students.

Based on the given STEM-associated learning activities, the findings of this research study showed that students who gained better robotics had higher computational thinking on all dimensions, including problem-solving, logical thinking, and creative thinking. Moreover, they could provide more relevant responses on learning engagement towards the proposed workshop activities.

However, this workshop presented some limitations due to the availability of school context, students' prior knowledge, number of robot kits and workshop schedule. These might affect the effectiveness and the results of this study. Therefore, the authors would provide some suggestions for further studies. Early investigation of participants' background would be conducted to adjust the instructions. Different missions would be integrated to generate interactive learning environment and collaboration. Finally, more exciting and challenging learning missions based on real-world activities could be provided to better enhance their engineering and computation thinking, such as wireless controlling, navigating the route, escaping the complicated space.

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