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A Study Using the Low-Cost Robot Kit as a Tool to Promote Students' Engagement in STEM Education

Santi Hutamarn[1], Sasithorn Chookaew[2] and Suppachai Howimanporn[3*]

Faculty of Industrial Education, King Mongkut's University of Technology North Bangkok, Thailand[1,2,3**]

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Abstract

Learning as part of the engineering design process. In an engineering education context, robots are employed to motivate and transfer the problematic concepts of interdisciplinary integration. Most existing educational robotics have been developed to teach programming and basic robotics in many countries. However, a market survey found that many brands of robots tend to be expensive and inflexible for use by students in upper-middle-income countries. Therefore, we have designed and built a modular educational robot kit called entitled the MEC-Ed robot kit designed to be a low-cost resource for student learning as part of the engineering design process. We used a robotics design performance score and engagement questionnaire to collect quantitative data in the experimental case study. The participants in this experiment were 29 senior high school students in Thailand. The authors found that the framework supports the engineering design process and enhances the students' positive perceptions concerning low-cost robot kits.

Keywords: STEM, engineering education, educational robot, robotics, interdisciplinary, engineering design process

Introduction

Presently, it is clear that engineering education involves important principles for learning which can be applied to scientific and mathematical concepts in such a way as to develop peoples' lives for the better. It is a part of the STEM concept (science, technology, engineering, and mathematics) that acts as an educational system foundation for developing many countries throughout the world. Technological learning is more significant than ever to prepare our students with the right tools for their future. Robots have been

*Corresponding author. Tel.: -
Email address: suppachai.h@fte.kmutnb.ac.th

used to teach STEM concepts through educational robotic activities (Castro et al.,2018; Brand, 2020, Sisman, Kucuk & Yaman, 2020). The use of educational robots has attracted a great deal of attention from researchers and educators. Teaching robotics lessons to students in school can increase their ability to be creative thinkers and innovative inventors of society. Using a robot in the learning process as a tool for enhancing technological thinking, increasing student's confidence in using technology, developing essential twenty-first-century skills, and increasing.

student's self-confidence (Zviel-Girshin, et al., 2020). As robotics becomes more prominent in today's society, many educators have introduced educational robotics within the classroom. Therefore, commercial robot kits have rapidly become learning tools to support learning activities in the classroom or during learning activity/workshops. Robot kits are a perfect solution for teachers and students to continue learning about STEM fields and understand robotics concepts. For example, using the mBot robot kit means that its ease-of-use allows students to get hands-on experience with graphical programming via the relevant learning activity (Hutamarn et al., 2017; Zhong & Wang, 2019; Sáez-López et al., 2019 Giang, Piatti & Mondada, 2019).

In addition, robot kits are popular with a new generation of students. For example, LEGO Mindstorms are commercial robot kits for increasing students' motivation and knowledge (Arís & Orcos, 2019). They do this with ease of building and the need for minimal amounts of mechanical skills for students in support of computer programming (Chalmers, 2018; Taylor & Baek, 2019; Orlando et al., 2019). However, it is more expensive than other robots on the market. This issue makes it difficult to use such a resource for student learning in lower and upper-middle-income countries.

Furthermore, many other robots are often expensive. In addition, many are inflexible and are not easy to modify for different learning activities, with teachers frequently having to adapt the robot kits for specific learning objectives. Therefore, many studies have proposed the need for a low-cost robotic platform that supports the development of hands-on open-source robotics that is both inexpensive and reliable and can be used to support student learning (Darrah et al., 2018; Tribelhorn & Dodds, 2007).

Reform of the Thailand educational system has attempted to improve the teaching and learning process involved in delivering the school curriculum by adopting new technologies and innovative learning. Many schools in Thailand have integrated robotics training and education by offering more robotics classes and adding new robotics courses into the classroom. The primary purpose of this study is to present educational low-cost robot kits to promote students' learning as part of the engineering design process.

Research Questions (optional)

RQ1 . Do students who use low-cost robot kits promote their learning as part of the engineering design process?

RQ 2 . What are students' engagement toward low-cost robot kits to promote students learning with the engineering design process?

Literature Reviews

Robot in STEM education

Many studies have found that using robots in education is increasing as a significant aspect of teaching and learning. The integration of STEM is crucial for students' future success in the 21st Century (Kelley & Knowles, 2016; Larkin, 2017). The educator used robots in education through hands-on learning activities for students, both inside and outside the classroom (Julià & Antolí, 2019; Chookaew et al., 2018). In addition, robots have been advocated as emerging instruments for encouraging interdisciplinary integration relevant to the students'

experience, particularly in light of the complexity of the global situation (Ching et al. 2019; Negrini & Giang, 2019). Many studies have pointed to the benefits of using it to motivate student learning in the STEM disciplines (Sullivan & Heffernan, 2016). For example, Chen and Chang (2018) proposed a robotics curriculum that highly integrates STEM, uses open software and hardware, and tests its effects on high school students' learning outcomes, interests, and perceptions of STEM. Barak and Assal (2018) proposed a STEM robotics course to motivate the students' learning in STEM subjects through project work activity. Jackson, Mentzer & Kramer (2019) presented robot design lessons for a high school student to foster students' STEM interest. Lindsay et al.

(2019) proposed a group-based robotics program to foster an interest in STEM disciplines early on that can help to expand their career options. Jawaid et al. (2020) presented a robotics system course to creates capacities and abilities in critical thinking and problem-solving with a collaborative project-based learning approach. Noh and Lee (2020) employed a robot in programming education could help students understand computer-science concepts more quickly. Furthermore, Souza, Andrade, and Sampalo (2021) proposed the impact of robotic activities on CT development and subject learning in Technical and Vocational Education in high school. In addition, many studies present the preparing teacher to integrate educational robotics in classrooms (Alimisis, 2019; Yang et al., 2020; You, Chacko & Kapila, 2021 Schina et al., 2021).

In general, educational robotics kits still have some restrictions like high cost, long setup time, and licensed software. However, many studies attempt to propose

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a low-cost robot for use with open-source in education (Darrah, Hutchins & Biswas, 2018; Rengifo, Segura & Quijano, 2018; Al Khatib, Jaradat, & Abdel-Hafez, 2020; Taengkasem et al., 2020; Chau et al., 2021; Lopez-Rodriguez & Cuesta, 2021; Abidin et al.,2021). The benefits of using a robot in class can help the students improve their knowledge and attract them to the topics taught in school (Ponce et al., 2019). Additionally, an educational robot should be based on sound teaching and learning strategy and touching and manipulating manners using a robot kit to deliver learning activities (Casey et al., 2021). There is evidence that students' learning of engineering design concepts has increased due to robots allowing students to engage in practical hands-on activities in the classroom, even when teachers teach the students with no engineering background (Ziaeefard et al., 2017). Numerous studies indicated that most of these studies focused on preparing students' essential skills to survive and succeed in the real world in a time that's changing and developing so rapidly (Chalmers, 2018; Negrini & Giang, 2019; Chookaew, Howimanporn & Hutamarn, 2020; Angeli & Valanides, 2020 Chevalier, Giang, Piatti & Mondada, 2020).

Engineering Design Process

Most high school students have shown interest in studying engineering during the last decade, but they do not understand engineering practice. Consequently, the students have to prepare to embrace knowledge in terms of the work and practice of engineering design to meet future challenges. Arık and Topçu (2020) addressed one of the fundamental ideas of engineering education is a design process. It is essential to the disciplines of engineering and technology. Engineering design is an essential element of engineering education that illustrates a students' competency in being an engineer after graduation (Atman et al., 2007). The engineering design processes (EDP) employed in engineering encompass various topics and fields of study. With the increasing interest in STEM at the high-school level, several studies have proposed the engineering design approach integration of knowledge on science, technology, engineering, and mathematics (Fan et al., 2017; Lammi et al., 2018). For example, Yu, Wu, and Fan (2019) proposed the effects of knowledge and critical thinking on the final design product of high school students through the engineering design process. Winarno et al. (2020) proposed the steps of the EDP are defining the problem, building, testing, evaluating, and redesigning that used in science education. In addition, Hill et al. (2018) applied EDP to create lessons engaging students in solving real-world problems by applying the concepts they learn as part of STEM education. EDP is the foundation of the process used by engineers. It consists of five steps: The Asking step is defined as identifying an engineering type of problem. The Imagining step involves brainstorming ideas. The Planning step involves choosing the best idea, sketching it out, and making a list of the necessary materials. The Creating step involves making a prototype. The Improving step is necessary for a product that has a problem, as shown in Figure 1.

Figure *1.* Engineering design process framework (Hill et al., 2018)

Methods

Development of low-cost robot kits

In this study, we developed low-cost robot kits entitled MEC-Ed (mechatronics education robot) that are designed for assembly in many different forms, and then the robot parts are printed using a 3D printer (3-dimensional printer). In addition, the MEC-Ed robot consists of many sensors, which allows it to detect the tasks in various scenarios. For example, there is an ultrasonic sensor in the form of an electronic device to measure distances using ultrasonic sound waves. A line-follower sensor can detect colors that allow the robot to follow black or white lines. An infrared (IR) flame sensor is a detector that can be used to detect the presence of fire or other infrared sources, and an RGB color sensor is a color detector for detecting primary colors (red, green, and blue). Furthermore, robot wheels are driven using a DC motor with a maker drive, while a gripper uses an RC servomotor to control rotation angle holding torque. This is suitable for building lightweight mechanisms that require angular rotation control. Also, the MEC-Ed robot kit can be controlled through the use of the Scratch programming environment. The program is a drag-and-drop block for writing commands to the robot to operate with the mBlock program. This is a freeware program that can be used to control the Arduino board (Maker UNO), as shown in Figure 2. The MEC-Ed robots are introduced as a complete learning material package that can be employed in engineering design as a motivator for teaching STEM education.

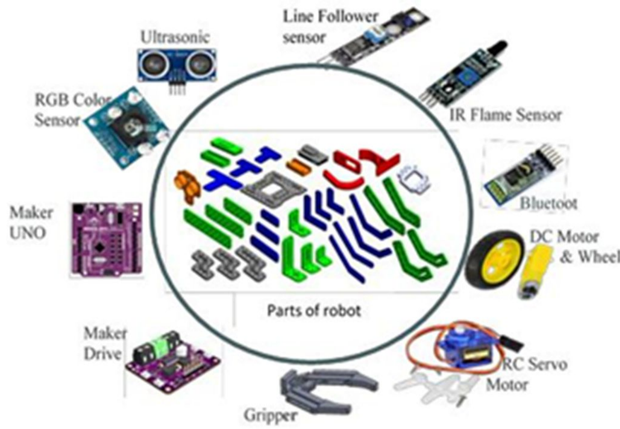

Figure 2. The components of the MEC-Ed low-cost robot kits

Participants and procedure

The participants in this study were 29 senior high school students (17 male and 12 female) who were willing to participate in our research. The students ranged from 16 to 18 years of age. They were divided into ten small groups of 2-3 members per group. In this learning process, the students are assigned a task involving using a MEC-Ed robot kit. They can learn using the online manual that comes with the robot. Each student learned about the design process about the electronics and structure of robotics following the five stages of the engineering process. The stages of the engineering design process are as shown in Figures 3-7.

- Asking stage: the students are given questions about robotic work based on their experience. For examples of open questions, if you want to create a robot car for shipping, how do you design it? What are the robot components? The students then have to define it as an engineering problem. In this section, the teacher has addressed motivation to student-related robots that are important in daily life. After that, they have introduced the functions of the robot and the introduction robot components based on the engineering design process. At this moment, the students have to get acquainted with the robot components such main control board, sensors, communication options, and battery (Figure 3).

Figure 3. The students answer the questions

- Imagining stage: the basis of STEM is to encourage students to pursue STEM-related careers. Therefore, this section is essential to link the robot-based around real-world in routine or industry applications. In activities, the students develop solutions to real-life problems by carrying out collaborative studies, and then they design the robots for this purpose. The students in each group have to brainstorm ideas. They may come up with several ideas from seeing the parts of the robot. The students' imagination is connected to their experience. Their ideas may be based on their experience (Figure 4).

Figure 4. Sharing ideas and collectively brainstorming

- Planning stage: this step is the process of thinking about the activities required to achieve the group's goal. All students must treat their work seriously by allocating enough time for planning and organizing actions. They choose the best idea and sketch it out while preparing a list of materials (Figure 5).

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Figure 5. Planning and organizing actions

- Creating stage: the students have to build a robot prototype in terms of their idea. These early versions of the design robot help the group verify whether or not the design meets the original challenge objectives. This encourages creativity and imagination in design. They can be learning by starting with robot instruction at their own pace with the group's mentor. This section required students to get acquainted with each part and join each part by robot function. The students used mBlock based on Scratch 2.0, the graphical programming software for writing on a laptop/PC. During this phase, students in each group program the robot and then require to test the code in a stepwise manner. They have programmed the robots with block-based or text-based visual programming tools. The result of this step acts as an outcome to improve the robot (Figure 6).

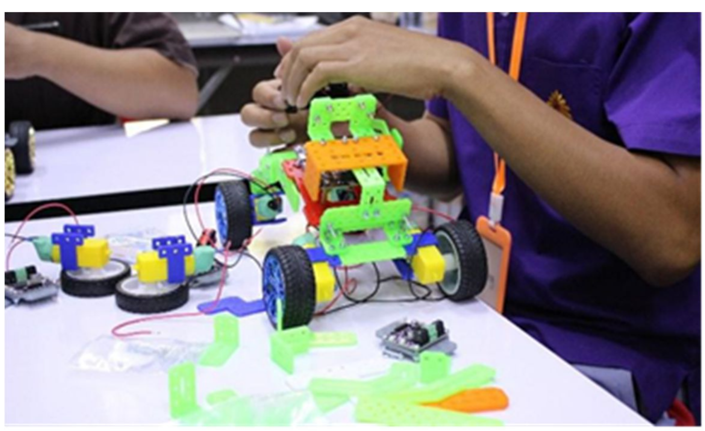

Figure 6. Building a robot prototype

- Improving stage: in this step, the students can improve the robot if there are any problematic aspects. For example, if the robot's structure is unbalanced, it can be improved and modified (Figure 7).

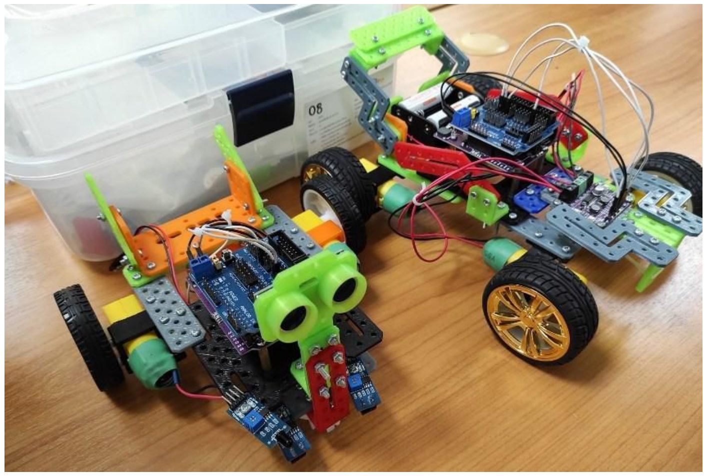

Figure 7. Improving and modifying a robot

Once this has been accomplished, the students make up ten small groups. Each group has two robots – one with two wheels and one with four wheels. Each group then makes an oral presentation of the concept or idea about constructing the robot for evaluation purposes. They have about 5 minutes to present and answer questions. The designated representative of each group makes an individual presentation of the group's thoughts and findings of the design. The representative summarizes the views of several different group members. In this section, the students have opportunities to share knowledge. They have learned about each other helps build positive thinking. They have presented points regarding the robot-based design based on the questions that helped them develop their idea, such as Why have we designed a robot in this way? Did you find the construction easy or difficult? How could we have improved our design? What robot can do in their daily lives?

The oral presentation of students' design concepts showed their creativity because it stimulated their imagination. They have shown ideas and proposed the organize of robots connecting their experience, as shown in Figure 8.

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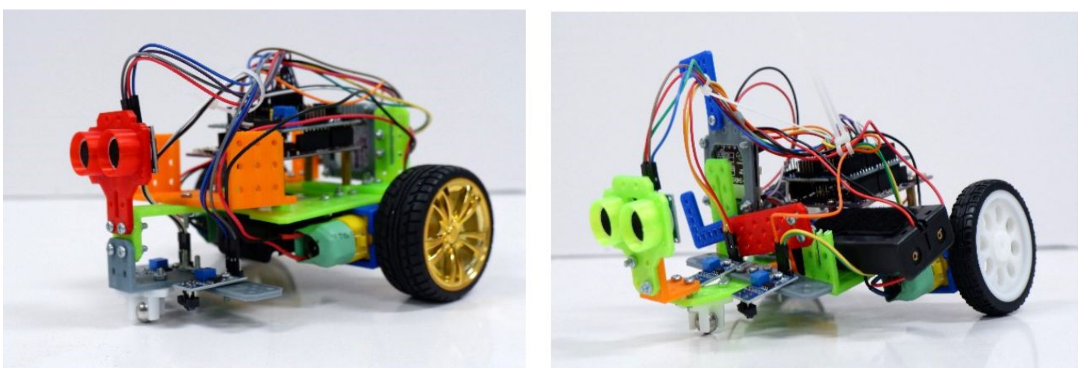
Figure 8. Illustration of the students' oral presentations

Furthermore, the essential principles of design provide a balance. The arrangement of the elements that make up the individual parts of the composition appears equally essential. The arrangement of the elements creates an equal distribution of visual weight throughout the robot body (mechanical structure). If a composition appears heavier on one side, it will not be visually balanced. The symmetrical structure (the proper balance) of the robot body means that it is equally weighted on both sides of a centerline.

If it is asymmetrical (the informal balance), the form is unevenly weighted radially, such that the weight of the robot body radiates from a center point (Figure 9). The students then modify the robot's structure to be able to work before going to another step.



(a) Robot body balanced (b) Robot body unbalanced

Figure 9. Example of robot prototypes created by students

The students of each group work together on the given tasks ranging from testing the robot on the field. The member in each group has to adapt the modular robot and the programming instructions to overcome different challenges. This section is the basis for improving reliable robot working. When the robot was assembled by students that programmed to control the robot based on tasks, the testing to operate, prove system functionality, and gain confidence that a system will perform as expected. Testing in the field also allows the student to learn the robot's weaknesses, problems, and constraints and improve upon them. The field used in robotics activities will be designed for different situations in the actual context, as shown in Figure 10.

Figure *10.* Robot testing in the field

Research instruments

In the experimental case study, we used a robotics design performance score to collect quantitative data with the observation checklist during learning activities by teachers. This involved criteria assessment using 20 points per robot (each group has two robots) for a total of 40 points (100%), as shown in Table 1.

Table 1.

The design robot criteria

Category	1 point scale	3 point scale	5 point scale
Idea	Students have a conventional idea in terms of building the robot.	Students have a good idea in terms of building the robot.	Students have an excellent and creative idea in terms of building the robot.
Symmetry	The robots' body has many Problems with regard to symmetry.	The robots' body has some problems with regard to symmetry.	The robots' body has appropriate symmetry.
Duration	Students were unable to build the robot in time.	Students built the robot on time.	Students built the robot ahead of time.
Meticulousness	Students have made the robot crudely.	Students have made the robot to an acceptable standard.	Students have made the robot meticulously.

In addition, the research instrument used to measure the students' engagements was constructed by Hutamarn et al. (2017). three dimensions of students' engagements after attending the

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robot learning activity that consisted of 11 items to assess behavioral engagement (3 items), cognitive engagement (4 items), and emotional engagement (4 items), while the latter examines students' engagement on 5-point Likert scale, ranging from "5" (Strongly agree) to "1" (Strongly disagree). The internal consistency for the overall scale was 0.79.

■ Results and Discussion

Results

This section shows the results obtained in order to answer the research questions formulated above. To better understand the effects of using low-cost robot kits to support student's learning, the difference between gender is considered in the case of three groups consisting of 5 all-male groups (n=14), three all-female groups (n=9), and two mixed female and male groups (n=6), as shown in Table 2.

Table 2.

The students' robotics design performance in terms of gender

Category	Male group (n=14)	Female group (n=9)	Mixed group (n=6)
	Mean (SD)	Mean (SD)	Mean (SD)
Idea	9.20 (0.98)	9.33 (0.94)	10.00 (0.00)
Symmetry	8.40 (1.50)	6.67 (1.89)	8.00 (0.00)
Duration	8.40 (1.50)	6.67 (0.94)	8.00 (0.00)
Meticulousness	6.80 (0.98)	10.00 (0.00)	9.00 (1.00)
Total (40 points)	32.80 (3.71)	32.67 (3.40)	35.00 (1.00)

Table 2 summarizes all the mean scores and standard deviations about students' robotic design performance. The mixed groups' mean in robotic design performance is the highest (M=35.00, SD=1.00). Note that the students in this group have the creative idea to build the robot based on the students' experience in the learning activity. Next comes the male groups' mean (M=32.80, SD=3.71), while that of the female groups is the lowest (M=32.67, SD=3.40). It should be noted that the female groups designed and assembled robots meticulously - better than the male groups - but that they spent more time doing so.

Table 3.

Correlation matrix of robotic design performance dimension

No.	Category	1	2	3	4
1	Idea	1.000			
2	Symmetry	0.709	1.000		
3	Duration	0.218*	0.671	1.000	
4	Meticulousness	0.342*	-0.275**	-0.499**	1.000

*p < 0.05, **p < 0.01

Table 3 the results of the correlation coefficient showed significant positive correlations between duration and idea (r=0.218*< 0.05), meticulousness and idea (r=0.342*< 0.05). Furthermore, the findings in terms of students' engagement with the low-cost robot kits as a means of promoting student learning through the engineering design process are as presented in Table 4.

Table 4.

Means and standard deviations in terms of students' engagement

Students' engagement component	Male group (n=14)	Female group (n=9)	Mixed group (n=6)
	Mean (SD)	Mean (SD)	Mean (SD)
Behavioral Engagement	4.53 (0.54)	4.42 (0.57)	4.67(0.47)
Cognitive Engagement	4.42 (0.64)	4.38(0.60)	4.42(0.49)
Emotional Engagement	4.55(0.59)	4.47(0.56)	4.71(0.45)
Overall	4.49 (0.59)	4.42(0.58)	4.59(0.49)

Table 4 presents the descriptive data concerning student engagement using a low-cost robot as part of the engineering design process. The three gender groups have a positive attitude regarding three different aspects consisting of behavioral, cognitive, and emotional engagement. The analysis shows that the positive attitudes of students in the mixed groups (mean =4.59; SD=0.49) is greater than that of the other groups, while students in the male groups had a mean of 4.49 (SD=0.59), and students in the female groups had a mean of 4.42 (SD=0.58). Overall, the engagement of the students in using the robot kit for learning was high level.

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Discussion

Regarding robotics design performance with a low-cost robot learning, the gender group comparison showed that all groups have high performance after participation. This result was consistent with the results from previous research that robotics education can effectively enhance the students' performance of all gender (Taylor & Baek, 2019). The gender composition of the group did not demonstrate any difference in learning performance towards robot activity. However, these gender differences were reflected in students' performance in some processes. The female group may be a slow movement rather than the male group. At the same time, meticulousness was improved more in females than males. Additionally, students' engagement using a low-cost robot shown a more positive attitude toward learning activity (Chen & Chang, 2018). These results provide essential information about the robot as a tool to enhance and collaborate in science, technology, engineering, and mathematics (STEM) activities (Jung & Won, 2018; Sisman, Kucuk & Yaman, 2020; Üçgül & Altıok, 2021). The three-day workshops of robot activities to develop the students' skills in each STEM field significantly affected the students' attitudes and motivation (Chookaew et al., 2018). This study shows that the initial evidence of the need for specific instructional interventions on STEM education significantly, the low-cost robot learning kits to drive learning activities aimed at student development. The robot acts as a learning tool that can help students construct knowledge rather than receive it from an instructor (Anwar, Bascou, Menekse & Kardgar, 2019; Xefteris & Palaigeorgiou, 2019).

■ Conclusion

In this article, the authors have proposed using a low-cost robot we call MEC-Ed robot kits as a tool for supporting student learning through the engineering design process framework. The MEC-Ed robot kits can support student learning through an engineering approach to drive educational development activities. The results demonstrate that the students' three dimensions of engagement (behavioral, cognitive, and emotional) are high. To introduce the proposed modular robotics kit into the classroom, there some guidelines for the teacher/educator. It is essential to introduce real problems to the students by connecting the actual situation. It may engage the students in thinking about creative design, using a robot, and solving the problem. Afterward, the teachers ask the students to construct the robot and its relevant components,

including modular, power supply, sensors, programming, and transferring the program into the mobile application to control a robot. The students are encouraged by teachers to share and discuss the construction of robots to complete the mission.

However, three different gender groups have demonstrated differences in terms of robotic design performance scores. Students of different genders can improve student learning activities because they can think and share different learning experiences when designing and creating robots appropriately. It can significantly boost the learning environment. In the meantime, the students involved can naturally understand the learning phenomena, both positive and negative, to improve later.

Limitations and Recommendations

The findings presented in this paper illustrate the advantages of the use of educational robots that integrate with the learning approach in such a way as to enhance student learning with the engineering design process. This study includes several limitations. First, the findings from this study may not generalize to other classrooms. Future research should extend it to different realities because of the student experience and the local and regional norms. Second, this study focuses on the narrow concept of engineering education rather than related robotics. Third, there is a generalization issue due to the involvement of only one sample group. Therefore, the experimental research design should compare the students' learning achievement and engagement in different treatments reflecting the proposed learning-related concept effectiveness in further studies. In the future, a comparison between different sample groups, different experiments, or different interventions, could enhance the impact of these findings. In the end, this study could be utilized for teaching higher-level courses like essential artificial intelligence and the internet of things. To motivate students could be familiarized with integrated engineering aspects by conducting robot learning activities.

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