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Low-cost educational robotics for promoting STEM education

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Abstract. Robotics in education has been gaining attention from teachers and researchers in education. The use of robotics in education allows teachers to combine four disciplines, namely science, technology, engineering, and mathematics (STEM), to promote student learning simultaneously. With educational robotics, teachers can make science and mathematics concepts more concrete in a real-world context by combining technology and engineering altogether. This paper explores the designing process of educational robotics to promote STEM learning. Teachers were involved in designing and constructing robots. The "Big Ideas" exploration became an essential step to gather any insights from teachers on how robotics are built.

1. Introduction

In the era of the industrial revolution 4.0, the emergence of new technologies such as robotics, cloud computing, big data analytics, artificial intelligence, and the Internet of Things (IoT) has influenced almost all areas of life, including education [1]. Robotics, for example, are currently widely used as a tool to support student learning. The robot used as a learning tool in the classroom is known as educational robotics [2]. Educational robotics usage for teaching and learning activities has gained more attention from educational researchers, teachers, and academicians because it can enhance students' skills and knowledge [3; 4]. Students can learn many concepts in designing and utilising a robot by combining four disciplines: science, technology, engineering, and mathematics (STEM), simultaneously [5]. Applying educational robotics in STEM learning enables students to link the material being learned with real-world problems. The integration of educational robotics in learning is a learning innovation that is very much in line with the times and developing trends [6]. The application of STEM-based learning has been proven can improve students' scientific reasoning abilities [7].

The application of robotics is still limited because it has a small scope and focuses more on technology. The concept of "Independent Learning", coined by the Minister of Education and Culture of The Republic of Indonesia, provides flexibility for teachers to create and apply learning methods fitted with their respective schools' culture and character. Educational robotics is one of the alternative learning tools that can cover all of those aspects. With educational robotics, students are urged to use their technology-based multidisciplinary capabilities to create a well-built robot. Using educational robotics enables the students to develop a contextual problem relevant to the material being studied. With technology-based education, such as utilising robotics as a learning tool, students are expected to be more independent because they have full rights to explore their skills and knowledge in the learning process. Educational robotics is able to strengthen students' skills, developing their knowledge through

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the creation, design, assembly, and operation of robots. Educational robotics has proven to be a useful learning tool. In the last few years, the implementation of robotics in education is widely used as a STEM learning tool [8].

One of the pedagogical approaches commonly used as a vehicle to teach STEM fundamentals is project-based learning (PjBL) [9]. The PjBL approach provides a framework to guide students to actively construct their knowledge and generate a potential solution. Using the PjBL approach enables students to improve 21st-century skills, namely communication, collaboration, creativity, critical thinking and problem solving [10].

Various educational robotics have been created and implemented, such as KIBO, Dash and Dot, BeeBot, and LEGO Mindstorms. However, they are inaccessible to the local school in Indonesia due to their high cost, and also they need to install specific software and set up the configuration of the programming connections. This can be problematic for teachers without proper training. This paper outlines the low-cost educational robotics development to promote STEM education. One research question is posed: How does low-cost educational robotics is developed?

2. Materials and Methods

2.1. Requirements

The design of the proposed robotics kit in this current study is driven by four basic requirements [11]:

(a) Low-cost: the components used in the current study must be affordable to most school. This requirement impacted on restricting somehow the level of functionality and performance implemented by the kit.
(b) Appeal: it must be appealing to the teachers and students to stimulate their enthusiasm in working with the robotics kit. This requirement limits, to some extent, the use of low-cost components off-the-shelf such as the Arduino platform.
(c) Simplicity: the design of the robotics kit concept is simply easy to be assembled, operated, and maintained.
(d) Open source: an open-source is the best way for spreading this innovative idea. In this regard, the robotics kit must be accessible to all interested parties, including teachers, students, and IT support staff.

2.2. Development Platform

In this subsection, the hardware and software platforms used in the design of the robotics kit were introduced. In this current study, we built a Screwless/Screwed Modular Assemblable Robotic System (SMARS) robot as an educational robotics kit.

2.2.1. Hardware

The hardware of the robotics kit comprises low-cost components, as listed in table 1. All components, as mentioned in table 1, is depicted in figure 1.

Table 1. Component of the robotics kit

#	Component	#	Component
1	Chassis	9	Mount HC-SR04 ultrasonic
2	2 master wheels, 2 slave wheels	10	Jumper cables
3	Motor locking	11	HC-SR04 ultrasonic
4	L293D motor drive shield	12	Cap
5	Arduino Uno	13	Holding board (for 18650 battery 30 AMP)
6	LCD 2x16 include 12c	14	LCD holder 2x16 include 12c
7	4 motors	15	Mount LCD holder 2x16
8	4 bolts	16	Mechanical track

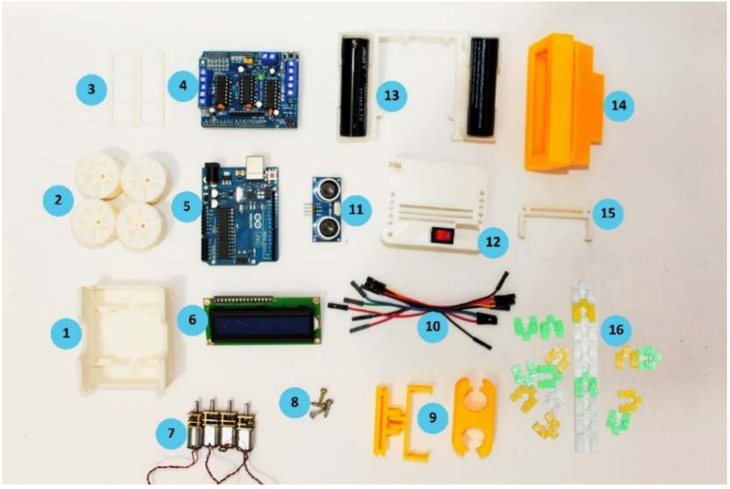

Figure 1. The components of the SMARS robotThe robot components were then assembled. The SMARS robot that has been assembled can be seen in figure 2. Some components were self-printed using a 3D printer to reduce cost, such as chassis, wheels, mechanical track, holding board, mount ultrasonic, and mount LCD

Figure 2. The SMARS robot after it is completely assembled

2.2.2. Software

In this current study, mBlock 3 was used. MBlock 3 is a block-based programming application that enables the Makeblock controller boards to interact with Arduino-based hardware. This allows users to create interactive hardware applications. The mBlock application can be accessed through https://mblock.makeblock.com/en-us/download. The main page of mBlock can be seen in figure 3.

Figure 3. Main page of mBlock

2.2.3. Programming with mBlock
The codes were defined into four command blocks: MAJU (for a step forward), MUNDUR (for a step backwards), KIRI (for turning left), and UTAMA (the Arduino program). The four command blocks are depicted in figure 4-7, respectively.

Figure 4. Command block MAJU

Figure 5. Command block MUNDUR

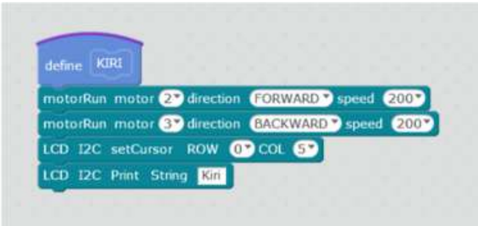

Figure 6. Command block KIRI

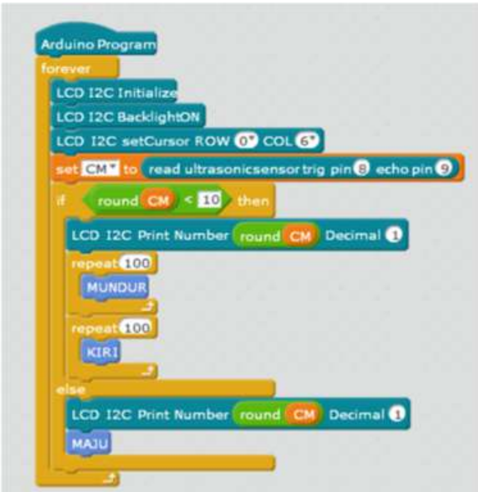

Figure 7. Arduino program

2.2.4. Uploading program to the robot and test it
To upload the programs to the robot, we need to connect the USB connection from the computer to the robot. Uploading the program can be carried out by clicking the Upload to Arduino button, as depicted in figure 8. The code was then transferred into the robot.

After the uploading process is done, the robot can be tested to ensure that it can run properly. When there is a logical error, all codes need to be revisited, and we go through the same process again until the robot runs according to what we programmed.

3. Results and Discusion

Four teachers from different schools were engaged in the robot trial in workshops. The first encounter of the workshop was introducing the robot. In this workshop, each teacher was provided a robot package contained robot components. They were then introduced to each component of the robot and asked for assembly it accordingly. After they have done assembly the robot, they were given the assignment to identify relevant topics that can be explored with STEM education. Table 2 illustrates the detail of the teachers' ideas.

Table 2. STEM ideas with educational robotics

Teacher Code	Level	Subject	Topics and idea
Teacher 1	Junior high school	Mathematics	**Perimeter and the area of a triangle** The robot is programmed to create a triangle. The students then asked to find the perimeter and area of the triangle.
Teacher 2	Junior high school	Natural Science	**Constant velocity and constant acceleration** The use of robotics to simulate the concept of constant velocity and constant acceleration
Teacher 3	Senior high school	Mathematics	**Vector** the robot is employed for a game in understanding the concept of vector
Teacher 4	Senior high school	Mathematics	**Translation** The robot is used for gaming in understanding the concept of translation

An example performed by Teacher 1, he used a robot for creating mathematics problems. The robot was programmed to be able to draw a triangle. After an object was drawn, the students then asked to analyse whether the object is a triangle or not by complying with the triangle properties. When the students were successfully identifying the object as a triangle, they then asked to find the perimeter and the triangle area using the concept of mathematics. From this example, Teacher 1 integrates science, technology, engineering, and mathematics altogether, as shown in Table 3.

Table 3. The STEM aspect of Teacher 1's performance [12]

Science Applying the concept of measuring various quantities using standard units (standard)	**Technology** Program the robot to be able to move to form a triangle.
Engineering Merakit robot ardiuno	**Mathematics** 1) Understand the concept of the area and perimeter of a triangle. 2) Solve the contextual problem related to the perimeter of the triangle

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4. Conclusion

This paper has outlined the educational robotics kit's development process, from assembling the components to the process of uploading the codes to the robot. The mBlock was selected to make it easier for the users to program the robot. The process of installation was easy, and the block programming looked like a puzzle. Teachers and students will be easy to master block programming. To reduces the cost, some components of the robot were self-printed using a 3D printer. With low-cost educational robotics, it is expected that teachers and students will be able to have it. Teachers have explored the idea of how the robot is used to promote student learning by emphasising the basis of STEM education.

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