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A STEM-based Learning Activity Instructional Design of Quadruped Bionic Robots

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ABSTRACT
This study designs a STEM–based learning activities related to bionic robots and examines students' learning performance of the instructional design. With the rapid development of science and technology, robots play an important role in human society, helping people in solving repetitive work using automatic objects in biological mechanical structure. However, quadruped bionic robots are usually expensive due to its mobility and stability control of locomotion. In this study, a quadruped bionic robot is designed using the linkage mechanism using 3D printing combined with the Micro:bit control board for motion. The purpose of this study is not only to experiment the making of a bionic robot, but also to construct an instructional design for the first-time STEM and robotics learners to learn basic mechanical structure, fabrication process, and programming using MakeCode. This production process is expected to inspire the students' learning motivation in the robotic production, and to improve mechanical concept and computational thinking.

KEYWORDS
Bionic Robot, STEM, Linkage Mechanism, Instructional Design, Computational Thinking

1. INTRODUCTION
STEM education has received a lot of attention recently. In order to be able to deal effectively with problems in the STEM field, the importance of computational thinking (CT) skills is highlighted. STEM is also considered to be a factor that can affect technological and economic development (Xie, Fang, & Sauman, 2015). Robots are also a technological trend in today's society (Li et al., 2011). This study believes that the technology of bionic robots is particularly important, since bionic robots imitate the walking methods of animals in nature, so it can adapt to a variety of special terrains. But in order to reduce the cost of making and to release cognitive loads, the linkage mechanism will be taught to construct bionic robot legs.

In this activity, students will learn about STEM, computational thinking, bionic robots, linkage mechanisms and related algorithmic concepts. Students will also build their first bionic robot. During the activity, students will be provided with components to assemble robots with their own design, and they will be guided to find out how to make their bionic robots move faster and more stable across various terrains. This paper mainly uses qualitative analysis and supplemented by quantitative analysis to explore the following research questions:

1. What are the processes and strategies used by learners in the process of making bionic robots? (Qualitative analysis)
2. What is the level of understanding and absorption of the linkage mechanism by the learners? (Quantitative analysis)

2. LITERATUR REVIEW

2.1. Computational Thinking
Computational Thinking has become an important cognitive skill to develop relating to all areas of education. Computational thinking can be traced back from Wing (2006) by saying that computational thinking is to allow humans and computers to cooperate and solve problems instead of thinking like a computer. Nowadays "computational thinking affects research in almost every discipline, including the sciences and humanities" (Bundy, 2007, p.67). Bundy stated that computational thinking is an important skill for problem-solving and thinking skills that apply in multiple disciplines. To learn computational thinking skills, education is important to enhance and reinforce intellectual skill so that CT can be used in various disciplines (Wing, 2011). Selby and Woollard (2013) divided CT into five major themes: abstraction, decomposition, algorithm, evaluation, and generalization.

1. **Abstraction** is about creating and defining the relationships between problems and formulating rules that can be solved step-by-step for similar problems and implemented repeatedly to simplifying information (Council, 2010); and displaying only the information that is needed (Peel & Friedrichsen, 2017).
2. **Decomposition** is the classification of potential elements to determine the substantive elements and the relationship between elements. Different strategies are used to decompose such as means-end, bottom-up, multivariate, and etc. (Rich, Egan, & Ellsworth, 2019).
3. **Algorithm** is a sequence of steps to solve a problem (Peel & Friedrichsen, 2017), and to develop rules that can solve similar problems step by step in order to be implemented repeatedly.
4. **Evaluation** is the process of ensuring that algorithms and solutions are feasible. Various properties of algorithms need to be evaluated, including whether they are correct, fast enough, use resources efficiently, and easy to use.
5. **Generalization** is the process of creating models, rules, principles, or patterns of observation to test predictions; and the step to identify how some small pieces can be

repurposed and reapplied to similar or unique problems (Selby & Woollard, 2013).

“CT is an essential skill for navigating today’s complex technological world (Peel & Friedrichsen, 2017, pp.21).” The purpose of this study is to encourage junior high school students to learn to use computational thinking. Through the above five skills to complete the activities held by this study, students can effectively use CT ability when encountering problems in various disciplines.

2.2. STEM-Based Instructional Design

STEM is composed of four core fields: Science, Technology, Engineering, and Mathematics (Xie, Fang, & Sauman, 2015). Increasing attention has been paid on STEM education in recent years. For students to deal with the problems encountered in real-life more effectively, STEM is a must-learn course (Julià & Antolí, 2019). The instructional design of STEM education has become an important part. How to design a course that can attract students to learn and can effectively strengthen students' ability in STEM has become an important topic for teachers. Khalil and Elkhider (2016) identified five pedagogical principles of instruction:

1. The learner is dedicated to engage in solving real-world problems.
2. Activate existing knowledge as a basis for new knowledge.
3. Demonstrate new knowledge to learners.
4. Learners applied the new knowledges.
5. Learners integrated the new-learned knowledge into the learner's world.

There are many types of instructional designs, among which project-based learning is a design that effectively helps learners learn from the process of creating a project (Guo et al., 2020). The part of making a project is the same as this study, so the project-based learning theory is used to design the activities of the study. The project-based learning approach to learning concentrates on constructing and explaining meaning, and that (1) knowledge is constructed; (2) it must be preceded by the teaching of prior knowledge; (3) the whole is slowly constructed from the parts; (4) requires effort to engage in purposeful activities to build useful knowledge structures (Gómez-del Río & Rodríguez, 2022). The activities in this study were designed based on the above STEM-based instructional design combined with project-based learning, and the activities allowed students to learn computational thinking skills.

2.3. Bionic Robot with Linkage Mechanism

In recent years, legged robots are getting more attention. Robots with wheels are fast and easy to control, but they cannot adapt to rough terrains. In contrast, legged robots can adapt to a variety of different terrains, and more and more people are developing diverse kinds of legged robots for various situations. For example, a bionic cheetah is developed by Massachusetts Institute of Technology (MIT) that can walk on rough terrain (Singh & Kotecha, 2020). Mammals including humans have developed a unique way of walking, which can effectively adapt to various terrains in nature (Li et al., 2011). Therefore, the bionic leg mechanism becomes the best reference for the design of walking robots. However, the high development cost and complex control limit the prevalence and application of this type of robot. Therefore, the linkage mechanism of the leg has become a new research direction. Ujjiban Kakati (2015) designed a two-leg walking chair using linkage mechanism that can replace a wheelchair. It can adapt to various terrains due to the national geographic conditions of India. Its price is the same as the basic price of existing wheelchairs in India providing convenience for the physically challenged people to improve their lives. The value and potential of using bionic robot legs with linkage mechanism was successfully demonstrated.

Based on the above examples, this research believes that it is particularly important to establish some basic robotics knowledge for modern students, especially the related knowledge of bionic robots and linkage mechanisms, and there are few studies on using bionic robots in instructional design. Therefore, this research develops a bionic robot to give students inspirations when learning related knowledge, and to guild students to make, improve, and elevate their self-designed bionic robot.

3. RESEARCH DESIGN

3.1. Research Process

This study will be conducted in a junior high school in Taiwan with about 20 students. Students will be divided into 3 to 4 groups, and each group has 6 students. The learning activity begins with a simple quiz with five questions about the course to define students’ prior knowledge level. Then the whole course will proceed from 2 to 4 hours depends on the students’ levels. After the students have basic knowledge, they will carry on with the programming activity of the bionic robot, which takes about 90 minutes. After experiencing the bionic robot test-drive, and learning from robot model, students will spend about 2.5 hours making their own bionic robot. Then, the teacher will conduct a competition between groups for about 30 minutes. Finally, after the competition, the teacher will guide the students to review the key points learned from this activity and reflect on their own production. Questionnaires will be distributed to receive students’ feedbacks, and analyze the students’ learning effectiveness through post-test (as shown in *Figure 1*).

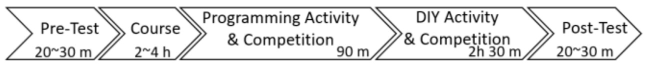

Figure 1. Activity Process

4. Activity DESIGN

4.1. Learning Objectives

Students are expected to learn CT skills as well as the knowledge of making bionic robots. The learning objectives include:

1. Understand what a four-bar linkage is, and how to build robot with the linkage mechanism;
2. Chose the best leg model to construct;
3. The ratio of motor hand for bionic robot;
4. The ratio of the linkage bars to move faster;

5. The key component of the leg mechanism that influences bionic robot's speed;
6. The process and strategies when students improve their bionic robot's speed.

These skills when constructing their bionic robots can be analyzed according to CT skills used in these activities:

1. Understand course content by finding out the relationship between each type of four-bar linkage. (Abstraction)
2. Break down the parts of a four-bar linkage to gain a better understanding of each part's function. And to figure out what will happen when different parts are connected in a different way. (Decomposition)
3. Students must make their own algorithm when coding the bionic robot, for example: first turn left, next go forward, then turn right, finally go forward. (Algorithm)
4. Revise the code after the first algorithm is tested. (Evaluation)
5. After students finish making their first bionic robot, they will have to test it out, then make some adjustment to improve it. (Evaluation)
6. Students will gain some knowledge on adjusting which part of the linkage to make it go faster after some try-and-errors. (Generalization)

After the activity is completed, the teacher collects the learning sheets which is also an assessment to students' CT performances. The pre-test and post-test results can show how well students learn from the activity.

4.2. Course Teaching for the Activities

After the establishment of prior knowledge of bionic robots, students participate the following activities. The topics, objectives, and contents of the course are shown in Table 1.

Table 1. Topics, objectives, and contents of the course

Topics	Contents	Objectives
STEM	The origin of STEM, definitions, meanings.	Knowing how this activity is related to various fields in STEM.
Bionic Robots	Basic concept and applications of bionic robots. Introduction of Bionic beasts and bionic robots. Bionic robot with four-bar linkage mechanism.	Understand the basic knowledge of bionic robots.
Linkage Mechanism	Introduction of Linkage Mechanism and how to apply it. Four-bar linkage mechanisms: Crank-Rocker mechanisms, Double-Crank mechanisms, Double-Rocker mechanisms.	Establish the knowledge of the linkage mechanism.
Motors	Introduction of DC Motors and Servo Motors.	Learn about the motors that will be used in the upcoming activities.
Micro:bit and Block Programming	Introduction of Micro:bit. MakeCode block programming.	Learn about the possibilities and basic programming of Micro:bit.

The five topics are described in details as below.

4.2.1. STEM

In this session, students learn about the origin, definitions, and the meanings of STEM, and understand how this activity is related to various fields in STEM. For example, when students make their own bionic robots, they are experiencing the "Engineering" part in STEM field.

4.2.2. Bionic Robots

In this session, students understand the basic concept of bionic robots, and the application of robots. Bionic beasts and bionic robots are introduced, among which the robots with four-bar linkage mechanism (Terefe, Lemu, & K/Mariam, 2019) are emphasized.

4.2.3. Linkage Mechanism

In this session, knowledge of linkage mechanism is introduced, including basic terms and four-bar linkage definitions, classifications, and variations. Professional terms, such as crank and rocker, are mentioned and demonstrated (as shown in *Figure 2*) so the students have sufficient knowledge to make their first bionic walking robot in the following DIY activities.

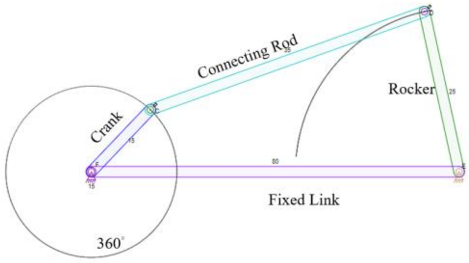

Figure 2. Basic Four-Bar Linkage Terms

There are types of four-bar linkage mechanisms (Martinez et al., 2012), for example: crank-rocker mechanism, double-crank mechanism, and double-rocker mechanism (as shown in *Figure 3*). They have common features, when the sum of the longest rod and the shortest rod is less than or equal to the sum of the other two rods, then it can form a four-bar linkage. When the fixed link is the dual rod of the shortest rod (the neighbor of the shortest rod), it is crank-rocker mechanism. When the fixed link is the shortest rod, it is a double-crank mechanism. When the fixed link is on the opposite side of the shortest rod, it is double-rocker mechanism.

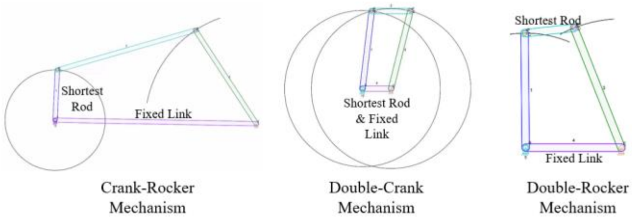

Figure 3. Three Types of Four-Bar Linkage Mechanism

In order to give students inspirations in making their own bionic robots, this session introduces two types of four-bar linkage leg designs: M-shaped four-bar linkage and Cross-shaped four-bar linkage. The M-shaped linkage is a double-rocker mechanism, and the Cross-shaped linkage is a crank-rocker mechanism (as shown in *Figure 4*).

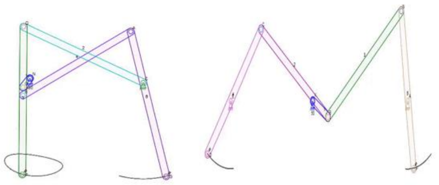

Figure 4. Cross-Shaped & M-Shaped Four-Bar Linkage

4.2.4. Motors

Motors are the basic equipment of most robots (Wahde, 2012). This session introduces basic motor knowledge to students focusing on the various types of motors. This activity introduces two types of motors, DC motors and servo motors. During the bionic robot programming activity, students will use Micro:bit development software MakeCode to write block programming to control servo motors; and use DC motors to mobilize their first bionic robot in the DIY activity.

4.2.5. Micro:bit and Block Programming

In order to control the motor, a control board is required. This activity uses Micro:bit to connect to the Micro:bit expansion board, Mbitbot. The pins of the servo motor are directly connected to Micro:bit. Students are taught to use MakeCode to write block programming (as shown in *Figure 5*) to control the motor movements.

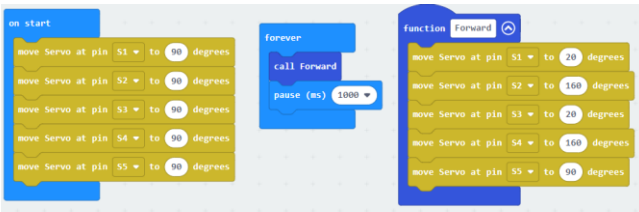

Figure 5. MakeCode Block Programming Example

4.3. Bionic Robot Programming Activity

The experience of using a program to control the movement of a bionic robot may give students inspirations when making their own bionic robots. In order to allow students to experience how a basic bionic robot movement and to see how a professional structure is constructed, a bionic robot with eight-bar linkage was developed in this study.

This bionic robot is mainly developed with reference to " Eight-Bar Linkage Walking Mechanism (Yan, 2007)". First, sketch the robot components on SolidWorks before using 3D-printing to produce the parts. Then, assemble the parts with motors, Micro:bit and Mbitbot. Finally, write programming to mobilize the bionic robot. The constructing process is shown as Figure 6 below.

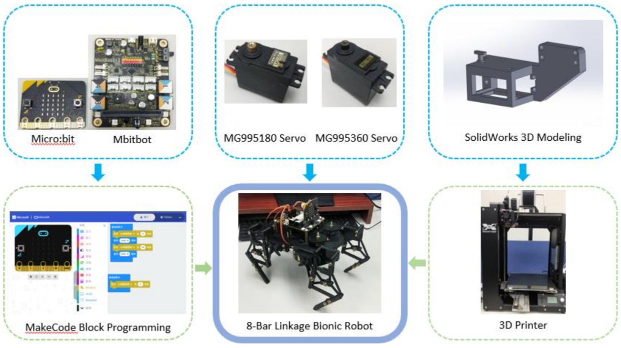

Figure 6. Bionic Robot Constructing Process

The bionic robot programming activity is for students to write the block program in MakeCode to control the bionic robot through obstacles. Students will be divided into groups of three, controlling the bionic robot to move from the starting point to the ending point, and return to the starting point after obtaining a component card. Students need to get three component cards including: linkage rod set 1, linkage rod set 2, and motors. The group that gets the three component cards and returns the fastest wins. The winning team can gain advantages in the competition session of the DIY bionic robot.

4.4. Bionic Robot DIY Activity

In this session, students use the component cards they obtained to exchange with the teacher for the components of bionic robots including linkage rod sets and motors. Students work on their own and use these parts to assemble their first bionic robot. Students can make the M-shaped four-bar linkage or Cross-shaped four-bar linkage taught in the course, or they can use their own creativity to make other linkage mechanism. During the process, a learning sheet will be distributed to the students which not only guide them through the production process but to document the changes of their designs and difficulties that they encounter as well as explain why and how they make adjustments. Reflection questions are also included to help students reflect on their designs, such as: What if I extend the length of the crank, will the bionic robot walk faster? During the construction process, the teacher will give scaffolding assistance (Sawyer, 2005) so that students can maintain interest and curiosity in the learning process.

After the students have assembled their own bionic robots, they will participate an in-class competition. Students will place their own bionic robots at the starting line. After the robot reaches the finish line, the students will answer some questions about the course. If the students answer correctly, they can turn the robot around and go back to starting line to get the points. If they answer incorrectly, the teacher will teach the students about the correct answer. Each successful round counts as one point, and the student who earns the most points within five minutes or who answers all the questions the fastest wins. The winner will advance to reach the final championship and get a small prize from the teacher.

5. EXPECTED RESULTS

5.1. CT Performances

In order to evaluate how students' CT performance are, students will have to document the constructing process. With the documents students wrote, teachers can find out how well individuals perform. This research expects that students can gain better understanding of the course content through the learning worksheet and guides (Learn to do “Abstraction” and “Decomposition” in CT skills.). They can learn how the linkage moves and the bionic robot’s architecture in the programming activity (Learn to do “Abstraction”, “Decomposition”, and “Algorithm” in CT skills.). When students are making their own bionic robots, they can improve their linkage concept through continuous experiments and evaluations (Learn to do all five CT skills.).

5.2. Knowledge Acquisition of Bionic Robot with Linkage Mechanism

There will be a pre-test and post-test before and after the learning activity. The difference between the pre-test and post-test can be used to observe whether the students have acquired the relevant knowledge of the bionic robot with linkage mechanism after this activity. Questionnaire include basic linkage mechanism and the understanding of bionic robots, for example: What is a four-bar linkage mechanism? This research expects students to acquire basic linkage knowledge and comprehend the knowledge of bionic robots through a series of activities, and gain inspiration for their future projects or designs.

5.3. Overall Satisfactions

At the end of the activity, students will be asked to fill out a questionnaire. The questions include their thoughts and general feelings about each stage of the activity. Students will also be asked if there is any room for improvement in each stage of the activity, and it is expected that the content of this activity can be adjusted through the feedback of the students.

6. CONCLUSION

Nowadays, technology is developing rapidly, modern people will have to learn interdisciplinary skills. Students need to develop basic exploration, research, and problem-solving skills, of the 21st century information literacy. In order to keep up with the progress of the times, this research will guide students to explore the field of bionic robots. For example, the impact on bionic robots when changing the proportions and length of various components, and give scaffolding (Sawyer, 2014) to assist students in learning.

Technology products can be seen everywhere in life. No matter one is an expert or an ordinary worker, learning CT skills and understanding STEM fields can make one be more competitive. Computational thinking skills can allow one to effectively solve problems in life. Therefore, it is hoped that students can develop relevant abilities through this activity.

In this learning activity, learners will explore the field of STEM and CT from scratch by designing and creating their own bionic robots. This study expects that learners can increase the ability of computational thinking and master the basic knowledge of linkage mechanism, and enhance learning motivation. This study expected to provide a curriculum model as a reference for future instructional designs, especially of STEM-related activities, so that young learners can be proficient problem-solver.

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