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Four-bar Linkage Quadruped Biorobotic Instructions: Gamified Design and Development

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Abstract:
STEM education are embedded into formal education in many secondary schools around the world since students need to understand electrical and mechanical principles as well as computer controls to solve future life problems. In order to enable students to absorb the knowledge more effectively and be more curious about these knowledge, this study proposed a gamified hands-on four-bar biorobotic instruction by teaching the knowledge of linkage mechanism. Four-bar linkage biorobotic require mechanical thinking that emphasizes on balance, free movements, speed, and potential connections to computerized interactions. Through trials-and-errors, students use adjustable skeletons created by 3D printing technology that allows the effect-testing of the various ratios of the connecting rods, which are connected with a DC motor and Legos to enable remote computer controls. This paper not only introduces the design of the biorobotic instruction for junior high school students but also introduces the application possibilities and future studies for this development.

Keywords:
Biorobotics, four-bar linkage, linkage mechanism, 3D-printing, gamified instruction

1. Introduction

STEM education are embedded into formal education in many secondary schools around the world, especially Taiwan, since students need to learn the basic principles of mechanics, electronics, and technology at the same time to strengthen the computational thinking skills (Selby & Woollard, 2013) such as problem solving and logical analysis. The main purpose of this study is to design a four-bar linkage quadruped biorobotic instruction for use in the life science and technology class of Taiwan's junior high school curriculum. In order to make the robot easy to use, simple to assemble, and easy to learn for the students, LEGOs were used as the leg part in this research. LEGO has high variability that allows the development of creative quadruped robots. Although LEGO linkage bionic robots already exist, it requires a LEGO motor and LEGO EV3 controller to program. Not only it is more expensive, most robotics do not mimic real skeleton structure of quadruped animals, such as horses.

Therefore, this study proposes the biorobotic instruction to start with the principles of the linkage mechanism, so the biorobotics can be driven by simple DC motors. There are three parts of quadruped biorobotics, including a DC motor, legs using LEGO parts, and a skeleton that link the previous two. This paper presents an instructional design of the quadruped biorobotic instruction with hands-on linkage mechanism lessons and gamified activities with simple block programming. Computational thinking in both programming and problem-solving are included to prepare students for facing future problems.

The difference between this curriculum and the Taiwan cram school is that students are taught how to assemble robotics using standardized manuals with extensive hours on achieving highest speed and accurate paths. On the other hand, the LEGO camps stress on creative assembly of parts and components. With combined goals, this curriculum extends its emphasis on the fundamental understanding of biorobotic skeletal structures and movement mechanisms so students' creativities can be presented in the making process. Such instruction not only integrate interdisciplinary literacy of biology, science, mechanical engineering, and technology, the cultivation of students' independent research skills for tackling problems with mechanical and technological resources are practiced so students are more prepared for solving future problems.

2. Related work

2.1 Biorobotics and linkage mechanism

Biorobotics is a kind of robotics that imitate a living creature in terms of biological forms and mechanical structures. There are various kinds of bionic robots, such as bionic birds (e.g., Pan et al., 2021), quadruped bionic robot (e.g. He & Gao, 2015), bionic fish (e.g. Yan et al., 2022), bionic reptiles (e.g. Li et al., 2022), and so on. The cost of building a bionic robot is generally high, and the use of a linkage mechanism can reduce the number of motors to lower the cost. Among which quadruped bionic robots are the more common biorobotics. There are several existing kinds of linkage robot leg designs, such as Jansen’s 12-linkage mechanism (Patnaik & Umanand, 2016) which can be difficult for students without basic knowledge. Thus, this study focuses on the development of four- bar linkage bionic robots that allows students to learn the linkage mechanism and its related creations. There is little recent research on four-bar linkage mechanism leg designs, especially for the education of the younger generation.

2.2 3D printing: materials

In order to provide students durable components in low cost, and the materials used for 3D printing should be tough, relatively inexpensive, and environmentally friendly. There are many kinds of 3D printing materials, such as PLA, ABS, and PETG. PETG is the most environmentally friendly material, while ABS is the least one (Kumar et al., 2022). Comparing to PLA, PETG is superior in terms of toughness, relatively transparent, and equal cost (Popa et al., 2022). For easy access and low cost, PLA is chosen to be printed using fused deposition modeling (FDM) 3D printers.

3. Biorobotics Instruction

3.1 Four-bar linkage leg design

There are two-leg designs of the four-bar linkage biorobotics known as: cross-shaped and M-shaped four-bar linkage biorobotics (Figure 1). The cross-shaped design is the double-rocker linkage mechanism, and M-shaped is the crank-rocker linkage mechanism. This study designs a kit (Figure 2) so that students can use the components in the kit to assemble the two designs of leg structures. The skeletons come with holes to allow versatility for structure design and to test the effects of different length ratios.

This kit mainly provides a skeleton that allows the DC motor to combine with LEGO. LEGO parts are replaceable with other objects for variations of products. Using 3D printing skeletons allow us to use general DC motors instead of EV3 to reduce cost. A kit for this proposed instruction (Figure 2) cost less than $5 U.S. dollars. The same low-cost kit can be assembled with other Lego parts to creation various kinds of final projects; for example, with the addition of Lego pulleys, students can make cranes; with the addition of fan blades, students can make windmill or boat. This kit has high variability and high availability as teaching aids at very low cost.

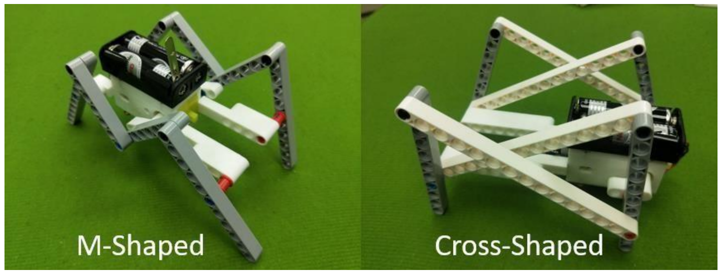

Figure 1 M-Shaped and Cross-Shaped four-bar linkage biorobotics

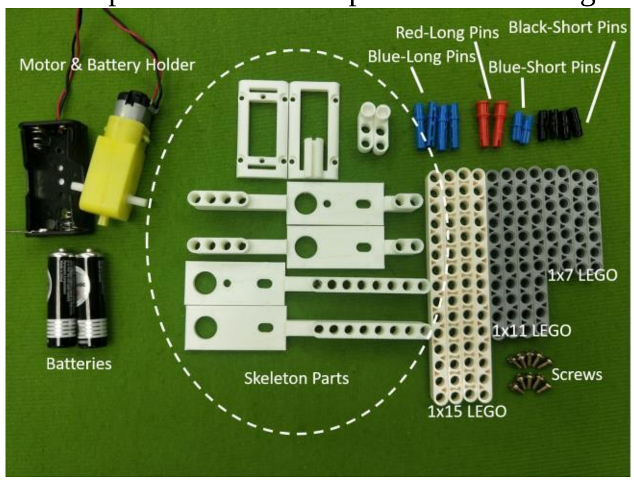

Figure 2 Four-bar linkage biorobotics kit

To prepare learning materials, SolidWorks is used in this study to draw the skeleton, which are saved as STL files which are native to the stereolithographic CAD software created by 3D systems. Then, the slicing software Cura is used to turn the 3D drawing into a gcode file that can be read by a 3D printer (Figure 3). A set of materials for one biorobotics requires approximately seven hours to print excluding failure printings. Nevertheless, the long start-up preparation can produce high cost- value teaching project materials.

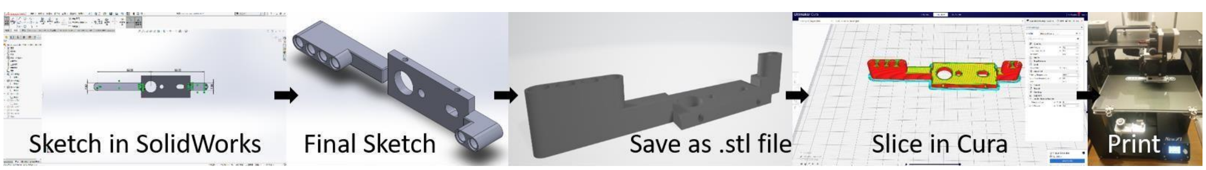

Figure 3 3D printed skeleton making process

3.2 Biorobotics skeleton design

The design of the skeleton is divided into upper cover, lower cover, left bar, and right bar (Figure 4).

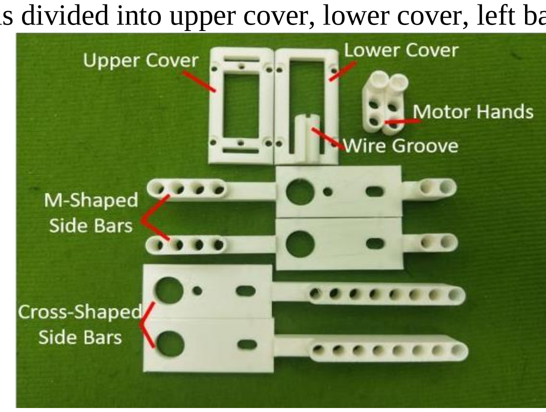

Figure 4 Skeleton Parts

The design of the upper and lower cover is not only used to combine the left and right bars, but the upper cover also added screw holes to attach the battery holder, and the lower cover adds a groove to hide the wires to prevent the robot from tripping over the wires when walking. There are two types of left and right bars, one is designed for assembling M-shaped and the other is designed for assembling cross-shaped. Four parts surround the motor and are screwed together to form a motor holder. The pole part of the skeleton has many holes dug in it for connecting LEGO and allows students to decide the length of their biorobotics. The developed biorobotic kit was tested on two master students, both of whom have no mechanical background and did not receive the M-shaped leg assembly instruction. However, both students were able to assemble and improve three generations of biorobotics within two hours, and one of them made an M-shaped four-bar linkage leg design and the other one made a cross-shaped four-bar linkage leg design. With detailed instruction and help from the teachers, it is believed that the junior high school students could also design at least three generations of biorobotics within two hours. This idea will be tested in the future.

3.3 Instructional Design

The instruction can be either implemented into formal education which requires two class period or practiced as a half-day summer camp activity (Figure 5). The content includes a) the introduction to linkage mechanism; b) M-shaped biorobotic assembly; c) hands-on practice; d) gamified assessment;
e) reflection and showcase. Learning sheets are used to guide students through the course, besides to enhance their understandings of the course content, their learning processes are documented as learning profiles. In summer camps, teachers can take more time to cover additional topics, go into more details about course content, show exemplary products, or allow students to use block programming to mobilize their robots once they are done. The instructional process is as follows.

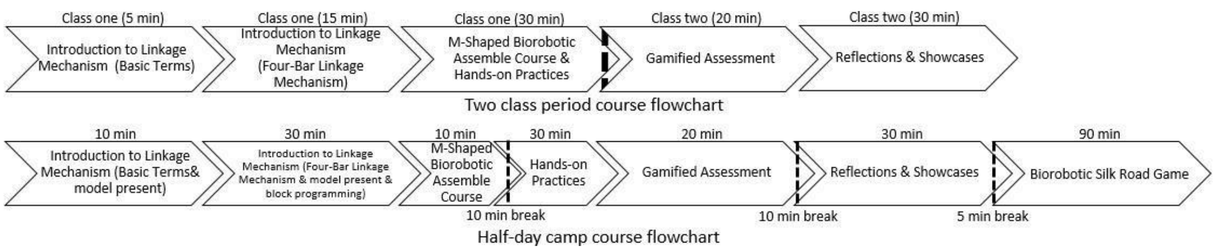

Figure 5 Course flowcharts

a) The introduction to the linkage mechanism. This section introduces the basic terms, definitions, and applications of M-shaped and cross-shaped linkage mechanisms. Examples are shown to illustrate the use of linkage mechanisms, such as M-shaped is used in bicycle and cross-shaped is used in windshield wiper.

b) M-shaped biorobotic assembly. To demonstrate the basic assembly and layering concepts, teachers guide the students step-by-step assemble of a basic M-shaped biorobotic so that students can have sufficient knowledge on how to assemble a biorobotic and know about the possibilities to improve it.

The following explanation use M-shaped skeleton as the example. Figure 2 shows parts of the M- shaped. To assemble the skeleton, first, attach the two M-shaped side bars on to the motor and screw in the upper and lower cover (Figure 6a). After finishing the skeleton, tug the battery holder wire into the wire groove of the lower cover (Figure 6b), and screw the battery holder on the upper cover to install the battery (Figure 6c). For the leg part assembly method, first of all, install the motor hands on the motor and install it in the opposite way on both sides, then install the red-long pin into the end of the longer end of the skeleton, and install the blue-long pin into the end of the shorter end of the skeleton (Figure 6d). Next, install the blue-short pins into to the red-long pins (Figure 6e), then the pins can be connected to 1x11 LEGO as a foot (Figure 6f). Then, install a 1x7 LEGO with blue-long pins and motor hands together (shown as Figure 6g), and then in the other end of the blue-long pins connected to another 1x7 LEGO as part of the knee (Figure 6h), and finally using four black-short pins to connect the 1x7 and 1x11 LEGOs together to complete the M-shaped four-bar linkage biorobotic assembly (Figure 6i). After finishing the assembly, the students are ready for the upcoming hands-on section. During the hands-on practices, the students can choose from the M-shaped or the cross-shaped skeletons to assemble and elevate their design.

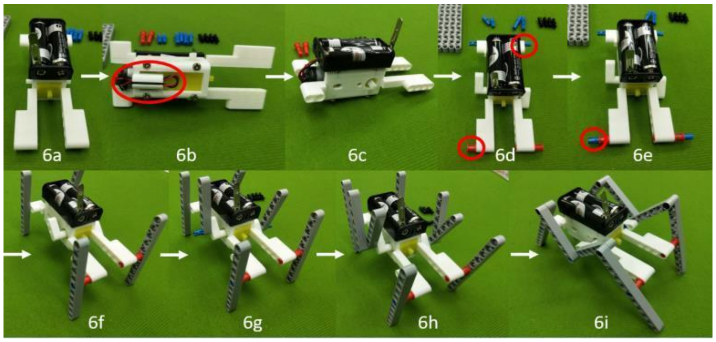

Figure 6 M-shaped four-bar linkage bionic robot assembly

c) Hands-on practice. Students test their own design with chosen linkage mechanism, investigate and improve their own assembled biorobotics. They document the use of length and ratio of rods, motions, balances, and speeds of every trials of their biorobotics on their own learning sheets, and use it to review and compare their different effectiveness.

d) Gamified assessment. An in-class competition will be conducted wherein individual students test their biorobotics, modify them, and perfectionize them. The competition is based on a ranking system with repechage to give student the opportunity to showcase their works.

e) Reflection and showcase. Students show their final biorobotics to the whole class with their design concepts, and the analysis of their strengths and weaknesses. The learning sheets are used to review students' understandings to the linkage mechanism, creativity, and effectiveness of the makings.

f) Interactive game. Additional gamified application can be added in the summer camp.

In this study, a Biorobotic Silk Road Game is designed for a whole-class interdisciplinary interaction. A 4m x 4m room-size map of the ancient Chinese Silk Road is displayed on the floor. Students are divided into groups of four and play various ethnicities in the historical scenario. Students in each group takes on different roles such as commander, warrior, trader, and diplomat. The commander is responsible for strategic directing the entire team who has the highest decision-making authority and speaks on behalf of their group. The warrior plans the wagon’s route and writes block programming to operate the biorobotic horse carriage which may involve in communications and battles. The trader is responsible for executing all transactions and management of funds, goods, and treasures. The diplomat is responsible for negotiating with other groups and reaching competitive agreements.

The Biorobotic Silk Road Game has several stages, each of which is based on a historical event with conflicts and tasks. The commander needs to observe the situation and guide the discussion to make action decisions. The diplomat then goes on to negotiate and solve problems. Only after the conflicts are resolved can the warriors program the biorobotic wagon to move to the designated location on the map to either look for trading opportunities, battling for defense or expand territories, or spreading out their cultural impacts. The geographical restrictions of the Silk Road routes must be observed, calculated, and planned so that they can move freely across the land. According to traffic rules, wagons will slow down when crossing the mountains and should reduce loads while crossing the deserts. Once the warrior has successfully driven the wagon to the designated location, the trader oversees and performs trading. When playing the Biorobotic Silk Road Game, students can learn and apply mechanical, electrical, geographical, and historical knowledge and skills in the half-day camp to achieve interdisciplinary learning.

4. Conclusion

4.1 Application possibilities

Although we don't often hear the term linkage mechanism, it is found in every corner of life, such as bicycles, car wipers, and factory machines, which often use the principle of linkage mechanism. Therefore, learning the basics of linkage will help us to have a better understanding of the objects we use in our lives. In fact, in Taiwan's education, the basic linkage is taught in life science and technology classes in junior high schools, and the linkage mechanism is also taught in the mechanical department of senior high schools, and the linkage course is also taught in many summer camps. If the robots are combined with a large map learning board game that incorporates geography and history, it can achieve interdisciplinary learning. For example, Biorobotic Silk Road Game. Students write block programming to control a biorobotic to specific locations to complete tasks and to learn when playing. In fact, the biorobotics developed in this research will be used in a learning activity of quadruped biorobotics, which includes knowledge teaching of linkage mechanism, DIY biorobotics, and simple block programming courses (Chen & Shih, 2022).

4.2 Future related studies

This linkage biorobotic is only the first generation of this robot, there can be more kinds of changes and research to be done. In the future, it will be combined with a large history education board game, allowing students to play with the robot in a large map, which allows students to first learn mechanical principles and block programming, then by applying it to control the biorobotic horse to certain places on the map to accomplish missions to learn multiple disciplines at the same time. Through the process of playing, students will learn the basic knowledge of electronics, electrical, mechanical, history, geography, etc., which is interdisciplinary learning. It will also be applied in STEM/STEAM education courses, allowing students to learn mechanical principles by assembling their own linkage biorobotics, and analyzing the students' building process through the records. Finally, we hope that future research and teaching will be more interesting and in-depth.

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