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Development of a Low-Cost Electrical Circuit Experiment Kit for Children Using Toy Blocks

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Abstract **–**Electrical, electronics, and computer engineering are among the most preferred professions globally. To foster awareness of circuits and coding—the foundational concepts of these fields—numerous hardware and software products have been developed, and related scientific studies conducted. In recent years, the use of such products in schools and educational centers has become increasingly popular for educating preschool and K-12 students. These products not only enhance students' analytical and systematic thinking skills but also provide fundamental knowledge related to engineering disciplines. In this study, a low-cost electrical circuit kit was designed and implemented using toy blocks. Ten electrical circuits were developed, and a user manual featuring circuit diagrams was prepared. This kit allows children to learn about electrical circuit components, their symbolic representations, how to assemble and interpret circuit diagrams, and how to create their own circuit diagrams. Due to its affordability and ease of construction, the proposed kit serves as an alternative to expensive commercial electrical circuit kits.

Keywords – Circuit Element Representation, Electrical Circuit Kit, K-12, Practical Skills, STEM.

I. INTRODUCTION

STEM is an interdisciplinary educational approach encompassing science, technology, engineering, and mathematics. This approach emphasizes applied learning through creative problem-solving, enabling students to develop the skills needed for future careers. In STEM education, experiment kits that incorporate both hardware and software applications are frequently utilized [1].

Although theoretical knowledge is valuable, applying a subject in practice is beneficial in many ways. Studies have shown that with experimental kits, children gain characteristics such as identifying problems, learning by doing, acquiring scientific vocabulary, understanding abstract scientific concepts, thinking systematically, discovering and searching for ways of realization, and seeing their potential [2, 3]. Experts emphasize that such hands-on applications can positively impact children's future education and career prospects, and recommend that these practices be implemented on a broader scale [2, 4].

There are many hardware and software products developed for commercial and educational purposes. These kits can be divided into three groups as hardware, software and hybrid (hardware and software together) kits. Bee Bot, Code-a-Pillar, Cubetto, Curlybot, Dr. Wagon, Electronic Blocks and KIBO are examples of hardware products. On software development, there are applications such as Cargo-Bo, Codeable Crafts, LightBot, and ScratchJr. In hybrid kits that include both hardware and software, there are examples such as microBlue-Bot, Tabletop puzzle block system, Puzzlets Starter Pack, Roberto and Strawbies [5].

The literature includes studies on experimental kits developed for educational purposes and the use of commercial experimental kits in the educational process. In a study, they developed a kit consisting of simple electrical circuits using puzzle blocks for junior high school students [6]. Four different circuits were implemented: Ohm's Law Circuits, Series and Parallel Electrical Circuits, the Combination of Series and Parallel Electrical Circuits, and Kirchoff's Law I Circuits. Another study aimed to address difficulties in understanding and using the micro:bit experiment board and breadboard [7]. Electrical circuit drawings were created, and circuit installations were conducted. Materials produced via 3D printing were developed for the implementation of the designed circuits, facilitating a better understanding of how to use and interpret circuit diagrams. Additionally, toys and kits developed for children under the age of seven were examined in a separate study [5]. A total of 30 kits were reviewed, including 18 physical kits, 8 virtual kits, and 9 hybrid kits. The common features, design aspects, computational concepts and applications, activities or project features, as well as the knowledge and skills required for each toy and kit, were evaluated in the review.

In a study, preschool students were taught using two different kits: magnetic blocks (LittleBits) with simple electrical circuit elements, and the Space Rover Inventor Kit, which included a motor and solar panel [2]. It was observed that this technology- and engineering-based education increased children's cooperation. Additionally, more curious children demonstrated greater persistence in making the circuits work and often assumed leadership roles by suggesting reasonable solutions to their peers. Another study developed an electronic circuit kit using Lego Duplo Primo blocks [8]. The behavior of children aged 4-6 and 7-9 years old when using this circuit kit was examined. The results indicated that children aged 7-8 showed greater interest and had a better understanding of the functions of the blocks. A separate study examined the effect of gender on attitudes and learning using Snap Circuits [9]. Students were divided into two age groups, elementary school and high school, and were given lessons on electrical circuits. Voltage, current, and resistance values were measured, and students were provided with information about Ohm's law. The findings revealed that concrete representations led to higher comprehension scores among elementary school students. Among high school students, male students scored higher in interest and understanding than their female counterparts.

In this study, a low-cost electrical circuit experiment kit was developed for children. The electrical circuit components were integrated into toy blocks that are familiar to children. Additionally, sample circuits were designed using these blocks, and a user manual was prepared to accompany the kit. The aim of this electrical circuit kit is to teach children the basics of electrical circuit elements, the representation of these elements using symbols, how the elements can be connected, how to assemble a drawn circuit diagram, and how to interpret the diagram of a pre-assembled circuit. Through the designed experiments, children will gain knowledge of various electrical concepts, such as series and parallel circuits, as well as components like buzzers, push-buttons, LEDs, LDR sensors, touch sensors, DC motors, and potentiometers.

Various issues arise in the installation and interpretation of electrical circuits, including a lack of understanding of variables such as voltage and current, unfamiliarity with circuit element symbols, incorrect connections, and erroneous measurements [10, 11]. To address these challenges, circuit diagrams for the developed kit incorporate real images of the circuit elements, represented as differently colored toy blocks. This approach facilitates the construction of circuits by providing clearer visual cues. These representations are included in the user manual for the experiment kit.

II. BLOCKS IN EXPERIMENT KIT

This experimental kit was designed by integrating circuit elements into toy blocks familiar to children. Small holes were made on the sides of the blocks to accommodate the circuit elements, pins, and sockets. Inside the blocks, these components were soldered together for electrical connections. Hot silicone was used to secure the pins, sockets, and circuit elements within the blocks. Cables with pin and socket ends were employed to connect the blocks. A total of 15 toy blocks were used in the experimental kit, as shown in Figures 1-3.

The toy blocks are categorized into three groups: general circuit blocks, sensor blocks, and action blocks. General circuit blocks include a battery (wide green block), a push-button (orange block), and resistors (1kΩ red block, 330Ω yellow block, 10kΩ potentiometer yellow block). Sensor blocks contain an LDR (orange block) and a touch sensor (green block). Action blocks consist of LEDs (red, yellow,

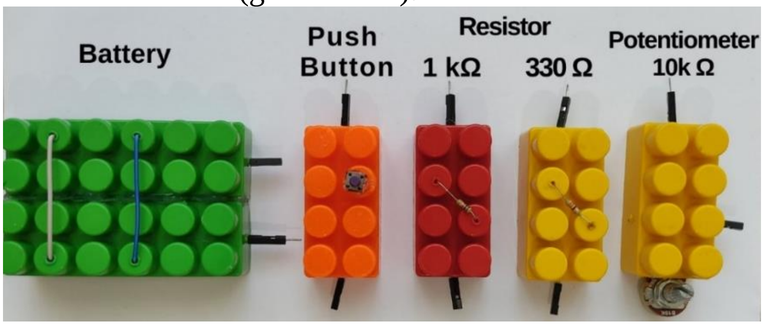


Fig. 1 General circuit blocks

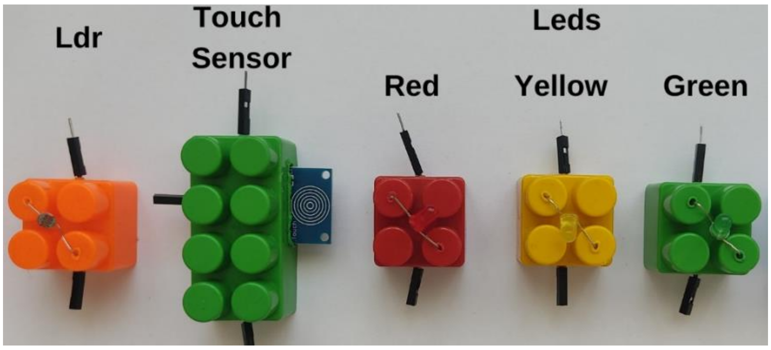


Fig. 2 Sensor blocks

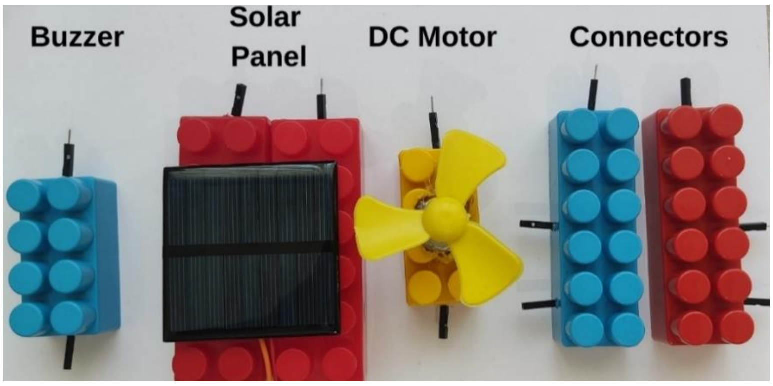


Fig. 3 Action and connector blocks

green blocks), a buzzer (blue block), a DC motor (yellow block), a solar panel (wide red block), and connector blocks (blue and red).

After placing the electrical circuit elements inside the blocks, 10 circuits were designed for use with these blocks. The circuits were ordered from easy to difficult. Initially, basic circuits involving LEDs, series and parallel connections, potentiometers, and push-buttons were taken place. Next, circuits incorporating LDR and touch sensor elements were given. Following these, buzzer and DC motor circuits, which convert electrical energy into sound and motion, were listed. Finally, a circuit utilizing a solar cell as a renewable energy source was created, commonly referred to as a solar panel circuit.

A. *Circuit-1: LED*

In the first circuit, a battery, a resistor (330 Ω), and a red LED are connected in series, as shown in Figure 4. The circuit diagram for this setup is also provided in the circuit diagrams chapter of the manual.

This diagram is included to demonstrate to children how to draw a circuit. For subsequent circuits, the diagram section will be left blank, and children will be asked to draw the circuit diagram for the installed circuit. This circuit can similarly be configured with yellow and green LEDs, and children can be asked to draw the diagrams for these variations. If children have some prior knowledge of electrical circuits, variables such as current and voltage in this circuit can be measured with a multi-meter and the results can be included as notes in the user manual of the experiment kit.

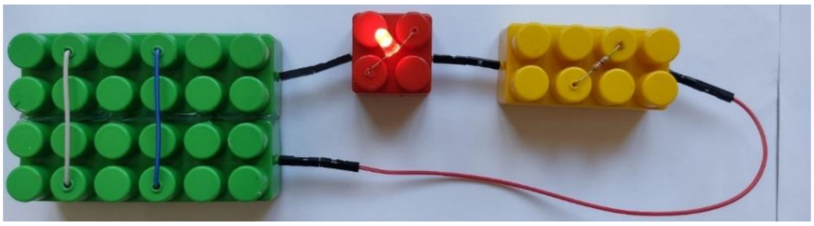


Fig. 4 Led circuit

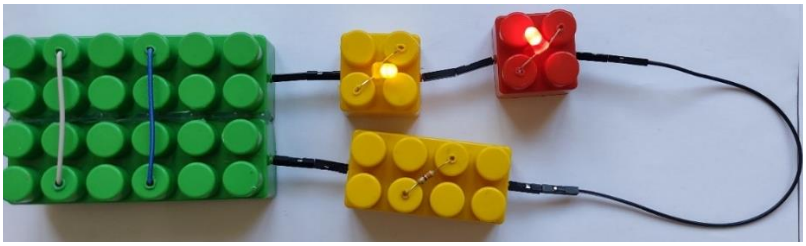


Fig. 5 Series connection circuit

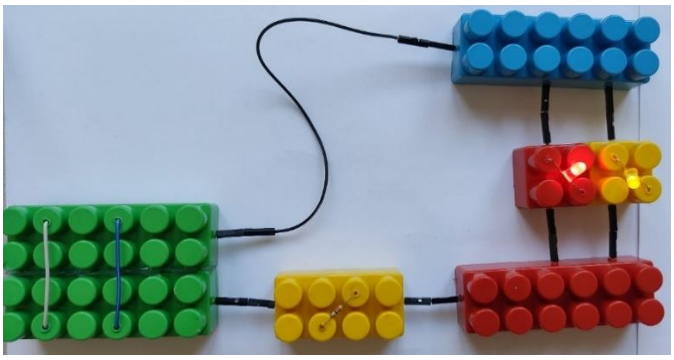


Fig. 6 Parallel connection circuit

B. *Circuit-2: Series Connection*

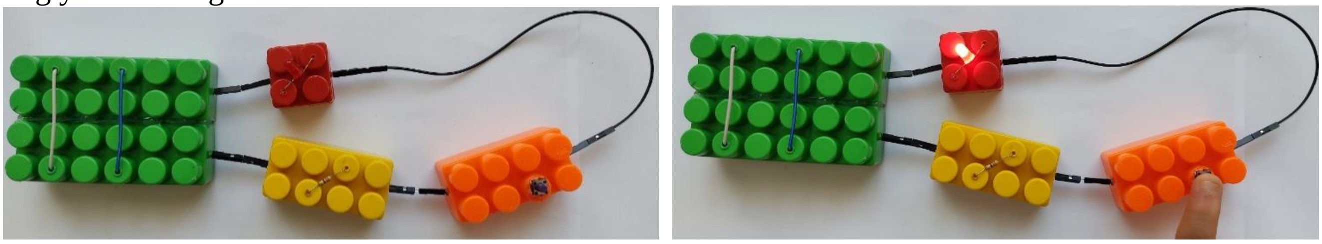
In this circuit, a series connection was established using a battery, a resistor (330 Ω), and LEDs, as shown in Figure 5. Red and yellow LEDs were selected for this setup. After assembling the circuit, children can be asked to compare the brightness of the LED in the first circuit with the brightness of the LEDs in the second circuit. This circuit can be further configured using combinations of red-green and yellow-green LEDs. Once the circuit is set up, children can be instructed to draw the circuit diagram in the blank space provided under the '2nd Circuit' heading on the last page of the experiment kit manual. If children have some knowledge of electrical circuits, the current flowing through both LEDs can be measured with a multimeter. This exercise can demonstrate that the same current flows through the components in a series circuit.

C. *Circuit-3: Parallel Connection*

In this circuit, a parallel connection is established using a battery, a resistor (330 Ω), red and yellow LEDs, and connectors, as shown in Figure 6. This circuit can also be reconfigured with yellow-green and red-green LEDs. The circuit diagram can be drawn in the user manual of the experiment kit. If children possess some knowledge of electrical circuits, a multimeter can be used to demonstrate that the voltage across the components in parallel circuits remains the same.

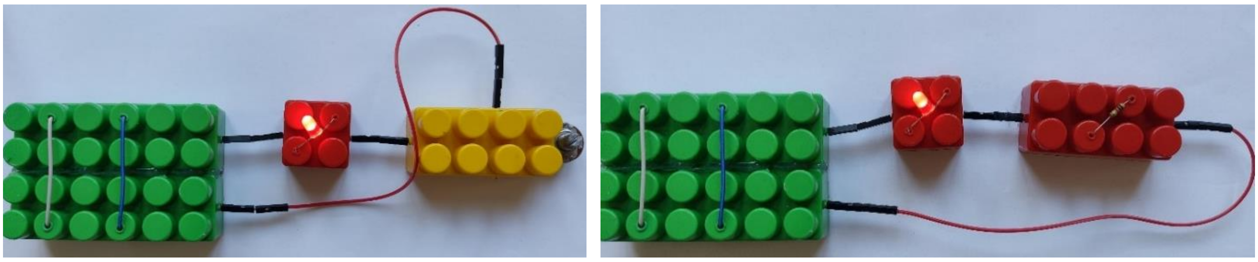
D. *Circuit-4: Push-Button*

In this circuit, a battery, a resistor (330 Ω), a red LED, and a push-button are connected in series, as illustrated in Figure 7. After the circuit is set up, the children are instructed to press the push-button. Upon pressing the button, the red LED will light up, as shown in Figure 7(b). The circuit diagram for the push-button circuit can be drawn in the user manual of the experiment kit. This circuit can also be reconfigured using yellow and green LEDs.



(a) (b)

Fig. 7 (a) Push-button circuit (b) Push-button Circuit with button pressed



(a) (b)

Fig. 8 (a) Potentiometer circuit (b) 1k Ω circuit

E. *Circuit-5: Potentiometer*

This circuit is a variation of Circuit 1, utilizing different resistors, as shown in Figure 8. A battery, a resistor, and a red LED are connected in series. In Figure 8(a), a potentiometer of 10 kΩ is used, while in Figure 8(b), a resistor of 1 kΩ is employed. The brightness of the LEDs in this circuit can be compared to that in Circuit 1. Additionally, by changing the resistance value of the potentiometer, variations in LED brightness can be observed. The circuit diagram can be drawn in the manual. This circuit can also be constructed using yellow and green LEDs. If the children have some knowledge of electrical circuits, they can measure various circuit parameters (resistance, current, and voltage) with a multimeter and discuss the measured values.

F. *Circuit-6: LDR*

In this circuit, a battery, an LDR sensor, a resistor (1 kΩ), and a yellow LED are connected in series, as shown in Figure 9. An LDR, or light-dependent resistor, exhibits a decrease in resistance with increasing light intensity. The brightness of the LED varies according to the ambient light levels. It can be observed that shining light on the LDR increases the brightness of the LED. Conversely, covering the LDR sensor with a hand to create a dark environment results in a decrease in the LED's brightness.

G. *Circuit-7: Touch Sensor*

In this circuit, a battery, a resistor (330 Ω), a red LED, a connector, and a touch sensor are connected, as shown in Figure 10. The touch sensor is a three-terminal component, with its terminals designated for ground, voltage, and sensor output, respectively. When the sensor is not touched, the LED remains off because there is no voltage at the sensor output, as illustrated in Figure 10(a). When the sensor is touched, as shown in Figure 10(b), the LED is energized and illuminates. The diagram for this circuit can be drawn using the symbols provided in the manual. Additionally, a yellow or green LED, a DC motor, or a buzzer can be incorporated into this circuit for testing purposes.

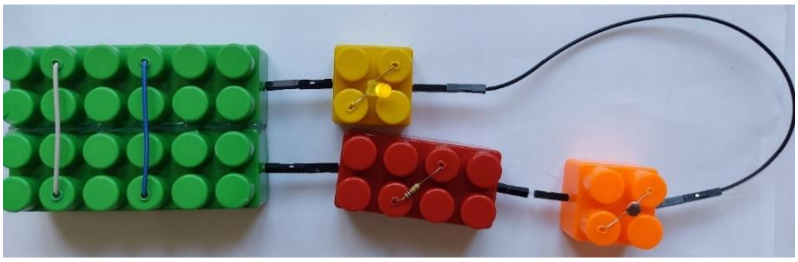
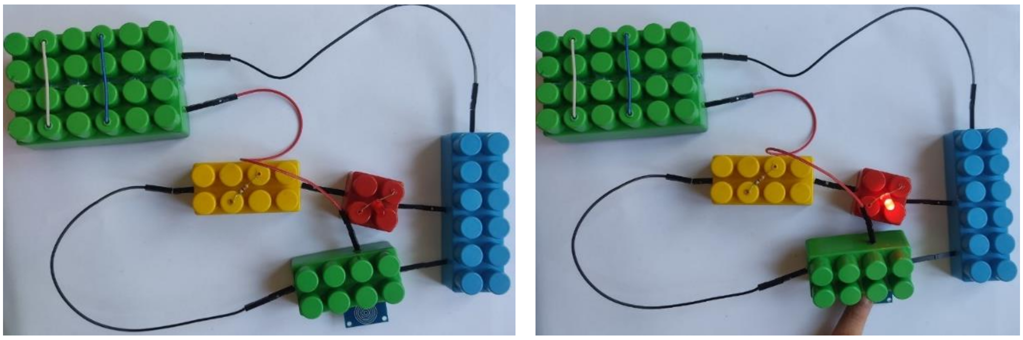


Fig. 9 LDR circuit



(a) (b)

Fig. 10 (a) Touch sensor circuit (b) Touch sensor circuit with sensor activated

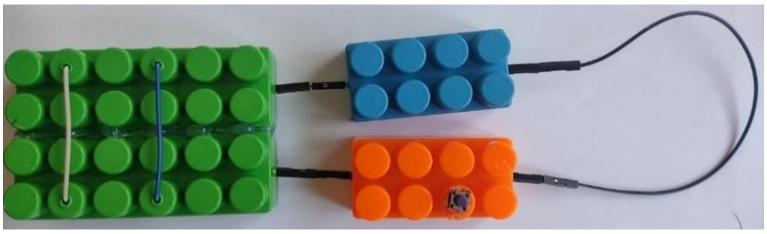
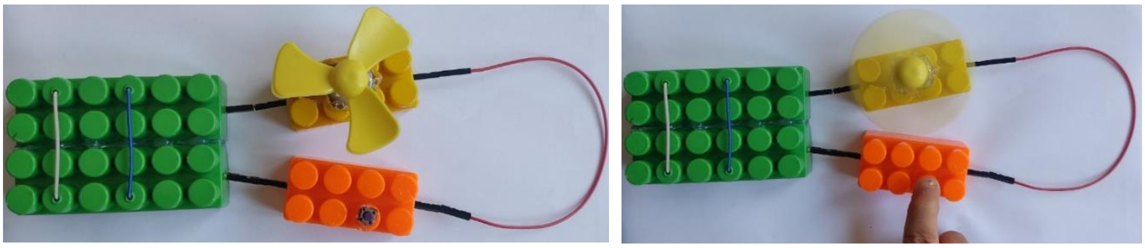


Fig. 11 Buzzer circuit



(a) (b)

Fig. 12 (a) DC motor circuit (b) DC motor circuit with button pressed

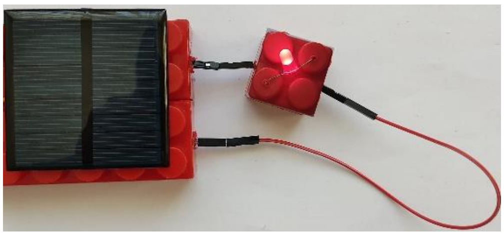


Fig. 13 Solar Panel circuit

H. *Circuit-8: Buzzer*

In this circuit, a battery, a push button, and a buzzer are connected in series, as shown in Figure 11. The buzzer converts electrical energy into sound energy. When the push button is pressed, a sound is produced by the circuit, and the diagram for this circuit can be drawn in the manual. Additionally, this circuit can be modified to provide both light and sound output by adding an LED in series.

İ. *Circuit-9: DC Motor*

In this circuit, a battery, a push button, and a DC motor fan are connected in series, as shown in Figure 12. The DC motor converts electrical energy into mechanical energy. The state of the circuit before the button is pressed is illustrated in Figure 12(a). When the button is pressed, the DC motor fan begins to rotate, as shown in Figure 12(b). The diagram for this circuit can be drawn using the symbols provided in the manual. Additionally, the circuit can be expanded by adding an LED or a buzzer in series.

J. *Circuit-10: Solar Panel*

In this circuit, a solar panel cell (5V) and a red LED are connected in series, as shown in Figure 13. In the dark, the LED does not light up; however, it can be observed that the brightness of the LED increases as sunlight reaches the panel. This experiment demonstrates the functioning of solar energy. The circuit diagram can be drawn in the manual.

III. MANUAL OF EXPERIMENT KIT

A user manual has been prepared for the electrical circuit set developed using toy blocks. This manual spans a total of 15 pages and is divided into four sections: the cover page, circuit element symbols, circuit diagrams, and diagram drawings. Screenshots of these pages are shown in Figure 14. The section on circuit symbols provides real images of each circuit element, along with the colour and size of the toy block it is embedded in, and the circuit representation of the element. This information, combined with the circuit connection pages, is designed to help children easily identify and use the elements in the circuits.

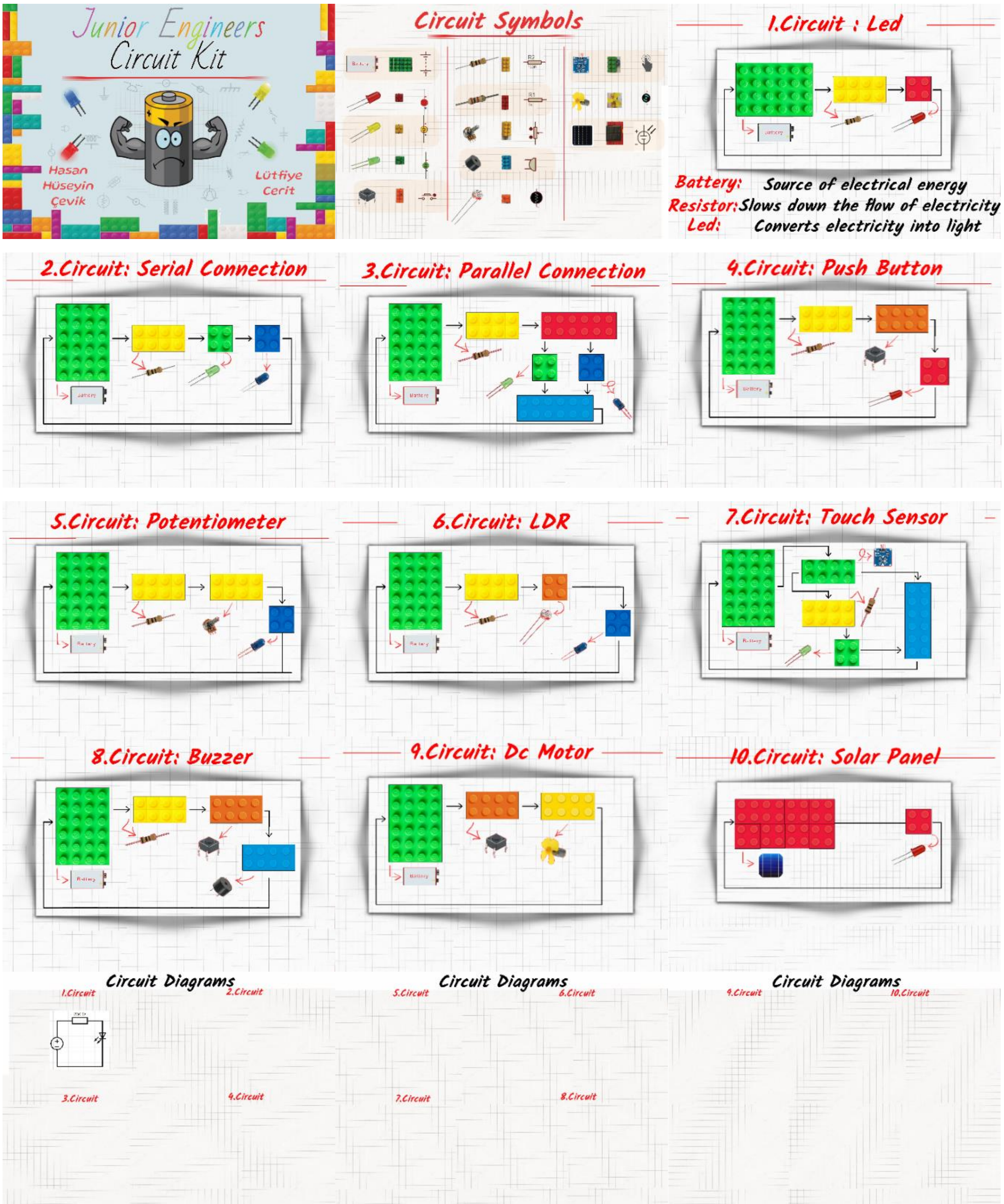


Fig. 14 Pages of the experiment kit manual

Additionally, children will be required to draw the diagrams for each circuit on the final pages of the manual. To assist with this task, only the circuit diagram for Circuit-1 has been provided as an example. Other circuit diagrams are not included, as they are intended to be drawn by the children conducting the experiment. For those with a basic understanding of electrical circuits, parameters such as current and voltage can be measured with a multi-meter during each experiment and recorded next to the circuit diagrams. These measured values can then be examined and used to compare different electrical circuits.

IV. RESULTS AND CONCLUSIONS

The electrical circuit experiment kit has made circuit construction engaging and accessible for children by incorporating toy blocks that they are familiar with from early childhood. Typically, breadboards are used to connect components in electrical circuits, which can be challenging for children conducting these experiments for the first time. This kit addresses this difficulty by simplifying the process, allowing children to focus on learning to recognize circuit elements and establish circuits.

The developed kit helps to concretize technical terms such as source, resistance, and sensor used in electrical circuits. Through hands-on experience with these circuits, children will understand these concepts and gain the ability to interpret circuit diagrams. Additionally, this kit provides a foundational understanding that will facilitate the use of software development PCB cards containing processors, thus preparing children for more advanced hardware and software applications.

This low-cost kit, easily assembled with toy blocks, offers an alternative to the expensive electrical circuit kits currently available on the market. By providing a more affordable option, this approach may contribute to reducing educational inequalities associated with income disparities.

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