PAPER

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Using Arduino and online block-structured programing language for physics practical work

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Abstract
Distance learning in physics is still facing challenges, mainly due to the difficult access to a laboratory for practical work. Practical work is an essential part of the physics classroom because it allows students to interact with authentic physics phenomena and develop their scientific abilities. In this paper, we propose alternative experiments that can be carried out at home with affordable apparatus. We explain the use of an Arduino UNO board and block-structured programming environment to design physics experiments about investigating light-emitting diodes and capacitor characteristics. Block-structured programming in the common-coding builder is used because it has extensive features such as plotting data in a graph directly and programming the Arduino board. Moreover, a user with no prior knowledge of programming can use it easily.

Keywords: Arduino, physics, practical work, block-structured programming, distance learning

Supplementary material for this article is available online

1. Introduction

In the past, the distance learning modes main obstacle was the lack of interaction among students and teachers. The advanced communication technology that we have nowadays has a significant impact on the distance learning process. The interaction among students and teachers during distance learning has been tremendously enhanced by various communication platforms and learning management systems. However, teaching physics in a distance learning mode is still challenging.

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Practical work plays an essential role in physics education to develop students' scientific ability, understand the process of scientific investigation, and connect the real physical world with theory [1–3]. The challenge for physics education in distance learning mode is how students can experience laboratory work effectively and safely. There are some alternatives for this challenge, including using computer simulations and portable experiment kits [4, 5]. Computer simulation may engage students in scientific processes such as manipulating variables, observing phenomena, and analysing the relationship among variables. However, it cannot bring authentic laboratory experience. Students can physically work on objects, practice using instruments safely, be aware of real measurement uncertainty, observe the real phenomena, and create conceptual models of the physical world.

Students may perform laboratory work at home by using an experiment kit. There are various experiment kits on the market, but they are mostly pricy and only can be used for specific experiment topics. However, the recent development of low-cost microcontrollers and sensors offers feasibility in bringing affordable physics experiment tools to distance learning [6].

Arduino is a low-cost microcontroller that has been widely used for physics education [7–10]. It can be connected with various sensors to measure many physical quantities [8, 11, 12]. Usually, Arduino programing uses C or C++ programming language. However, it might be difficult for a teacher to implement the programing language in the physics classroom because students may not have prior knowledge of computer programming [13]. Fortunately, a user-friendly programming environment, called block-structured programming language, can be used to program Arduino. In a block-structured programming language, the developer only needs to drag and drop the blocks to construct a program, and they do not have to memorise the syntax to write the code.

This paper shows the use of Arduino and block-structured programming language provided in common-coding builder [14] for a didactic physics experiment investigating capacitor and light-emitting diode (LED) characteristics. Common-coding builder is based on Scratch, a widely used block-structured programming language in STEM education [15]. However, the common-coding builder offers extension features such as chart, Google Sheet, and Arduino programming. Those features are useful for setting up physics experiments with Arduino, getting and analysing the data.

2. Investigating the characteristic of LED

2.1. Hardware set-up

In this experiment, the apparatus consists of an Arduino UNO board, a USB serial cable, LEDs, a 220 Ω resistor, a 10kΩ potentiometer, a breadboard, a computer with Windows operating system (OS), and internet connection. The circuit diagram to investigate the characteristic of LED is shown in figure 1. In this set-up, Arduino UNO is used as a voltage source, a current, and a voltage sensor. A potentiometer is used as a voltage divider. By adjusting the potentiometer, we can change the voltage across LED, and then measure the current.

2.2. Programing

To program Arduino UNO for a voltage source, a current, and a voltage sensor, we have to program it through the common-codding builder. Common-coding builder can be accessed online using a browser at https://common-coding.com/. The initial layout is presented in figure 2. To allow Arduino programming, we need to choose Arduino Windows extension (see figure 3); after that, download and run firmware to connect the Arduino Uno hardware to the software. The firmware application, ccb_connect.exe, is running in a Java environment. The complete procedure to allow connection between Arduino UNO and the common-coding builder for the first time is explained in the supporting information (available online at stacks.iop.org/PED/56/055028/mmedia). As a disclaimer, we test the common-coding builder in the Windows OS environment only due to the limitation of devices. However, the common-coding builder also provides features for Mac OS.

The code to program Arduino UNO in investigating the characteristic of LED is shown in figure 4. In this set-up, voltage and current are

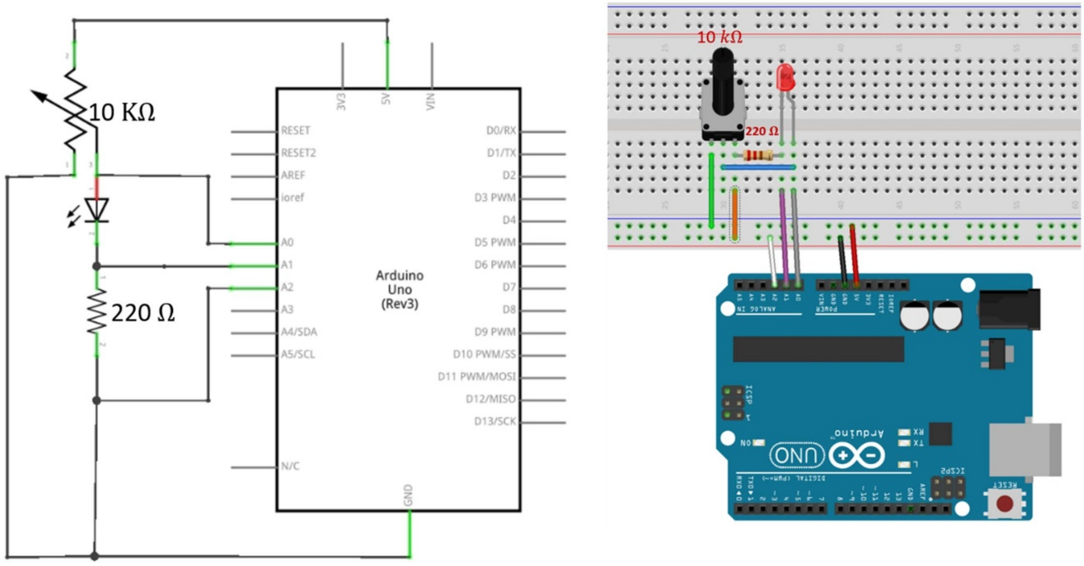

Figure 1. The circuit used in the experiment to investigate the characteristic of LED.

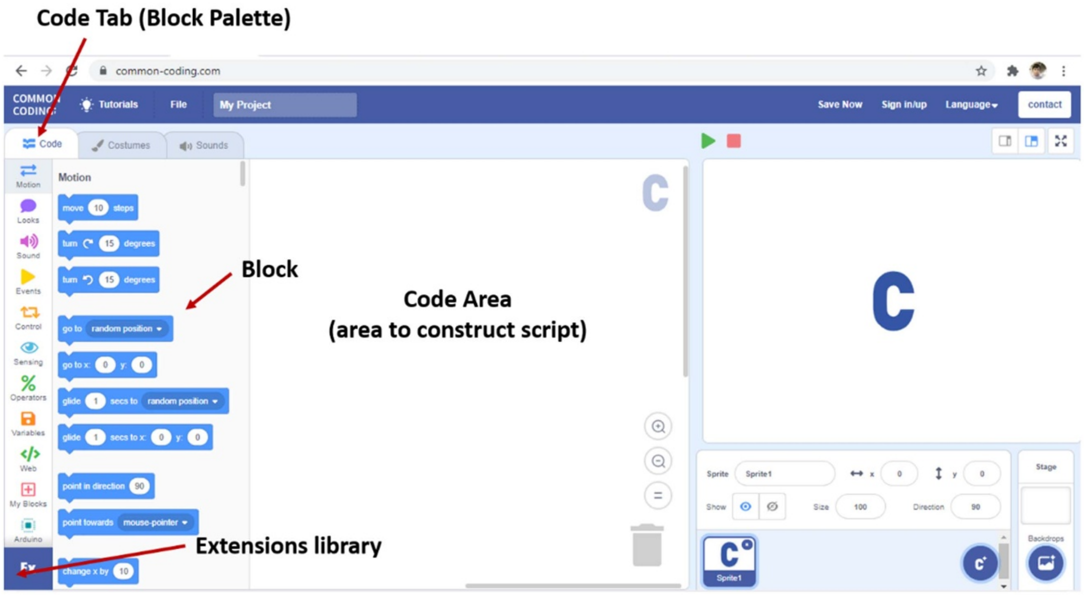

Figure 2. The layout of common-coding builder.

measured from the value recorded by the analog pin of Arduino UNO.

2.3. Discussion

Typically, LEDs consist of semiconductor materials which have an energy bandgap. Enough applied voltage can cause electrons to jump from one material to another. The electron transition from the conduction to the valence band causes light to emit. The voltage at which the first transition occurs is called the threshold voltage. The first transition can be observed from the first light emitted or the first current measured in the circuit.

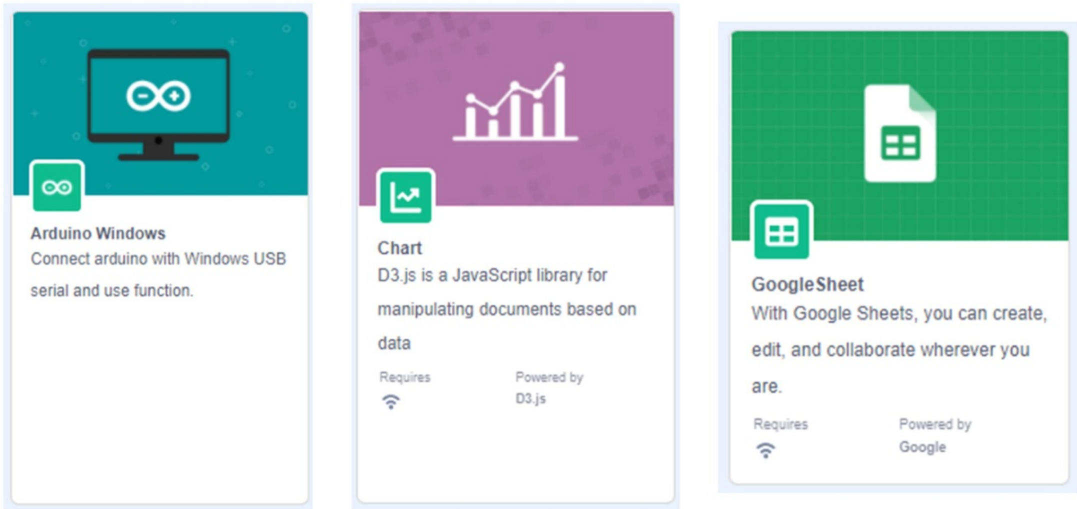

Figure 3. Some extensions library in common-coding builder, i.e. Arduino Windows, chart, and Google Sheet.

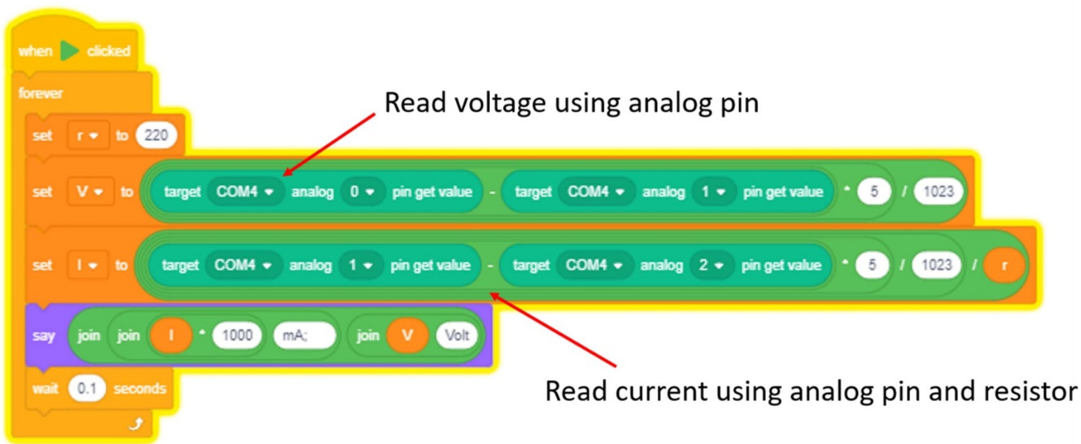

Figure 4. The code for investigating LED characteristic using the common-coding builder environment.

The energy band gap of each LED can then be calculated with equation (1). Each type of LED is fabricated from various semiconductor materials; thus, they have various energy bandgaps. Different semiconductor materials will produce multiple colours

$$E_{\mathrm{gap}} = eV_{\mathrm{threshold}}. \tag{1}$$

In this experiment, we investigate the voltage–current relationship in red, green, and blue LEDs. As shown in figure 5, for low applied voltage, current cannot flow through the LED. After the applied voltage is surpassing a specific threshold voltage, the current starts to flow. Table 1 presents the measured threshold voltage. Current in the red LED starts to flow when the applied voltage is around 1.67 V. For the green LED, the applied voltage should be higher than 2.16 V to allow current flow. Meanwhile, the blue LED requires the highest applied voltage, i.e. 2.46 V, to allow current flow.

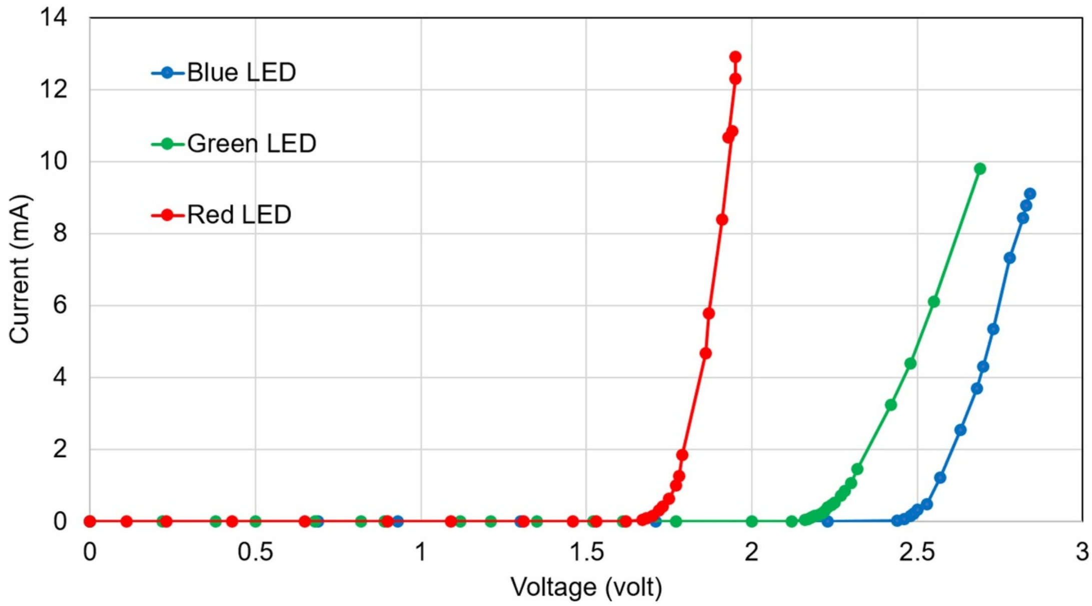

Figure 5. Voltage–current relationship in red, green, and blue LED at room temperature.

Table 1. The energy band gap of various colour LED.

LED	$V_{threshold}$ (eV)	E_{gap} (eV)
Red	1.67	1.67
Green	2.16	2.16
Blue	2.46	2.46

The experiment may help students to understand how a circuit with an LED works. It also can introduce the quantum properties of solids to students. Furthermore, this experiment can be extended with more colours of LED for determining the Planck constant value [16].

3. Investigating capacitor

3.1. Hardware set-up

The purpose of the 'investigating capacitor' experiment is to plot the capacitor voltage as a function of time during the charging and discharging process. The equipment consists of an Arduino Uno board, a USB-serial cable, a capacitor, a voltage sensor, a resistor, a breadboard, jumper wires, a computer with Windows OS, and an internet connection. The voltage sensor is not compulsory; we can use an Arduino board to read the voltage as long as the measured voltage is less than 5 V (see supporting information). The equipment set-up is presented in figure 6. In this set-up, a digital pin of Arduino Uno is used as a voltage output because it can be easily switched ON for charging the capacitor and switched OFF for discharging the capacitor.

3.2. Programing

The code used for charging and discharging capacitor is presented in figures 7 and 8, respectively. During the charging process, the digital pin output is set as 1 (HIGH) for supplying voltage. Meanwhile, when discharging cycle, the digital pin output is set as 0 (LOW) to cut the voltage supply.

3.3. Discussion

The basic diagrammatic circuit for the charging capacitor can be seen in figure 9. When a voltage source is connected to the capacitor and the resistor, analysis with the Kirchhoff rule will give:

$$\varepsilon - \frac{q}{C} - IR = 0 \quad (2)$$

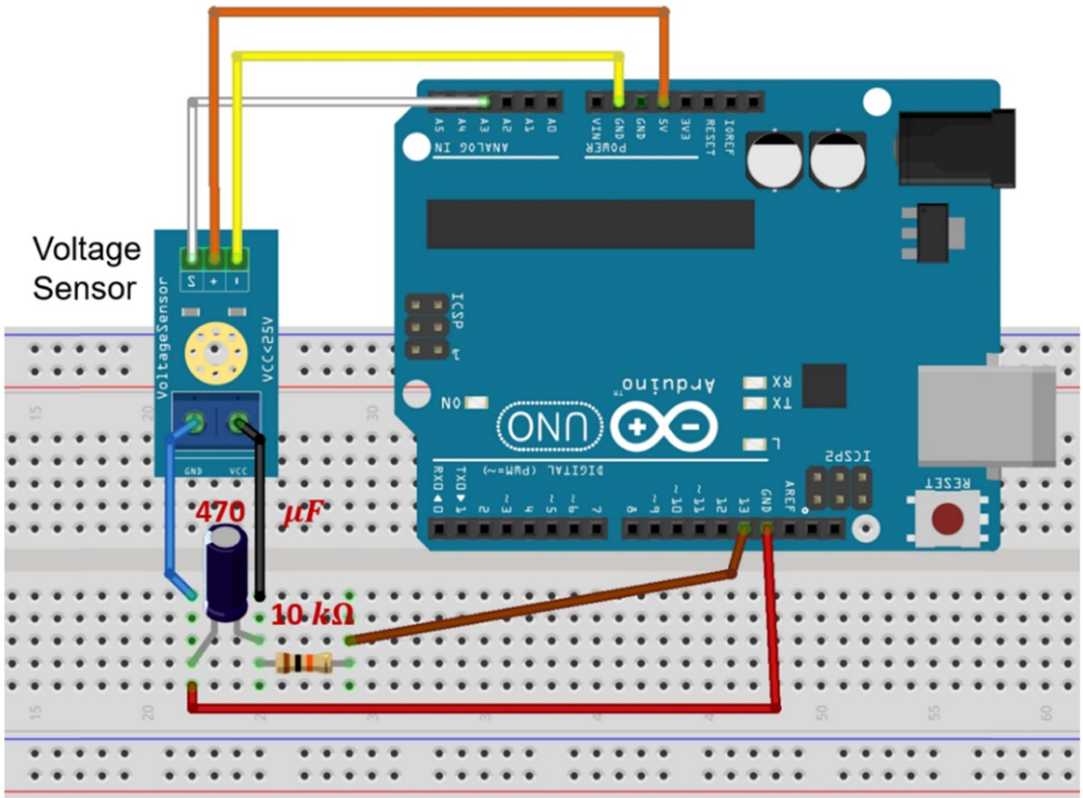

Figure 6. 'Investigating capacitor' experiment set-up.

where ε is the voltage source, IR is the voltage across the resistor, and $\frac{q}{C}$ is the voltage across the capacitor. By substituting $I = \frac{\mathrm{d}q}{\mathrm{d}t}$ and dividing all terms by R, equation (1) can be written as:

$$\begin{gathered}\frac{\varepsilon}{R} - \frac{q}{RC} - \frac{\mathrm{d}q}{\mathrm{d}t} = 0 \\ \frac{\mathrm{d}q}{\mathrm{d}t} = -\frac{q - C\varepsilon}{RC}\end{gathered}. \quad (3)$$

By solving equation (3) and using an assumption that the capacitor is initially discharged, we can yield charge in the capacitor as a function of time, i.e.:

$$q(t) = C\varepsilon\left(1 - \mathrm{e}^{-\frac{t}{RC}}\right). \quad (4)$$

Since $V = q/C$, the voltage across the capacitor, $V_\mathrm{c}(t)$ can be expressed as:

$$V_\mathrm{c}(t) = \varepsilon\left(1 - \mathrm{e}^{-\frac{t}{RC}}\right). \quad (5)$$

When the voltage source is disconnected, the capacitor will discharge. Analysis with Kirchhoff's rule will give:

$$-\frac{q}{C} - IR = 0. \quad (6)$$

We can model the voltage across the capacitor during the discharge process within the same procedure as the analysis for capacitor charging. The voltage across capacitor during the discharging process can be modelled in equation (7)

$$V_\mathrm{c}(t) = \varepsilon \exp\left(-\frac{t}{RC}\right). \quad (7)$$

With the Arduino and common-coding builder software, voltage across the capacitor during the charge and discharge process has been measured real-time and directly plotted in graphs, such as depicted in figures 10 and 11. Figure 10 shows the voltage as a function of time during the charging process. Initially, the capacitor voltage increases

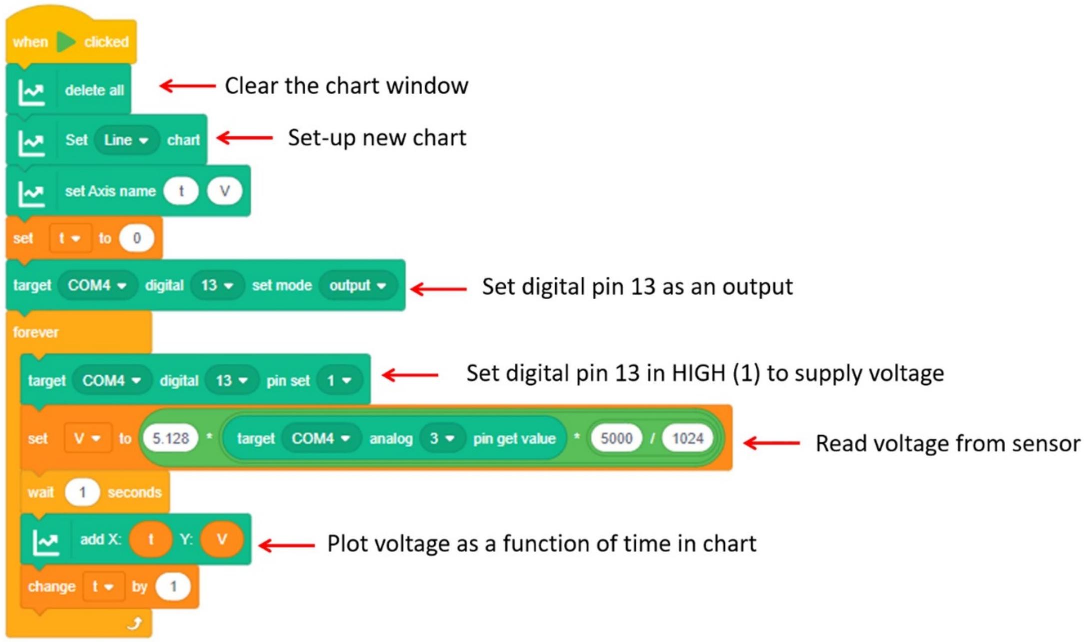

Figure 7. Code for investigating time-varying capacitor voltage during charging process.

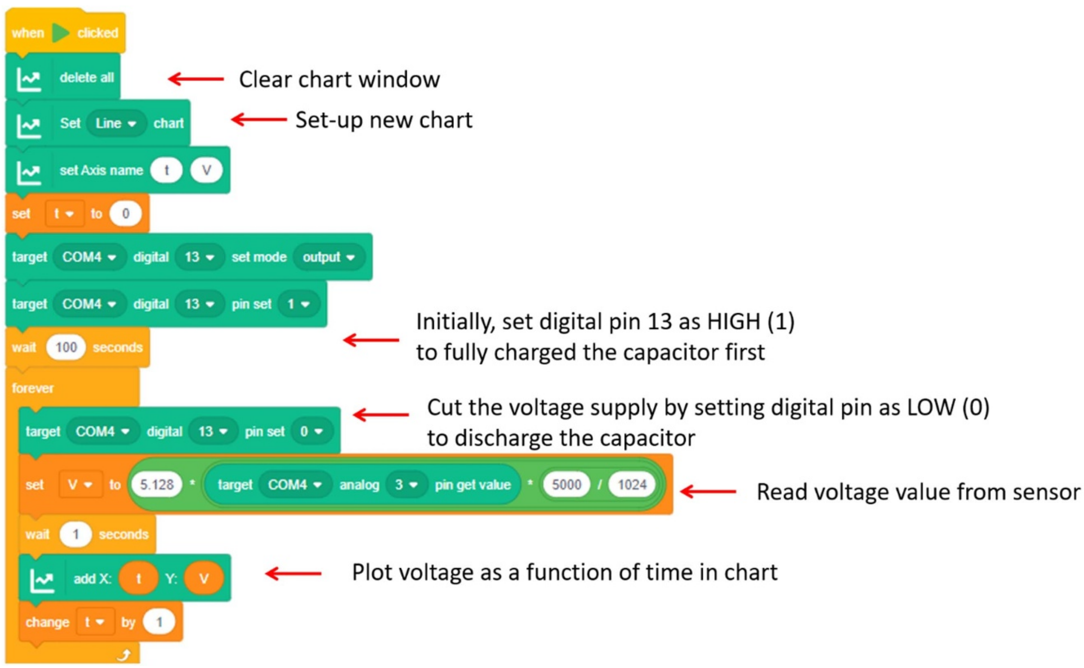

Figure 8. Code for investigating time-varying capacitor voltage during discharging process.

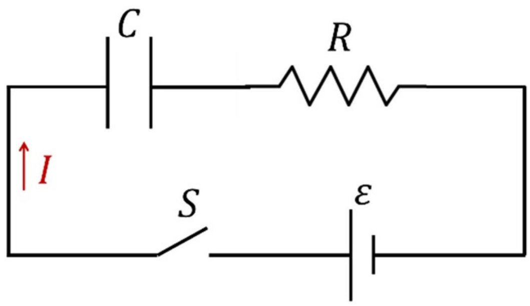

Figure 9. Basic circuit for 'investigating capacitor' experiment.

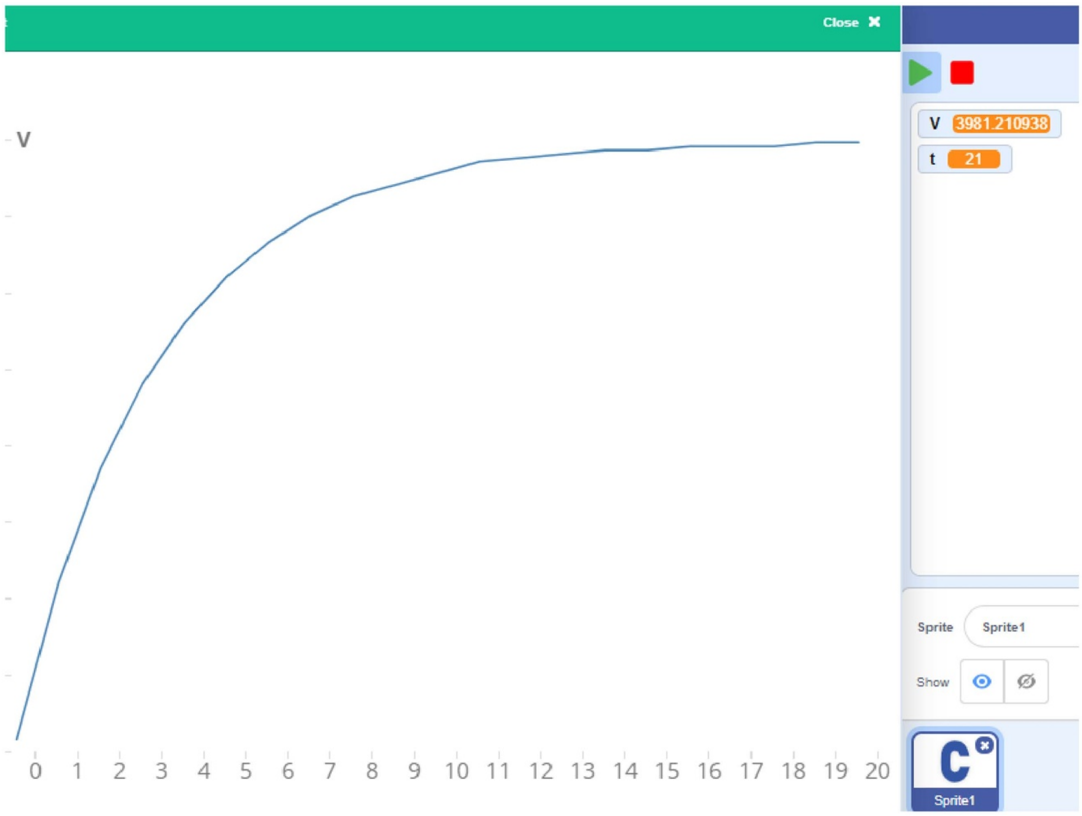

Figure 10. The time-varying voltage across capacitor during charging process presented in chart window available in common-coding builder. Voltage and time are in volt and second, respectively.

fast; then, the increment becomes slower until it reaches a steady maximum voltage. This result is in agreement with the theory presented in equation (5). Figure 11 shows the voltage–time graph when the capacitor is discharged. As predicted theoretically in equation (7), the experiment showed that the capacitor voltage decreases exponentially during the discharging process.

Data visualisation in the common-coding builder helps students understand physical phenomena with graph representation and connect experimental results with theoretical models. Moreover, with minimal knowledge of computer

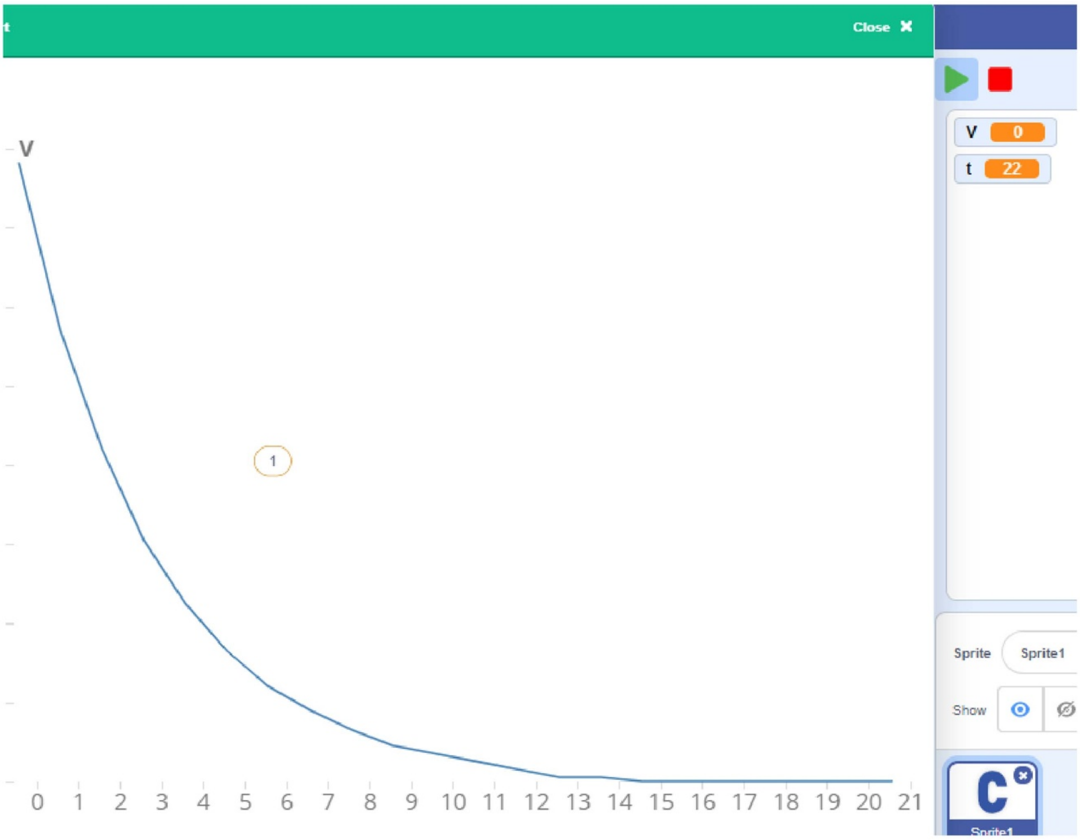

Figure 11. The time-varying voltage across capacitor during discharging process presented in chart window available in common-coding builder. Voltage and time are in volt and second, respectively.

programming, students can do the activities at home. Although common-coding builder has advantages such as introducing a foundation of computational thinking to students with minimal knowledge of programming, it has several limitations. First, to connect the common-coding builder to Arduino UNO, we need to pre-install Java and the firmware application (ccb_connect.exe). Hence, the teacher has to give a prior explanation or tutorial to students. Second, common-coding builder for computers only works online. For students who work in inadequate internet facilities, it may become an issue.

4. Conclusion

Arduino and block-structured language programming, like common-coding builders, can be used to design various experiments to support physics learning. The apparatus is affordable, and the programming can be done easily by students who do not have prior knowledge of coding a program. Teachers can design experiments with various topics and assign students to try them at home. Since access to a laboratory is difficult for physics distance learning, this experiment can become an alternative to training students' practical skills, science process skills, and computational thinking skills. During a difficult time, such as the COVID-19 pandemic, it may be useful to support high school students or early year college students when exploring physics from home.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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