JCSHD COGNITIVE SCIENCES AND HUMAN DEVELOPMENT

AC-Duino Kit: Enhancing the Teaching and Learning Experience of Root-Mean-Square Current in Alternating Current through Arduino Microcontroller Application

Pek Chun Hoe*, Siti Farina Binti Abdul Shukor, Nurfatin Aizzatul Natasha Binti Mohd Nasir & Lye Pei Lui @ Rebecca
Physics Unit, Science Department, Kolej Matrikulasi Labuan, Malaysia.

ABSTRACT

Root-mean-square current in alternating current is an abstract concept that appears challenging to students in the absence of any hands-on experimental tool. Therefore, the AC-Duino Kit, utilising an Arduino Uno microcontroller and ACS712 current sensor, is developed and used in an experiential learning activity involving real-life household electrical appliances to enhance this topic's teaching and learning experience. Two-cycle action research was conducted on forty-six students undertaking a one-year matriculation program with data collected from document analysis, interview, and observation. The result shows that the students could relate root-mean-square current to power consumption, differentiate between heat and motor appliances, and relate peak current to electrical safety. The study confirmed that this activity could bridge the theoretical concept to real-life applications.

Keywords: Arduino microcontroller, root-mean-square current, alternating current, experiential learning, action research

ARTICLE INFO
Email address: bm-3278@moe-dl.edu.my (Pek Chun Hoe)
*Corresponding author
https://doi.org/10.33736/jcshd.6705.2024
e-ISSN: 2550-1623

Manuscript received: 25 February 2024; Accepted: 27 March 2024; Date of publication: 31 March 2024

1 INTRODUCTION

Root-Mean-Square (RMS) current measures the average current in an Alternating Current (AC) circuit. The current constantly changes direction in AC circuits, unlike in Direct Current (DC) circuits, where the current flows in one direction. The RMS current (I_{rms}) is a way to express the equivalent steady DC current that would produce the same amount of heat or power consumption in a resistive load as the AC current does. For a sinusoidal AC current, the RMS current is related to the peak current (I_0) by the following formula:

$$I_{rms} = \frac{I_0}{\sqrt{2}}$$

Where:

I_{rms} is the root-mean-square current

I_0 is the peak current

RMS current value is a central concept to be learned in the topic of AC because this value is used to calculate the average power consumption (P_{ave}) of any electrical device. The formula to calculate the power consumption is as follows:

$$P_{ave} = I_{rms} V_{rms}$$

Where:

P_{ave} is the average power consumption

I_{rms} is the root-mean-square current

V_{rms} is the root-mean-square voltage

The study uses an Arduino microcontroller to enhance the teaching and learning experience of the RMS current concept in alternating current. Arduino microcontrollers are becoming increasingly popular in physics education. An obvious advantage concluded by Sukmak and Musik (2022) is that using Arduino allows students to repeat their physics experiments as many times as they need because the graphical presentations of lab data are generated in real time, thus skipping the conventional method of plotting graphs manually. Physics experiments are no longer complex and can be conducted quickly. Physics laws can be visualised directly, accommodating more insightful analysis and detailed discussion processes. By incorporating various sensors, Arduino devices can feed real-time lab data on many physics' subjects, such as kinematics, mechanics, electricity, electromagnetism, optics, heat, and temperature, in addition to programming knowledge.

In kinematics and mechanics, Azizahwati et al. (2020) created an experimental device using Arduino to facilitate the teaching of the angular velocity concept in a circular motion. Pratiwi and Fatmaryanti (2020) utilised a DC motor and a speed sensor LM393 module controlled by Arduino to show the phenomenon of acceleration and deceleration displayed in graphical form. This activity successfully enhanced their students' problem-solving skills by 2.2% in analysing kinematic graphs such as position-time and velocity-time graphs. A Physics Teacher Training

College in Argentina also utilised a speed sensor with Arduino to determine the moment of inertia of a steel flywheel (Dibarbora, 2021). In Hungary, the physics teacher education used a photogate with Arduino to investigate the accelerated rotation of a fidget spinner by generating angular displacement and angular velocity versus time graphs (Somogyi et al., 2022).

On the topic of simple harmonic motion, Sukmak and Musik (2022) developed a computer-based experiment set using Arduino and infrared (IR) sensors to study the vertical oscillations of a spring-mass system. Students analysed the displacement, velocity, and acceleration-time graphs using the Mathematica program and drew a relationship between periods of oscillation with mass or spring constant. Uzal (2022) and Megananda et al. (2021) both developed efficient distance measurement instrument using ultrasonic sensor HC-SR04 and Arduino, where students must point the sensor towards the object to be measured and distance values were generated automatically in LCD.

The popularity of Arduino as a lab tool also proliferated in the physics domain of electricity and electromagnetism. Cicuta and Organtini (2022) had set up a 'Smart Physics Lab' based on Arduino and smartphones. They showed that experiments that require expensive traditional equipment can be run inexpensively with Arduino. Educators no longer need the uncommon oscilloscope to observe capacitor charging or discharging exponential graphs in RC circuits. For an electromagnetic induction process requiring a sensitive galvanometer and coils with thousands of turns, Arduino allows the investigation using only a few tens of turns of the copper coil. A similar experiment was conducted by Galeriu et al. (2015), who used the Arduino to investigate the charging or discharging of capacitors in RC circuits. A semi-quantitative demonstration of Faraday's induction process using Arduino was also presented by Bezerra et al. (2019). An investigation of series-parallel circuits and Ohm's Law was conducted by Nurroniah et al. (2023), who designed an automatic light control system using Arduino connected to an Android smartphone via Bluetooth.

Previous research studies also showed that Arduino-based measuring tools were used extensively in more real-life situations, creating meaningful learning experiences. Pusch et al. (2021) introduced an easy circuit incorporating Arduino for measuring the electrical power of a solar panel, as well as the application of a smartphone app 'Phyphox' connected to Arduino via Bluetooth for displaying the measured data graphically in real-time. The circuitry allows for measuring solar panel power in different situations of light-intensity exposure. In studying gas laws, the Science Club students at Szekely Miko High School from Romania designed Arduino measuring devices and set up a school mini meteorological station. In their project, problem-based learning (PBL) was carried out where atmospheric physics phenomena and all ideal gas laws were taught in an interdisciplinary approach involving physics, biology, chemistry, maths, economics, and computer science (Peto, 2020). Similarly, using the BMP180 temperature and pressure sensor and Arduino, Moya (2019) investigated various gas laws, such as Avogadro and Gay-Lussac's Laws. Thus, this research paper aims to relate the physics concept with more real-life situations, enriching the context for students to learn about RMS current in the AC topic.

2 REFLECTIONS ON PREVIOUS TEACHING

Based on previous teaching experiences, the lecturers find explaining the concept of RMS currently complicated. The lesson is limited to rote memorisation of its definition in words and problem-solving using mathematical equations. Students cannot relate RMS current to real-life applications. The tools to demonstrate this vital concept to the students are not readily available in conventional lab settings. Traditionally, lecturers must use an expensive oscilloscope to help students visualise Alternating Current. Given the increasing popularity of Arduino with sensors as lab tools in physics education, the researchers have decided to build an experimental device using a low-cost Arduino microcontroller and ACS712 current sensor, namely AC-Duino Kit, to help demonstrate the concept of RMS current. This inexpensive kit can give the students better understand RMS's current true definition and real-life applications. Besides, it fills the part of the experimental gap left as none of the previous studies has yet used Arduino to demonstrate the current RMS concept.

3 STUDY FOCUS

The main objective of this study is to improve the teaching and learning process on the topic of AC using an Arduino microcontroller. Specifically, it intends to identify the student's understanding of the current root-mean-square (RMS) concept using the AC-Duino kit. In addition, the study also focuses on identifying the other knowledge gained by students on the topic of AC through this kit. The research was conducted with one-year matriculation program students from Labuan Matriculation College during their second semester of Physics subject (SP025). Forty-six students from two tutorial classes had been selected to implement the activity because the intervention was repeated and improved for two consecutive cycles.

4 METHODOLOGY

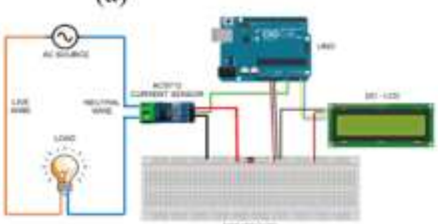
The research was implemented in the Action Research model founded by Kemmis and McTaggart (1988). This action research model has four stages: observe, plan, implement, and reflect for the following cycles. Data was collected through observation, document analysis, and interviews with lecturers and students. Lesson worksheet documents, documents of students' work, questionnaire survey data, audio recordings of interviews, observation photos and video recordings during the intervention were also gathered. All these data significantly contribute to the narrative analysis, as Jean and Jack (2002) suggested. Besides, the self-evaluation process can be enhanced within a community of critical friends (Jean & Jack, 2002). Therefore, the head of the physics unit, the subject matter expert (SME), and another two senior lecturers were invited to act as critical friends for the action research.

An ACS712 current sensor was utilised for the experimental setup to measure the current flowing in electrical devices. An extension wire was cut open, and the ACS712 current sensor was connected to the neutral (blue) wire. The live (brown) wire was avoided as it posed a considerable risk of electrical and fire hazards. A five-port extension wire was used to detect the flowing current as it allows for easier connection to multiple electrical appliances. A code was written in the

Arduino microcontroller to enable it to detect the peak current in the circuit and calculate the RMS current using the physics formula: cap I sub r m s equals cap I sub 0 over the $I_{rms} = \frac{I_0}{\sqrt{2}}$. The code would generate the corresponding average power consumption values in real-time using the formula: cap formula $P_{ave} = I_{rms}V_{rms}$. When calculating the average power, 240 V is used as the value for RMS voltage (V_{rms}) because this is the RMS voltage value available for local Malaysia household AC supply.

An Arduino Liquid Crystal Display (LCD) 1602+I2C was added to the microcontroller to display the LCD screen's RMS current and power consumption values. Two green and yellow light-emitting diodes (LEDs) were also added to the kit to add a function of differentiating high-powered or low-powered electrical appliances. This experimental device was named ‘AC-Duino Kit,’ with a low total cost of RM54.20, as shown in Figure 1.

(a) (b) (c)



(d)

No.	Item	Price (RM)
1	Arduino UNO Board (SMD) + Cable	32.90
2	ACS712 Current Sensor (20A)	6.90
3	LCD 1602 + I2C (Blue)	12.50
4	Mini Breadboard (170 holes)	1.00
5	Two 220-Ohm Resistors	0.20
6	Two LEDs (Green and Yellow)	0.20
7	Few Jumper wires (mixture of M-M, M-F, F-F)	0.50
	TOTAL	54.20

(e)

Figure 1. AC-Duino Kit: (a) top view, (b) front view, (c) side view, (d) schematic drawing, and (e) cost of apparatus.

To create a real-life learning experience, some household electrical appliances, such as a clothes iron, toaster, wall drill, and vacuum cleaner, were brought into the laboratory. Figure 2 shows that the AC-Duino kit was used to determine the RMS current and power consumption values of all these electrical appliances. The flow chart in Figure 3 shows the detailed steps in using the AC-Duino kit to explore AC graphs and RMS current.

(a) (b)

Figure 2. (a) Household electrical appliances and (b) lecturers' discussion.

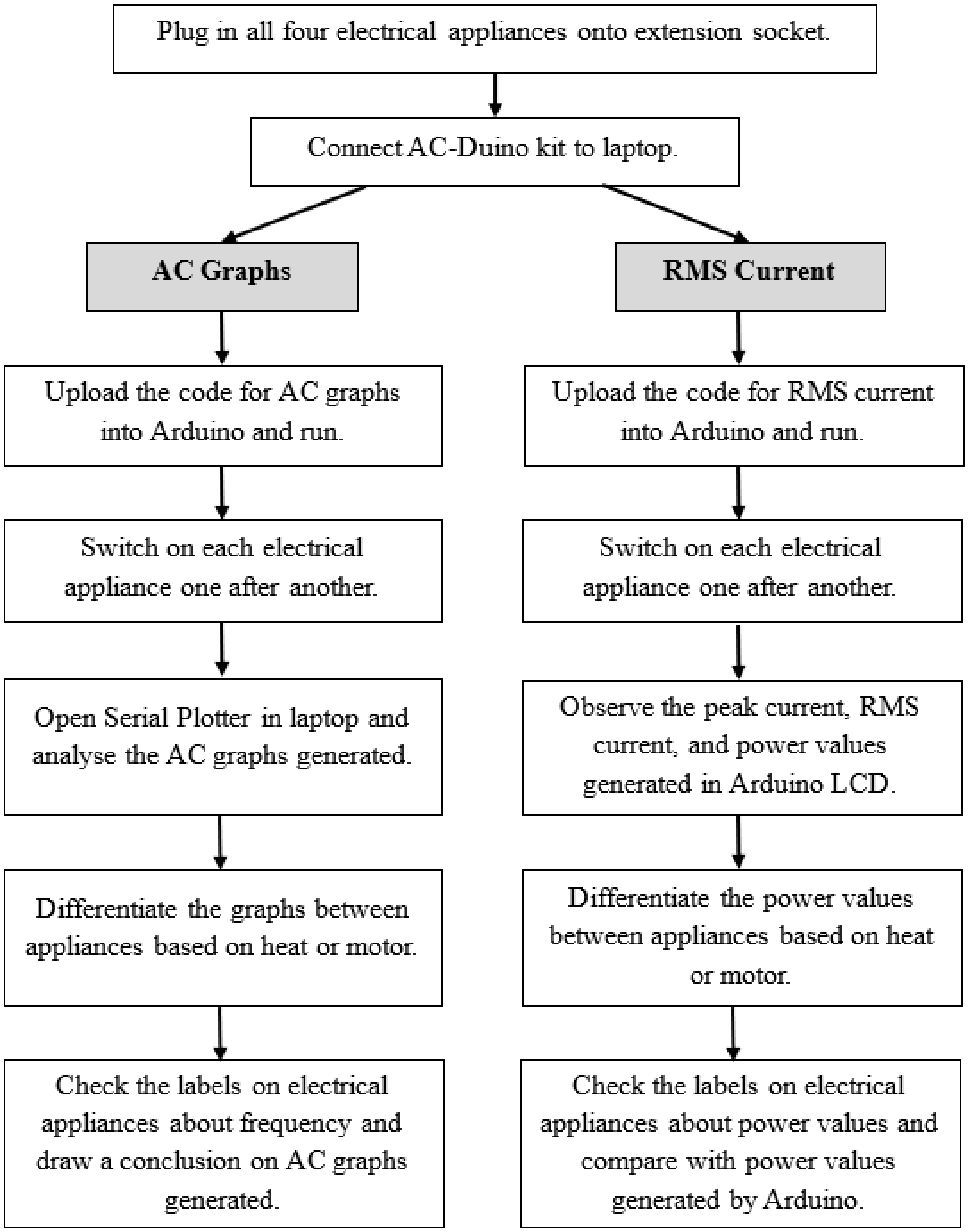


Figure 3. Flowchart of the detailed steps in using the AC-Duino kit.

5 INTERVENTION AND OBSERVATION

The action research had gone through two cycles. During the first cycle, the AC-Duino kit was used to demonstrate to students the formation of AC graphs and read the RMS current of selected household appliances. By the end of the session, it was noticed that the students could not relate to the demonstration and its concept. The students were still passive while listening to the demonstration, and some did not comprehend the explanation. In the reflection phase, several suggestions were pointed out by the critical friends on how to develop the session, such as actively involving students in experimenting by themselves, reading the coding, and relating the theory learned with the observation.

To address the problem, in the second cycle, Kolb's Experiential Learning Model (2015) was incorporated to facilitate the teaching and learning process using the AC-Duino kit. According to Kolb (2015), experiential learning involves a cycle of four key steps, namely Concrete Experience (CE), Reflective Observation (RO), Abstract Conceptualization (AC), and Active Experimentation (AE). These steps engage students in a holistic learning process. They start with a hands-on experience, reflect on it, build conceptual understanding through instruction, and then apply their knowledge in experiments or new situations. The detailed steps of the AC-Duino activities were laid out using the Experiential Learning Model, as shown in Table 1. Figure 4 shows some photos taken during observation as evidence of activity implementation.

Table 1. AC-Duino activities based on experiential learning model.

Phase	AC-Duino activities
Concrete Experience (CE)	● Using only one electrical appliance, such as a cloth iron, the lecturer demonstrated the AC graph and showed the RMS current and power consumption values generated through the AC-Duino kit to the students. ● The students read through the coding on the Arduino board, and a brief introduction was given. ● The students viewed all the electronic components in the AC-Duino kit, and a brief introduction to each function was given.
Reflective Observation (RO)	● Students reflected on what they had observed and experienced. ● A worksheet with guided questions was provided to help students share their thoughts about the AC graph and RMS current.
Abstract Conceptualization (AC)	● The integral concepts on peak current, RMS current, and characteristics of AC graph were introduced. ● The true definition of RMS current related to electrical appliance power consumption was emphasised.

	● Lecture notes or reading materials that explain their concepts were provided to assist students in relating to the experiment in real life.
Active Experimentation (AE)	● A project was assigned where students conducted experiments using an AC-Duino kit to check on all four electrical appliances: cloth iron, toaster, wall drill, and vacuum cleaner. Several objectives had been outlined. ● Students identified which electrical appliances are high-powered or low-powered by referring to the green and yellow LEDs. ● Students compared the power value generated by Arduino with the power value stated on the label of each electrical appliance. ● Students differentiated the AC graphs generated between electrical appliances based on heat or motor. ● Students checked the power limit (13 amp) on the extension port wire and discussed the importance of peak current in electrical safety. ● Students related the importance of RMS current in determining electrical appliance power consumption. ● Students reasoned about their observation data and presented findings to the class.

(a) (b) (c)

Figure 4. AC-Duino activities based on the experiential learning model: (a) students observing data generated by Arduino, (b) students checking labels on electrical appliances, and (c) students conducting experiments on various electrical appliances.

Throughout the second cycle, students achieved many noticeable key learning points. One meaningful lesson was learned when students used the Arduino microcontroller to investigate the graph of AC. As shown by the experiment in Figure 5, the AC graph follows a sinusoidal shape instead of a constant DC graph. Students could easily relate this observation to what they learned in their lecture notes, that alternating current is continuously changing and exhibiting positive and negative values.

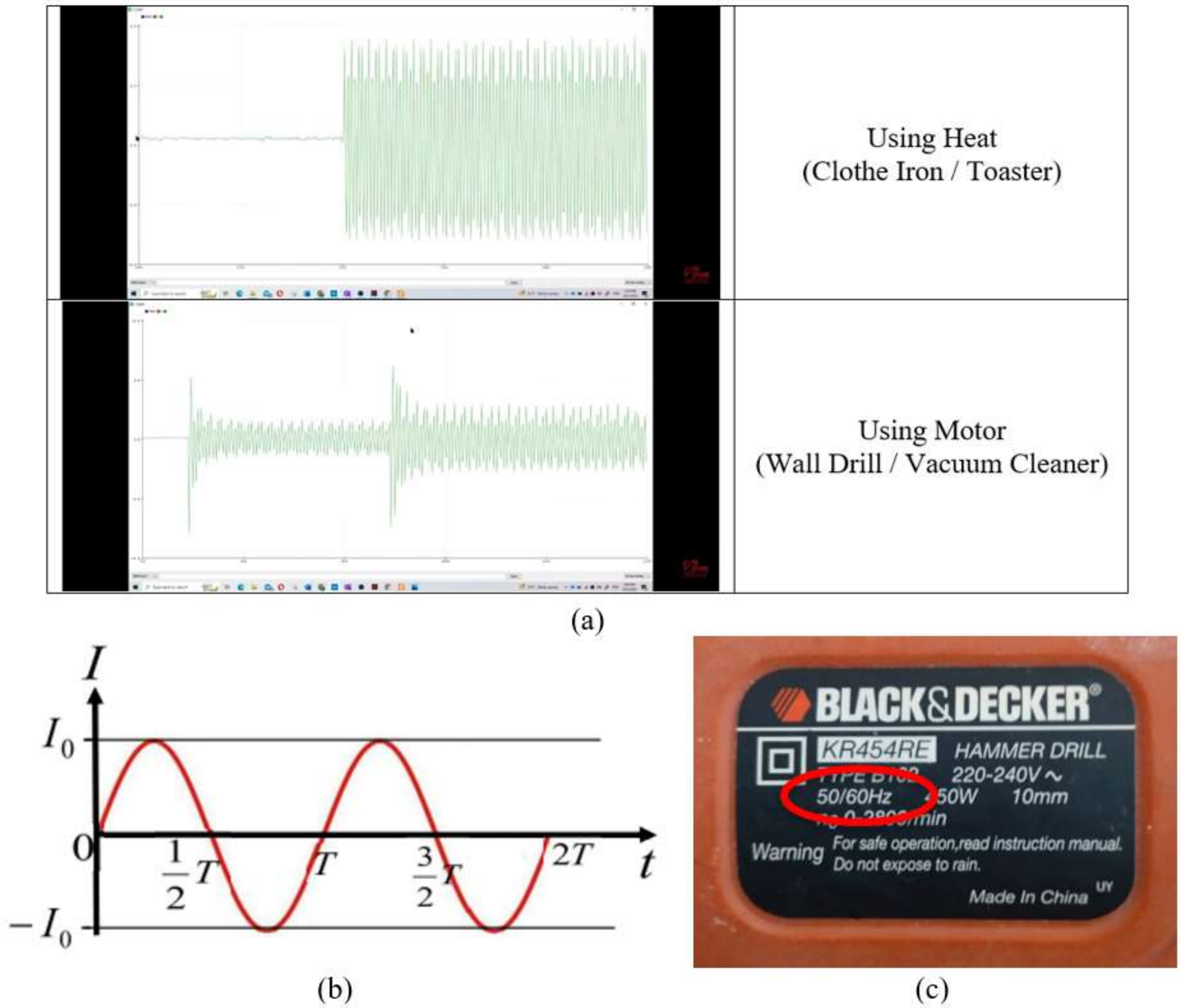


Figure 5. (a) AC graphs in reality, (b) AC graph in lecture note, and (c) label of an electrical appliance showing high frequency, 50/60 Hz.

However, a distinctive difference exists between the AC graph observed and the AC graph in the lecture note. Students might not realise that AC oscillates extremely fast, although they were verbally told it. The beautiful sinusoidal curve of the AC graph in their lecture note did not tell them the truth of fast oscillations in AC. This activity helped them realise the high AC frequency when they saw the sharp, spiky AC graph generated by the AC-Duino kit. This observation is especially proven when students check the label of electrical appliances; they notice that the alternating current operates on a high frequency ranging from 50 Hz to 60 Hz, which means that AC oscillates extremely fast, 50 to 60 times per second.

Another important discovery is that the AC graphs for electrical appliances operating on heat (cloth iron and toaster) show a remarkably high peak of current all the time, indicating very high-power consumption. On the other hand, the AC graphs for electrical appliances operating on a motor (wall drill and vacuum cleaner) only have an initial spike of current, indicating that they consume more power to rotate the motor initially but low power consumption later on most of the time. This is a good lesson for students too that they should not constantly switch on and off the motor unnecessarily as it will waste more electricity. Students also discovered the thermostat feature in cloth iron when the AC graph suddenly dropped to zero. The cloth iron cut off the power supply when its temperature raised to a specific value.

Figure 6 shows the various RMS current, peak current, and power consumption values detected by the AC-Duino kit for different electrical appliances. Students observed that the peak current could go above the RMS current value in alternating current, meaning that RMS current is just an average value representing AC. Arduino uses this particular RMS current value to calculate the power consumption value of any electrical appliance, based on the formula $P_{average} = I_{rms}V_{rms}$. Students also learnt that the RMS voltage (V_{rms}) value here is 240 V , as this is the AC supply in Malaysian households. When students compared this average power value with the power value stated on the label of the electrical appliance, they found that they almost had the same values, thus validating the power values generated by Arduino. Based on this activity, students understand the true meaning and significance of RMS current value more clearly, as it is the average value applicable to determining the power consumption of any electrical appliance in real-life situations. For example, the Cornell toaster is detected as having an RMS current of 6.04 A and power consumption of 1450.11 W by Arduino. This power value is remarkably similar to the 1400 W, as stated on the label behind the toaster.

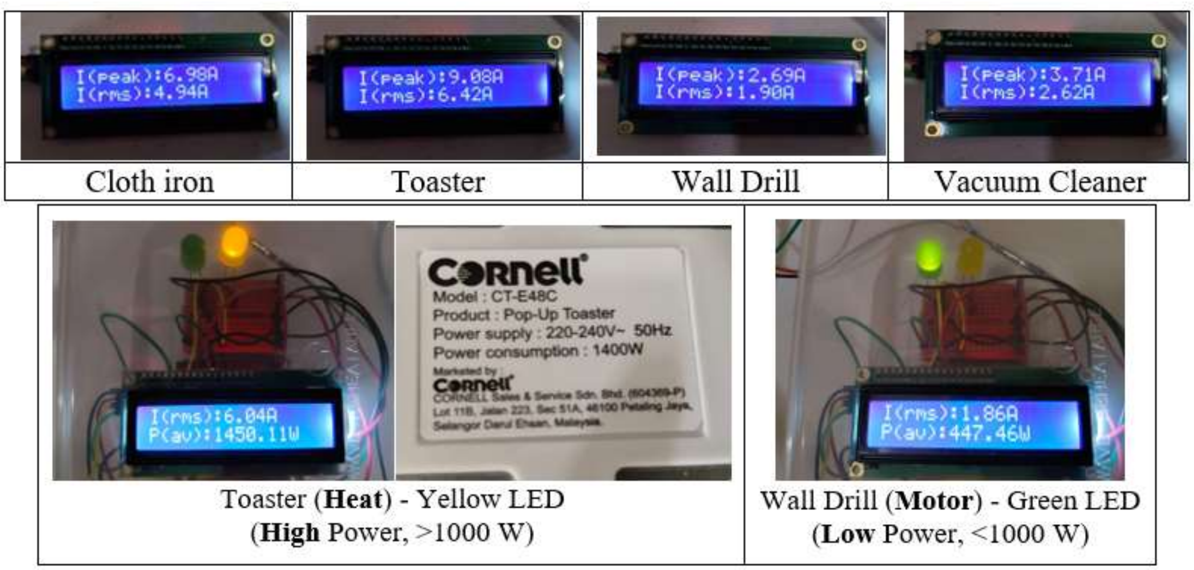


Figure 6. Arduino LCD readings of peak current, RMS current, and average power consumption for various electrical appliances.

Two green and yellow LEDs were incorporated into the AC-Duino kit to help students differentiate between high-powered and low-powered electrical appliances. Students could see that the electrical appliances operating on heat generally consume more power (above 1000 W) than motors. Figure 6 shows that the Cornell toaster operating on heat has the highest RMS current of 6.04 A and power consumption among all, 1450.11 W. Thus, the yellow LED was lit up the other hand, the wall drill operating on the motor has the lowest RMS current of 1.86 A and power consumption of 447.46 W only. Thus, it lighted up the green LED.

A survey was given to students to check their learning experience of AC between the conventional classroom and AC-Duino kit approaches. Figure 7 shows the findings from the survey. Most students claimed they did not understand the concept of AC current under conventional classroom instruction (mostly at lower scores). However, a substantial increase in scores of 4 and 5 was found after implementing the experiential learning activity using the AC-Duino kit, showing that most of them understood the concept of AC through this activity.

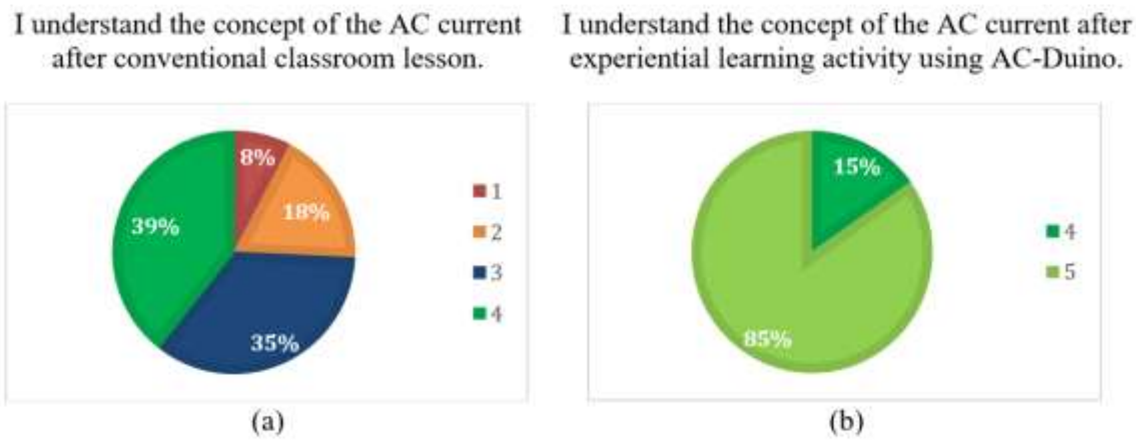
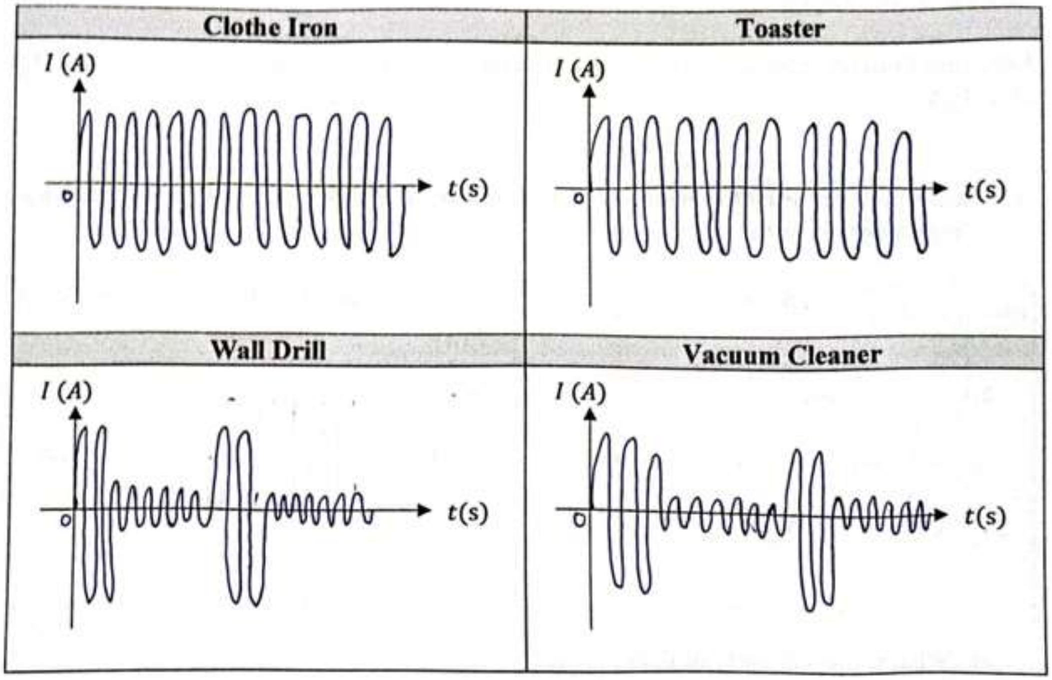


Figure 7. The learning experience of AC current: (a) conventional classroom instruction and (b) experiential learning activity using the AC-Duino kit (the scale ranges from 1-strongly disagree to 5-strongly agree).

Figure 8 shows that students could draw a correct sinusoidal shape for all AC graphs in the activity worksheets distributed. Students could also differentiate the graph shapes between electrical appliances operating on heat (cloth iron/toaster) or motor (wall drill/vacuum cleaner). The student could record all current and power values correctly in the table, as observed from the Arduino LCD screen. Here, students could make comparisons and discover that all power values are remarkably similar to the actual power values in the label, thus validating their understanding towards RMS current. Besides, students could make comparisons of power consumption among all electrical appliances and discovered that the toaster consumes the most power, 1425.25 W. They found out that appliances based on heat, like clothes irons and toasters, generally have power values above 1000 W, whereas appliances based on motor, like wall drills and vacuum cleaners, have power values below 1000 W.

4. Please connect to each electrical appliance one by one and sketch the AC graphs you observed from **all** electrical appliances:



(a)

3. Please record the values from Arduino LCD and compare with the label values from each electrical appliance:

Item	Power (Label) (W)	I_0 (A)	I_{rms} (A)	V_{rms} (V)	Power (W)
Clothe Iron	1100	6.30	4.45	240	1068.65
Toaster	1400	8.35	5.94	240	1425.25
Wall Drill	450	2.78	1.97	240	472.32
Vacuum Cleaner	600	2.00	1.42	240	339.74

4. Which item has highest power consumption?

Toaster

(b)

Figure 8. Activity worksheet (student's data sample): (a) AC graphs and (b) peak current, RMS current, and power consumption values for various electrical appliances.

An interview session was also conducted with students to collect authentic responses about students' learning experiences using the AC-Duino kit. Figure 9 shows the responses from several students in the interview session. Based on their responses, it is proven that students had gained a more holistic understanding of AC and its relation to real-life situations. For example, students learned about safety precautions, such as not applying excessive electrical appliances at the same electric port as any regular electric socket with a current limit of only 13 amp. Applying too many loads at the same socket will have the danger of a total current exceeding 13 amp and causing a fire hazard. Regarding the current limit of 13 amp, the peak current value should be considered instead of the RMS current value because the changing alternating current can rise beyond the RMS current value. Therefore, the peak current value is essential to be considered when in terms of electrical safety. In contrast, the RMS current value is specially used to determine power consumption and energy usage of electrical appliances. Through this activity, students can better differentiate the usage between peak current and RMS current.

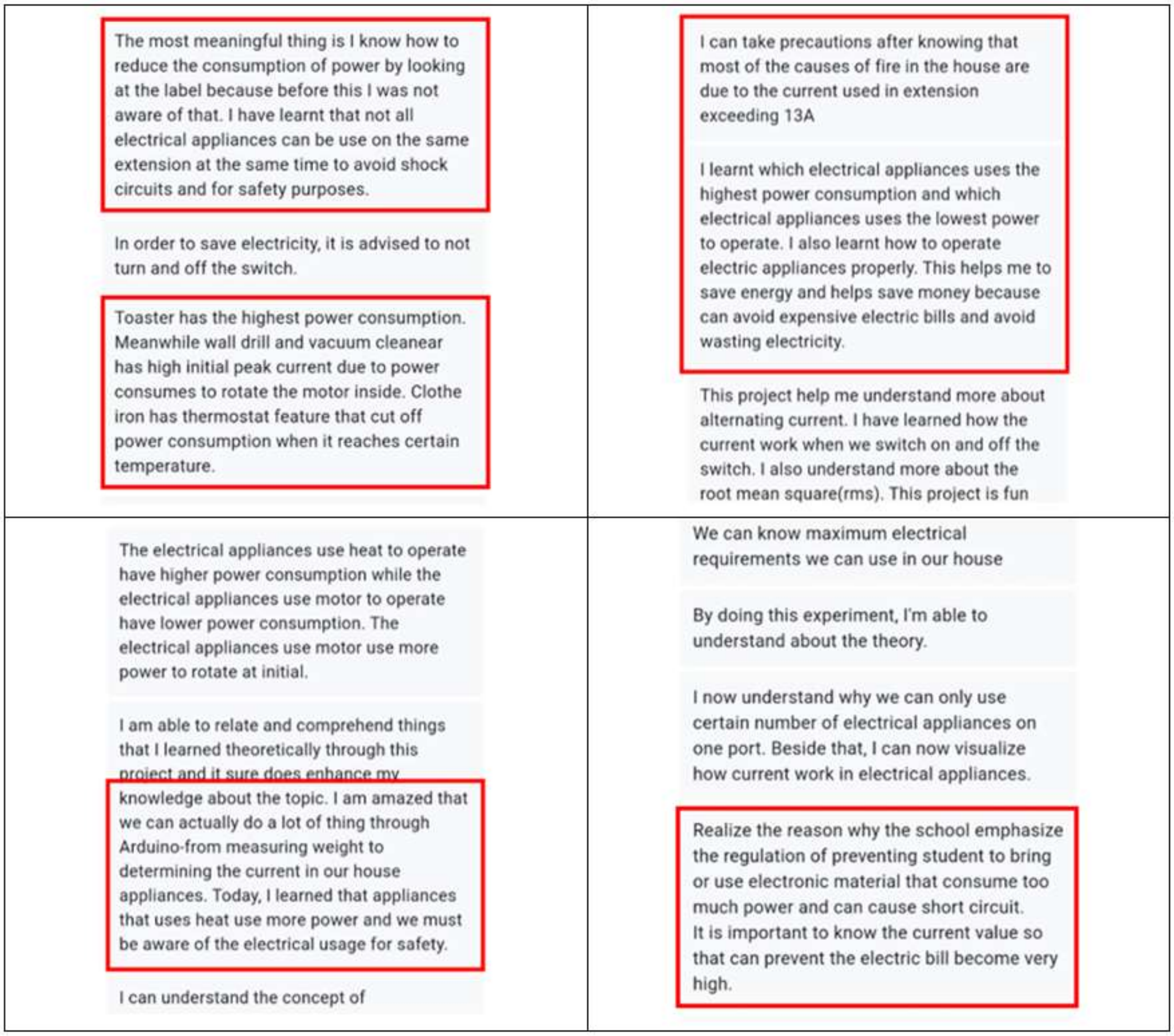


Figure 9. Students' interview responses.

Figure 10 shows that this AC-Duino activity helped students to realise that coding is not just a tool for programming robots but is a much more helpful tool that can be used to solve real-life problems. Many programming theories from Computer Science are being put into actual life applications in this activity. Knowing how to write codes that program the Arduino into collecting data for peak current, calculating RMS current, and ultimately generating the value of power consumption for any electrical devices certainly boosts the students' interest in programming knowledge as well as physics knowledge—it is likened to "killing two birds with one stone". A student even commented on creating such projects in the future.

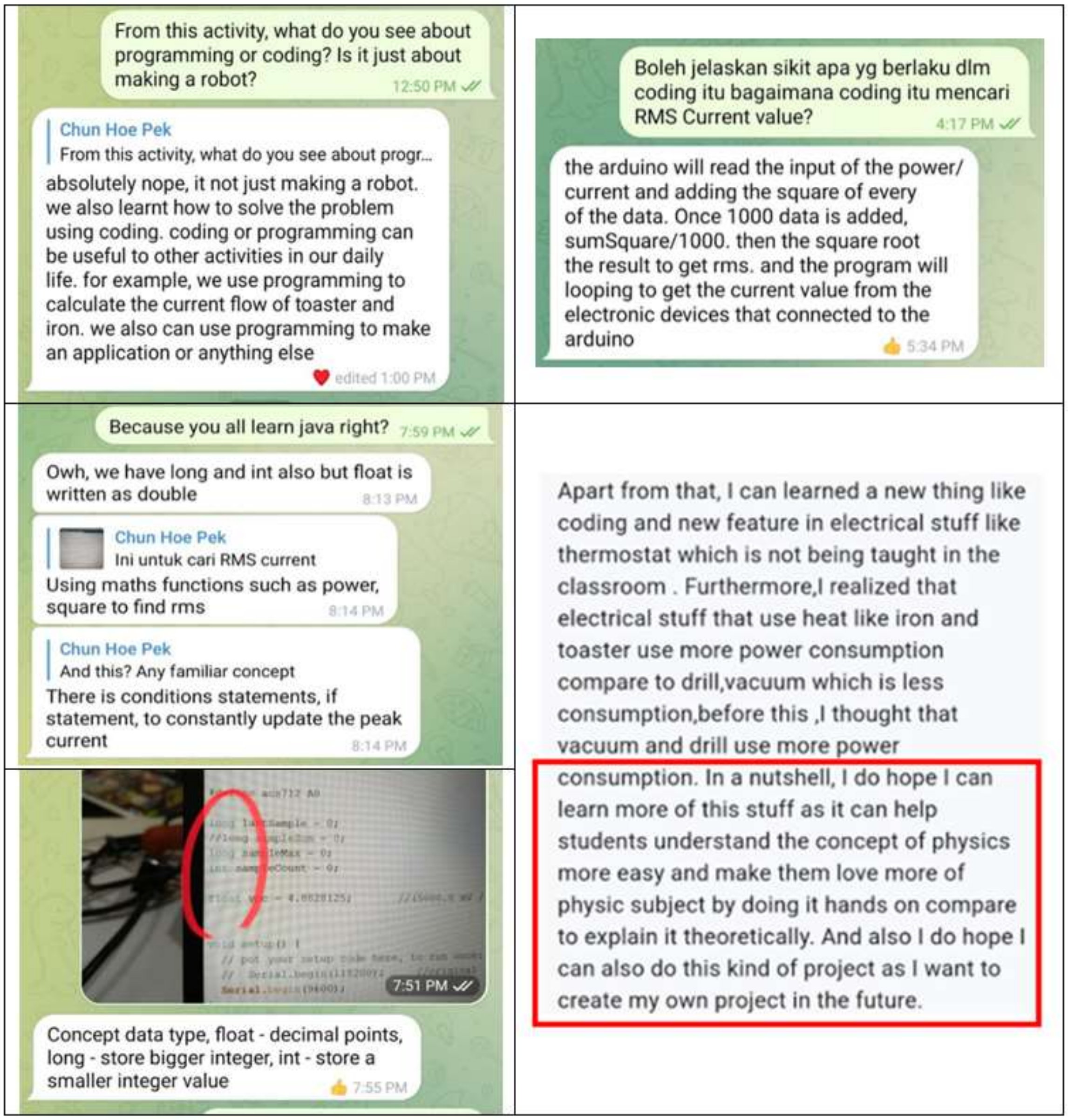


Figure 10. Students' interview responses. An interview was also conducted with lecturers who act as critical friends, and below were their responses regarding ways to improvise the project further:

Lecturer A: Use a projector or set up a few Arduino kits so that students can see the LCD easily.
Lecturer B: …The activity can be improved in terms of engagement… great to see the activity be more learner-centred and more aligned to the idea of discovery/exploratory learning.
Lecturer C: microcontroller can be connected to a Wi-Fi or Bluetooth module to send the current readings to a remote device, such as a computer or smartphone.

Based on suggestions given by the critical friend lecturers, the area of limitation for the second cycle of the AC-Duino project was identified. As only a set of Arduino microcontroller was available to the whole class for demonstration and experiment purposes, some students were not able to see the Arduino LCD screen or laptop screen easily. Thus, in the third cycle of the AC-Duino project, a few extra Arduino kits are planned to be set up so that more students in the whole class can experience them. Perhaps a projector can be set up to display Arduino data more prominently in front of the classroom. Another option is for the project to be further improved by incorporating Internet-of-Things (IoT) elements. The Arduino microcontroller can be connected to a Wi-Fi/Bluetooth module or even an IoT-supported device ESP32 to wirelessly transfer the real-time current readings to students' smartphones.

6 CONCLUSION

This experiential learning activity, which utilises Arduino microcontroller technology to demonstrate the concept of RMS current, has positively impacted students' learning process. Students can understand its definition more clearly after relating it to power consumption values generated by Arduino for various household electrical appliances. Many other unexpected gains of learning experience related to alternating current topics also happen when students learn through this real-life physics experiment involving robotic technology. The sinusoidal graph of alternating current, current limit of 13 amp on electrical socket, peak current consideration in electrical safety, RMS current significance in energy usage, thermostat feature in cloth iron, and differences between electrical devices based on heat or motor are some notable examples of meaningful real-life lessons exhibited through this AC-Duino activity. These lessons cannot be learned or experienced through regular classroom instruction using lecture notes. These benefits of real-life applications using Arduino as a teaching tool further confirm the findings of Pusch et al. (2021) and Peto (2020), who also successfully related physics content with real-life situations through Arduino microcontroller application.

Nevertheless, precautions must be taken seriously in this lab activity as a high current is involved. Since the neutral (blue) extension cord wire is cut open to be connected to the ACS712 current sensor, the point of electrical hazard is constantly exposed whenever the power is switched on. Absent-minded students may quickly get an electrical injury if they accidentally touch this part of the exposed wire. Therefore, it is of utmost importance that educators strictly supervise the students' lab activity of measuring current. Hot items such as cloth irons and toasters also pose the danger of burn injury if handled negligently. Besides, the ACS712 current sensor needs to be calibrated correctly in terms of coding before it can generate accurate measurement data. The RMS voltage value in the code also needs to be adjusted depending on the country in which the person is experimenting. In the United States, the RMS voltage should be 110 to 120 V, instead of 220 to 240 V in Malaysia. Educators can easily replicate this low-cost AC-Duino kit for use in their classroom setup by carefully adhering to the experimental setup, precautions, and calibrations.

Most importantly, using a low-cost Arduino microcontroller in teaching physics allows students to see the practical applications of physics laws and computer science programming knowledge in modern-day, real-life situations. By working with microcontrollers and sensors, educators and students can find modern ways of studying physics laws and phenomena, thus cultivating the students' interest in Science, Technology, Engineering and Mathematics (STEM). Rather than collecting lab data manually using slow conventional methods, microcontrollers are capable of fast real-time data feed where graphs and results are spontaneously generated. It allows students to observe physics laws happening directly in real-time. These benefits further confirm the findings of Sukmak and Musik (2022) that using Arduino allows students to repeat their physics experiments as often as needed and focus more on observing physics laws rather than scientific manipulative skills. Students will become more engaged, enthusiastic about learning, and more appreciative of the knowledge they receive. Besides, recent technologies in the learning process can be a factor of motivation and inspiration for students to embrace a career in STEM.

ACKNOWLEDGEMENTS

The authors are grateful for the valuable comments and suggestions from the head of the physics unit, the subject matter expert (SME), and two other senior lecturers who have agreed to act as critical friends throughout the action research. This publication is a token of appreciation for students who willingly participated and cooperated in this research.

REFERENCES

Azizahwati, A., Rahmad, M., & Hidayat, F. (2020). Development of a Circular Motion Experimental Device Using an Arduino Uno Microcontroller. *Journal of Physics: Conference Series*, *1655*, 012154. https://doi.org/10.1088/1742-6596/1655/1/012154

Bezerra, A., Cabreira, F., Freitas, W., Cena, C., Alves, D., Reis, D., & Goncalves, A. (2019). Using an Arduino to demonstrate Faraday's law. *Physics Education, 54*(4), 043011, https://doi.org/10.1088/1361-6552/ab1ce1

Cicuta, P., & Organtini, G. (2022). Smartphysicslab: a creative Physics Laboratory using Arduino and Smartphones. *Journal of Physics: Conference Series*, *2297*, 012013. https://doi.org/10.1088/1742-6596/2297/1/012013

Dibarbora, C. (2021). Computational models and experimental validation at the physics teacher training college using Scilab and arduino™. *Journal of Physics: Conference Series, 1882*. https://doi.org/10.1088/1742-6596/1882/1/012139

Galeriu, C., Letson, C., & Esper, G. (2015). An Arduino Investigation of the RC Circuit. *The Physics Teacher, 53*, 285-288. https://doi.org/10.1119/1.4917435

Jean, M., & Jack, W. (2002). *Action Research: Principles and Practice*. British: Taylor and FrancisGroup.

Kemmis, S., & McTaggart, R. (1988). *The Action Research Planner* (3rd ed.). Waurn Ponds: Deakin University Press.

Kolb, D. (2015). *Experiential Learning: Experience as the Source of Learning and Development.* (2nd ed.). New Jersey, United States of America: Pearson Education, Inc.

Megananda, A., Muzayyanah, E., Darmayanti, H. P., & Priana, Z. I. (2021). Development of Digital Distance Measurement Instrument Based on Arduino Uno for Physics Practicum. *IMPULSE: Journal of Research and Innovation in Physics Education, 1*(2), 80 – 88. https://doi.org/10.14421/impulse.2021.12-03

Moya, A. (2019). Studying Avogadro's Law with Arduino. *The Physics Teacher, 57*, 621. https://doi.org/10.1119/1.5135793

Nurroniah, Z., Anggraeni, N. P., Asy'ari, I. H., Putri, D. S., Sani, S. A., Harijanto, A., & Subiki. (2023, July). Design of an Arduino UNO-based Automatic Light Control System as a Basic Physics Teaching Aid on Ohm's Law. *Jurnal Ilmiah Wahana Pendidikan, 9*(13), 663-673. https://doi.org/10.5281/zenodo.8160171

Peto, M. (2020). Teaching atmospheric physics using Arduino-based tools. *AIP Conference Proceedings.* Romania: AIP Publishing. https://doi.org/10.1063/5.0002282

Pratiwi, U., & Fatmaryanti, S. D. (2020). Development of Physics Teaching Media Using Speed Sensors as Speed Analysis in Real-time based on Arduino to Remind Students of Problem-Solving Abilities. *Jurnal Ilmu Pendidikan Fisika, 5*(3), 151-158. https://doi.org/10.26737/jipf.v5i3.1789

Pusch, A., Ubben, M. S., Laumann, D., Heinicke, S., & Heusler, S. (2021). Real-time data acquisition using Arduino and Phyphox: measuring the electrical power of solar panels in contexts of exposure to light in physics classroom. *Physics Education, 56*(4), 045001. https://doi.org/10.1088/1361-6552/abe993

Somogyi, A., Kelemen, A., & Mingesz, R. (2022). Low-cost high-resolution measurements of periodic motions with Arduino in physics teacher in-service education. *Journal of Physics: Conference Series, 2297*, 012031. https://doi.org/10.1088/1742-6596/2297/1/012031

Sukmak, W., & Musik, P. (2022, January). Real-Time Graphing of Simple Harmonic Motion of Mass on Springs with an Arduino Based on an Experiment Set for Teaching and Learning Physics. *TOJET: The Turkish Online Journal of Educational Technology, 21*(1), 114-123. https://eric.ed.gov/?id=EJ1338131

Uzal, G. (2022, July). The Use of Arduino in Physics Laboratories. *TOJET: The Turkish Online Journal of Educational Technology, 21*(3), 88-100. https://eric.ed.gov/?id=EJ1345978