UNDERSTANDING RESISTANCE AND OHM'S LAW WITH ARDUINO-BASED EXPERIMENTS

ENTENDIENDO LA RESISTENCIA Y LA LEY DE OHM CON EXPERIMENTOS BASADOS EN ARDUINO

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The rapid development of technology has enabled many types of technology to be used frequently by educators in learning and teaching activities. One of these frequently used educational technologies is Arduino. This study aims to determine how resistance changes depending on the cross-sectional area, length, and resistivity of the conductor using Arduino. In order to determine the factors affecting the resistance in the Arduino-based experiment, the experiment utilized the graphite leads that students use in their daily lives. An inexpensive and high mobility experiment system has been developed. The data obtained by the experimental setup complies with theoretical laws. This experiment, along with the use of Arduino, will enable students to experience Ohm's law and enable them to better understand the concepts of potential, current, and resistance in a series circuit. In addition, it is thought that the experiment will attract more attention from students by offering a technology-supported learning opportunity. Researchers and teachers can turn this experiment into a science, technology, engineering y mathematics (STEM) activity by integrating it into a problematic situation.

El rápido desarrollo de la tecnología ha permitido que los educadores utilicen con frecuencia muchos tipos de tecnología en las actividades de aprendizaje y enseñanza. Una de estas tecnologías educativas de uso frecuente es Arduino. Este estudio tiene como objetivo determinar cómo cambia la resistencia según el área de la sección transversal, la longitud y la resistividad del conductor que usa Arduino. Para determinar los factores que afectan la resistencia en el experimento basado en Arduino, el experimento utilizó las minas de grafito que los estudiantes usan en su vida diaria. Se ha desarrollado un sistema experimental económico y de alta movilidad. Los datos obtenidos por la configuración experimental cumplen con las leyes teóricas. Este experimento, junto con el uso de Arduino, permitirá a los estudiantes experimentar la ley de Ohm y les permitirá comprender mejor los conceptos de potencial, corriente y resistencia en un circuito en serie. Además, se cree que el experimento atraerá más la atención de los estudiantes al ofrecer una oportunidad de aprendizaje respaldada por tecnología. Los investigadores y profesores pueden convertir este experimento en una actividad ciencia, tecnología, ingeniería y matemática (STEM) integrándolo en una situación problemática.

I. INTRODUCTION

With the swift developments in technology throughout the 21st century, the use of different types of technology in education and the integration of these technologies in lessons have come to the fore. The use of innovations that technology brings not only to our daily lives but also to our educational environments is increasing day by day. Today, many educational technologies with different features are used. Examples of these applications include augmented reality, mobile learning, wearable technology, holograms, digital storytelling, and digital games [1]. One of the technologies used in educational environments in Arduino. The fact that Arduino has a structure that is connected with many disciplines enables it to be easily integrated into educational environments. In particular, the fact that the software and hardware of such microcontroller cards are open-source, supported by block-based coded programs, and can grant access to many applications from the library without any coding knowledge ensure that Arduino-supported events are widely used in educational environments [2]. Also, the use of Arduino-style microcontrollers in education enables students to create a model that they can touch and see, and with Arduino-supported robotic activities, students have the opportunity to examine events they encounter in daily life [3]. In addition, Arduino-supported robotics and coding applications teach students algorithmic thinking, collaborative work, creativity, and problem-solving, as well as the scientific method, programming, and engineering design processes [4].

Arduino is used as educational technology in physics experiments due to its low cost, flexible and easily applicable structure, and fast data collection advantages [5–7]. More accurate results can be obtained more quickly by using computer technologies for various measurements and calculations in science and physics laboratories. Such technologies can enable students to see concepts more visually. In addition, it has been determined that laboratory applications using computer technologies attract the attention of students more [8]. Students can quickly and easily collect and process experimental data with sensors connected to a microcontroller. Thus, students can focus most of their time and attention on interpreting data, rather than

collecting data, and creating graphs [9]. Arduino can be adapted to many different subjects in physics teaching. There are many application examples, including various Arduino-based physics experiments developed to measure physical quantities such as potential, temperature, and pressure [10]. Arduino can be used in many different learning environments and for diverse topics such as mechanics [11–13], electricity [14–16], heat and temperature [17, 18]. However, Arduino is mostly used in electricity and electronics teaching, due to its nature.

Electrical resistance in conductors appears in the science and physics curricula at secondary, high school, and university. Factors affecting resistance such as the length, type, and cross-sectional area of the conductor are examined, and experiments on these effects are widely carried out in schools. Thus, students can easily comprehend and apply these factors [7]. In this study, how the resistance changes depending on the cross-sectional area, type, and length of the conductor is modeled using Arduino. The experiment presented in this study consists of Arduino and materials we use in our daily lives. An inexpensive and easily portable system has been developed. In addition, the presented experiment can successfully attract the attention of students by providing a technology-supported teaching opportunity.

II. ELECTRIC CURRENT AND RESISTANCE

Electricity is of interest not only to physics, but also to chemistry and biology. Today, the charging and discharging of our mobile phones is due to chemical reactions. The relationship between electricity and biology was first discovered by Luigi Galvani (1737–1798). While experimenting with frogs, Galvani noticed that electrical sparks caused the frogs' legs to twitch. As a result of this observation, Galvani made the wrong conclusion, arguing that there was electricity in the frog. Today, it is known that electrical currents are responsible for the transmission of messages between body muscles and the brain [19].

Physics teachers can make an analogy between water flow and current in lessons. For example, the amount of water leaving a faucet in a given time interval can be measured in units of liters per minute. Similarly, the flow of water in a river can be characterized by defining the speed with which water passes through a particular location. For example, the flow at the threshold of Niagara Falls varies between 1400 m^3/s and 2800 m^3/s [20].

To quantify current, it is assumed that the charges move perpendicularly through the cross-section of a wire. The current is defined as the rate at which the charge flows through this surface. If ΔQ is the amount of charge passing through this surface in the time interval Δt, then the average current I_{avg} is equal to the charge passing through this surface per unit time [20]:

$$I_{avg} = \frac{\Delta Q}{\Delta t}.$$ (1)

If the flow rate of the charge changes over time, the current changes over time. Instantaneous current (I) is defined as the limit of the average current as follows:

$$I = \frac{dQ}{dt}.$$ (2)

The charged particles that make up the current can be positive, negative, or both. Traditionally, the direction of the current is the chosen direction of the positive particles. In conductors such as copper or aluminum, current results from the movement of negatively charged electrons. Therefore, in ordinary conductors, the direction of current is opposite to the direction of the flow of electrons. In some mediums, such as gas and electrolytes, the current is the result of the flow of both positive and negative charges [20].

It is possible to define the current with a second equation, by considering the flow in the conductor in the micro dimension. Assuming that the charges that make up the current move with the same drift velocity of magnitude V_d, in a time interval dt, each particle moves at a distance V_d times dt. If the conductor has a cross-sectional area A and each particle has a charge q, then the charge dQ flowing through the unit cross-section of the conductor during dt is [21]:

$$dQ = nqV_dAdt,$$ (3)

and the current is:

$$I = \frac{dQ}{dt} = nqV_dA.$$ (4)

The current per unit cross-sectional area is called the current density J:

$$J = \frac{I}{A} = nqV_d.$$ (5)

The current density J in a conductor depends on the electric field E, and the properties of the material. Overall, this relationship can be quite complex. However, for some materials, especially metals, at a given temperature J is almost directly proportional to E, and the ratio of E and J magnitudes is constant. This relationship, called Ohm's law, was discovered in 1826 by the German physicist Georg Simon Ohm (1787-1854). It defined the resistivity (ρ) of a material as:

$$\rho = \frac{E}{J}.$$ (6)

The greater the resistivity, the greater the field needed to cause a given current density, or the smaller the current density caused by a given field. Materials that obey Ohm's law and thus show this simple relationship between E and J are said to be ohmic. However, it has been found experimentally that not all materials have this feature. It is said that those which do not obey Ohm's law are nonohmic [20]. Using the concept of potential difference (V) in the resistivity equation, if we write V/L instead of E, and I/A instead of J and edit the equation, we write the following:

$$\frac{V}{I} = \rho \frac{L}{A}.$$ (7)

The V/I ratio gives the resistance (R) of an ohmic conductor. R is equal to:

$$R = \rho \frac{L}{A}. \tag{8}$$

Based on this equation, it can be said that the resistance of a conductor depends on the length, cross-sectional area, and resistivity of the conductor.

III. THE TRADITIONAL EXPERIMENT OF FACTORS AFFECTING RESISTANCE

Experiments about factors affecting the resistance of a conductor have been carried out in secondary schools, high schools, and universities for years. Traditional materials required for this experiment are a generator, voltmeter, ammeter, rheostat, and resistance board. There are thin wires such as copper, nickel, and iron in the resistance board. The diameter of the wires must be known in order to calculate their cross-sectional areas. In order to examine the relationship between the resistance of the conductor and its length, the potential difference is applied to two points of the same wire with different lengths. By measuring the current, the resistance of the same type of wire in different lengths is found. For the relationship between cross-section area and resistance, the current-potential difference measurement is made in three or four different diameters and fixed lengths of the same type of wire. Different types of wires with the same diameter are needed to investigate the dependence of the resistance of the conductor on the type of the conductor. Figure 1 shows the tools used in a traditional experiment.

Figura 1. Equipment for a traditional experiment about Ohm's law.

These experiment materials have low portability and can be difficult to provide. It is certain that the new generation of students, who are called the Z-generation, will not find this experiment set-up technological. Updating such experiments in a way that satisfies the curiosity and interest of students is a responsibility that every educator should undertake, if their goal is to provide meaningful learning.

IV. NEW INTERPRETATION OF THE FACTORS AFFECTING RESISTANCE EXPERIMENT

This study aims to transform the experiment of factors affecting resistance into a more technology-supported format using Arduino Uno. The materials used in the experiment are as follows:

- Computer
- Arduino Uno
- 100 Ω resistor
- Jumper cables
- Graphite leads (0.3 mm, 0.5 mm, 0.7 mm, 0.9 mm)
- Copper wire (0.5 mm)

The expected learning outcomes of the students through the experiment are that they:

- Recognize the Arduino Uno board.
- Can use Arduino Uno input pins.
- Can connect two resistors in series.
- Apply Ohm's law.
- Analyze the variables on which resistance depends.

$$V_A = I(R_1 + R_2), \tag{9}$$

$$I = \frac{V_a}{R_1 + R_2}, \tag{10}$$

$$V_1 = IR_1, \tag{11}$$

$$V_1 = \frac{V_a}{R_1 + R_2} R_1, \tag{12}$$

$$R_1 + R_2 = \frac{V_a R_1}{V_1}, \tag{13}$$

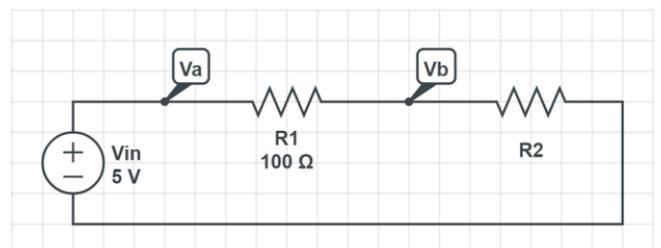$$R_2 = \frac{R_1(V_a - V_1)}{V_1}. \tag{14}$$

Figura 2. The circuit used in the experiment.

V. EXPERIMENTAL SET-UP

Graphite leads are used as unknown resistance in this experiment. Graphite is one of the allotropes of carbon. It is used in writing due to its soft structure and black color. The graphite used in pencils is not pure and contains clay and wax. Depending on the graphite clay ratio, graphite leads are divided into two main grades as H and B. Grade H shows the hardness due to the higher clay content while grade B is for blackness due to the higher graphite content. Typically, HB-grade pencils contain 60-70 % graphite [22]. The use of graphite leads in electrical experiments and showing Ohm's law is a previously tested case [23, 24]. Presenting the experiment based on Arduino in this research is an attempt to attract the attention of today's students. Graphite leads are placed vertically on a breadboard, and these graphite leads are connected in series with 100 Ω resistance. 5 V and GND outputs are used to create a potential difference in the circuit. A0 and A1 analog inputs are used to measure V_a and V_b potentials. The circuit diagram is given in Figure 3.
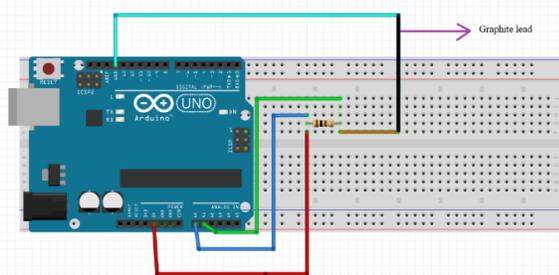

Figura 3. Arduino connection.

The Serial Port screen is used to read the collected data.

After the connections are made, the following codes are uploaded to Arduino:

```
float Va; // datatype of Va
float Vb; // datatype of Vb
float V1; // datatype of V1
void setup() {
Serial.begin(9600); // for communicating with
Serial Monitor
pinMode (A0,INPUT);// to define A0 as input
pin Mode (A1,INPUT);// to define A1 as input }
void loop() {
Va = analogRead (A0);// to read potential at point
Va
Va=(Va/1023)*5; // to convert ADC reading
toVoltage
Vb = analogRead (A1);// to read potential at point
Va
Vb= (Vb/1023)*5; // to convert ADC reading to
Voltage
V1=Va-Vb; // to calculate V1
float R2 = ((100*(Va-V1))/V1); // to define and
calculate R2
Serial.println (R2); // to print R2
delay (10000); // to wait for 10 seconds
```

VI. DATA ANALYSIS

In order to investigate the relationship of resistance with the cross-sectional area of the conductor, different cross-sections of the same type of conductor with a constant length are required. For this, 6 cm long, 0.3 mm, 0.5 mm, 0.7 mm, 0.9 mm diameter graphite leads are used. Table VI gives graphite leads' resistances according to different diameters. Figure 4 presented the resistance cross-section graph created by the data in Table VI. Since the cross-section area is the product of the square of the radius (r^2) and π, r^2 was used while drawing the graph. Figure 4 shows that the resistance is inversely proportional to the cross-section of the conductor.

Tabla 1. Resistance change with radius

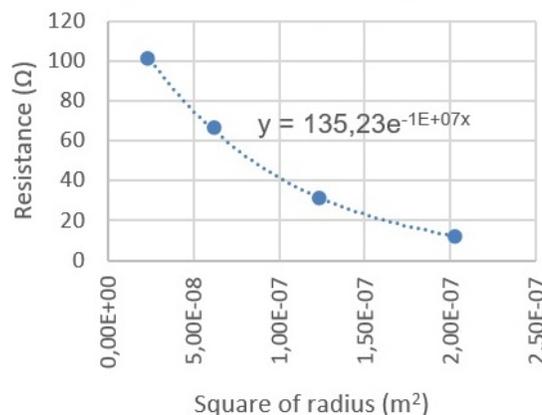| Diameter (mm)	Square of radius (m^2)	Resistance (Ω)
0.3	2.25E-08	102.08 ± 2.76
0.5	6.25E-08	66.72 ± 2.93
0.7	1.23E-07	31.02 ± 2.80
0.9	2.03E-07	12.36 ± 1.06

Figura 4. Relationship between resistance and r^2.

In order to investigate the relationship of resistance with the length of the conductor, it is necessary to measure different lengths of the same type of conductor with a fixed diameter. For this, 0.7mm diameter graphite lead was cut with scissors in 6 cm, 4.5 cm, 3 cm, and 1.5 cm lengths. Table VI gives the graphite lead's resistances of different lengths. Figure 5 presented the resistance-length graph created by the data in Table VI. According to Figure 5, as the length of the conductor increases its resistance increases, which is compatible with Ohm's law.

One of the factors affecting resistance is the type of conductor. To demonstrate this, two different conductors of the same length and diameter are needed. Copper wires inside telephone or internet cables can be used for this. The diameter of these wires is 0.5 mm. In Table 1, the resistance of 0.5 mm diameter and 6 cm long graphite was found to be 66.72 Ω. The resistance of the 0.5 mm diameter 6 cm copper wire removed from the telephone cable was measured as 0.21 Ω. In this measurement, the resistivity of the telephone wire was calculated as 1.75×10^{-6} Ω·m. The resistivity of copper is 1.68×10^{-6} Ω·m. Generally, cadmium-copper alloy is used in

telephone wires. This data shows us that the resistivity value of copper is lower than graphite. In other words, copper is a better conductor than graphite.

Tabla 2. Resistance change with length

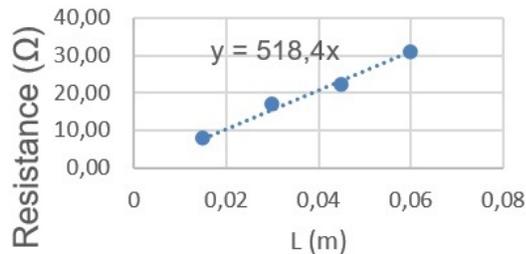| Diameter (mm)	L (m)	(Ω)
0.7	0.060	102.08 ± 31.02 ± 1.71
0.7	0.045	66.72 ± 22.35 ± 1.42
0.7	0.030	31.02 ± 17.09 ± 0.98
0.7	0.015	12.36 ± 7.97 ± 0.77

Figura 5. Relationship about resistance and length.

VII. CONCLUSIONS

This study revised the factors affecting the resistance experiment that has been done in schools for years. The experiment of factors affecting resistance has been made available to students, teachers, and researchers in a technological, highly portable, and inexpensive way. The use of graphite leads as a material to measure resistance has been presented as a cheap and easily accessible material.

In addition, the fact that the materials are materials used by students in their daily lives can positively affect their science process skills. Prajoko et al. [25] stated that using local materials in students' science experiments improved their science process skills. Besides, the experiment presented by this study will also improve students' coding skills.

Educators who want to take the experience of their students further can include an LCD screen to the experimental set-up and enable students to read the values from this screen. Educators who do not want students to be busy with coding can upload the codes to Arduino before the lesson, and expect the students to focus only on the experiment. Researchers and teachers can try this experiment as a STEM activity and integrate it into a problem situation and use it in their classrooms.

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