Newton's law of cooling experiment set using Arduino temperature sensor

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Abstract. The research aims to develop the experimental set of the temperature measurement in liquid by Arduino program displaying data on a smartphone via the Blynk application. The experimental set is composed of 1) 2 liquid temperature sensors (DS18B20 model), 2) Arduino program, and 3) LED screen for showing the temperature value in unit of °C and connect to a smartphone. The Arduino temperature sensor 1 and sensor 2 of the experimental set have 0.57% and 0.51% errors, respectively, compared with the temperature sensor of the B Smart Science Co., Ltd. company. The instrument is applied to the physics laboratory on Newton's law of cooling to find the cooling rate of water and coffee. This low-cost instrument revealed high accuracy results and easy to connect with other devices.

1. Introduction

Nowadays, there are several learning resources, easy to access and friendly to apply. Teaching and learning in educational institutions are required to promote the information and technology literacies as tools for learners' working. Moreover, learners must learn ways of thinking such as creativity, critical thinking, problem-solving, and learning ways of working such as communication and collaboration skills for success in today's world. It is the framework for 21st-century learning skills and knowledge students need to succeed in work and life [1]. Instructional tools and processes play a crucial role in activating learners to develop knowledge, skills, and attitudes, particularly in science and technology topics. This study aims to introduce a low-cost instrument developed by Arduino board illustrating results on smartphones via the Blynk application. This technology can be applied to encourage critical thinking, problem-solving, and collaboration skills of high school to university students in physics classrooms.

This study develops a temperature sensor based on Arduino and its technology to help students learn Newton's law of cooling concept. The Arduino temperature sensor is widely applied to classrooms because it has high accuracy and can measure extensive temperature range [2-4].

2. Instrument and method

2.1. NodeMCU V3 ESP8266

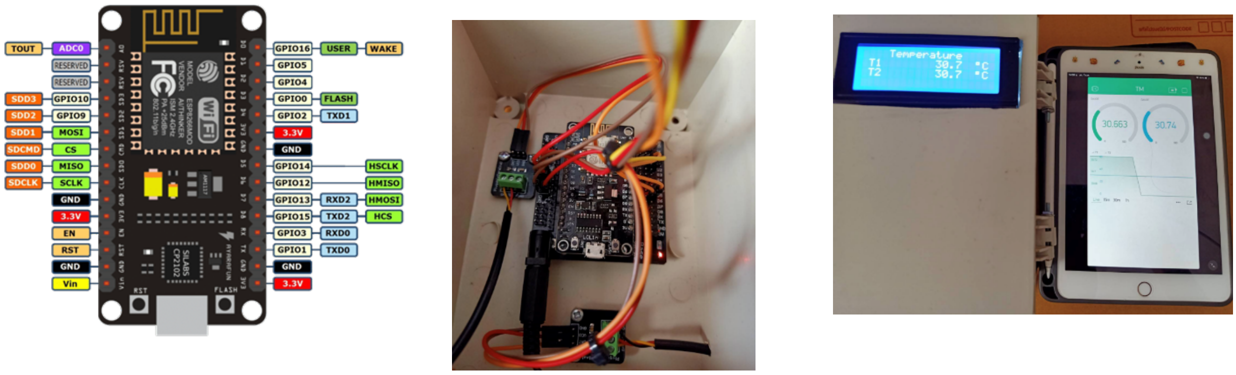
NodeMCU V3 ESP8266 is a microcontroller based on ESP8266 Arduino board and connected to a wifi signal. The main parts are nine digital input/output pins, one analog input pin, a USB connection, a power jack, and a reset button. The NodeMCU V3 ESP8266 can be programmed with the Arduino Software (IDE) and powered by an AC to DC adapter (or battery) to start.

2.2. DS18B20 temperature sensor

DS18B20 is a digital temperature sensor providing -55 °C to 125 °C measurable temperature ranges. It is one of the most popular temperature sensors on the market. It can be used as the temperature monitor tool in a smart farm, house, water station, and so on. It is similar to DHT11/DHT22 temperature and humidity sensor. The DS18B20 temperature sensor has many formats, such as IC and waterproof sensors. This study uses the ESPino32 board, reads data from a sensor, and displays results on a serial monitor. This Arduino board developed in this research was shown in figure 1.

2.3. Application blynk

Blynk is a free platform with iOS and Android applications to control Arduino. It is easy to program, real-time using, and simply to connect with Arduino, ESP8266, ESP32, NodeMCU, Rasberry pi.



(a) (b) (c)

Figure 1. (a) diagram of NodeMCU V3 ESP8266, (b) Arduino board used in this study, (c) Blynk application.

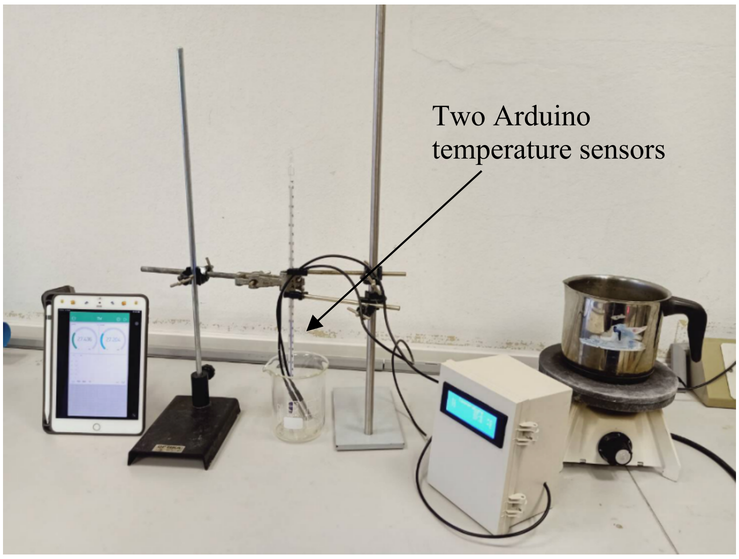


Figure 2. Newton's law of cooling experiment set using the Arduino temperature sensors.

2.4. Newton's law of cooling

Newton's law of cooling states that the rate of change of temperature of an object is proportional to the difference in temperature between the object and its surroundings [5], expressed by equation (1)

$$\frac{dT}{dt}(t) = -K(T(t) - A) \tag{1}$$

where $T(t)$ is the temperature of the object at time t, A is the temperature of its surrounding, and K is a constant of the cooling rate. A high K constant means a large change of the temperature over times, indicating a high cooling rate. The equation can be shown as

$$T(t) = [T(0) - A]e^{-Kt} + A \tag{2}$$

where $T(0)$ is the initial temperature of the object. This study applied the Arduino temperature sensor to investigate the cooling rate of water, as shown in figure 2. As a preliminary work, we asked the 4-year physics students from the faculty of education to conduct Newton's law of cooling experiment as a group of 2-3 students. They were asked to design an experiment to observe the change of temperature of water and coffee, and to find the K constant using the developed Arduino temperature sensor.

3. Results and discussion

The two Arduino temperature sensors were used to measure water temperature during 31°C - 50 °C, and compared the result with the thermosensor of the B Smart Science Co., Ltd. company, which is commonly used in the physics laboratory. It revealed 0.57% and 0.51% errors for the temperature sensor 1 and sensor 2, respectively.

An example graph of water for one group was shown in figure 3. They measured the temperature of 200 mL water in a beaker at 90 °C initial temperature and put it at 27.5 °C surrounding temperature. The temperature was recorded every 30 seconds until it reaches the room temperature. The graph showed a decreasing trend of temperature versus times, which agrees with Newton's law of cooling concept. Moreover, equation (2) was reformatted as:

$$\ln[T(t) - A] = -Kt + \ln[T(0) - A] \tag{3}$$

The collected data were plotted and computed the K constant. They reported the K constant of water as $0.70\times10^{-3}\,\mathrm{s}^{-1}$ with 2.3% error under the mentioned conditions. Furthermore, another group applied the Arduino sensor to measure the temperature of the 3-in-1 coffee contained in a 150 mL beaker at 90 °C initial temperature and put it at 27.5 °C room temperature. They found the K constant of coffee as $0.85\times10^{-3}\,\mathrm{s}^{-1}$ with 3.2% error.

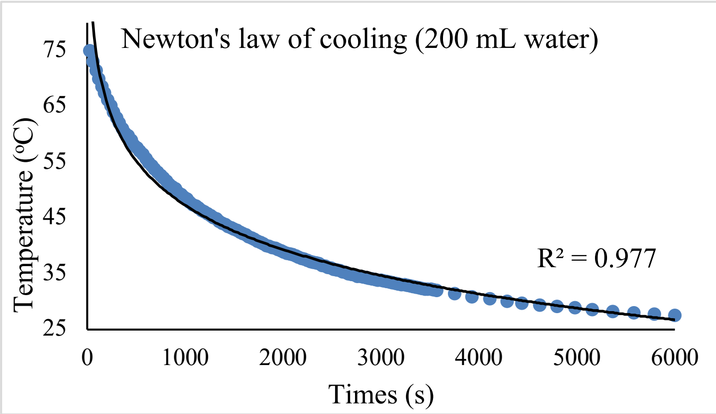


Figure 3. Newton's law of cooling for 200 mL water measured at 90 °C initial temperature and 27.5 °C room temperature.

Overall, the students were satisfied with this apparatus because it shows accurate values and easy to connect via wifi internet to other components. In addition, it can measure both solid and liquid materials within a large temperature range. Some students' groups planned and discussed using this instrument to measure the temperature of the coffee famous sells in the market, which has different ingredients to observe the cooling rate. It may guide sellers for decision-making. It reflects that working as a group of students in this study promotes both students' knowledge and higher-order thinking skills required for success in their life.

4. Conclusion

Newton's law of cooling experiment set based on Arduino temperature sensors developed in this study works well in finding the cooling rate constant of water and coffee. Advantages of the Arduino temperature sensor are low cost, high accuracy, and easy to link via wifi to free platform with iOS and Android applications or other devices. Thus, Arduino and its technology can be a highly effective instructional instrument in the active learning approach. Moreover, learners should have an experience in programming the Arduino and learn to extend the Arduino project.

Acknowledgments

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