Local Culture Integration in Physics Experiments: Exploring Angklung with Arduino-Enhanced Frequency Measurement

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Abstract **– Experimental activities in physics learning are important to encourage students to interact directly with physical phenomena. This study integrates local culture with technology through an innovative approach to the design of physics experiments. Arduino, a low-cost microcontroller, is extensively utilized for learning physics. The local culture examined in this study is *Angklung*, a traditional musical instrument from West Java, Indonesia. This study utilizes Arduino with a microphone sensor to design experiments investigating the sound produced by *Angklung*. The experimental activity aims to determine the frequency generated on each musical instrument on the diatonic *Angklung* and the factors that influence that frequency. The experimental results show that each musical instrument has a different frequency. Programming on Arduino is easy for students even though students do not have basic programming knowledge. The results of this study can be used as a reference for conducting alternative experiments using affordable equipment and objects familiar to students.**

Keywords **– Arduino, frequency measurement, local culture, physics experiment.**

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1. Introduction

The rapid development of science and technology also affects education [1]. Creating an interactive and fun learning environment is challenging for teachers in teaching and learning activities. Integrating various disciplines into learning strategies is considered very important. Technology enables students to learn independently and discover their skills through exploration [2]. Technology has the potential to offer captivating experiences and create opportunities for developing realistic, engaging, and enjoyable learning environments [3].

Learning physics should immerse students in real-life scenarios to make physics concepts more relevant and meaningful to them [4]. Physics has many abstract concepts that can pose challenges for students to comprehend. Therefore, teachers must guide students in systematically applying physics principles, fostering their ability to employ similar strategies in real-world situations. Addressing the low ability of students to comprehend abstract concepts and their lack of engagement in the learning process requires solutions that increase student motivation and learning achievement [5]. Experimental activities are essential in learning physics because they can increase the interaction between teachers and students. In addition, experiment activities can also develop scientific abilities and investigation processes and help understand concepts in the real world with applicable theories [6].

Experiment activities are usually conducted in the laboratory, but not all schools have adequate facilities. Laboratory equipment often entails numerous expensive and complex instruments. In many cases, the availability of these instruments is limited, and they cannot be utilized simultaneously by every student. Therefore, this experiment activity can be done outside the laboratory using a simple kit. However, most experiment kits are too expensive and can only be utilized for specific topics.

The emergence of low-cost microcontrollers and sensors has recently attracted the attention of researchers and teachers, especially physics teachers who design more affordable experiments [7]. Arduino, a low-cost microcontroller, is extensively utilized for teaching and learning physics [8], [9]. Arduino can be connected with a variety of sensors to measure experimental variables [10]. Arduino makes it possible to equip laboratories with enough instruments to enable each student to carry out many experiments and measurements with limited investment.

Sound is one of the physics concepts that is considered abstract but often found in daily life. The sound is close to musical instruments. Unfortunately, the younger generation's interest in traditional musical instruments has decreased. Angklung, a traditional musical instrument made of bamboo, was recognized by the UNESCO in 2010 [11]. Integrating Angklung into physics experiments is a method to preserve world cultural heritage that still exists in young generations. Contextual learning using Angklung can help students understand the concept of sound according to what they see and hear [12]. Angklung can be a learning medium for teaching sound in the classroom. The sound produced by the Angklung arises from the collision of the tube, resulting in a "kleung" sound. This study aims to describe the design of a physics experiment using Arduino for frequency measurement of sound Angklung. It also explores how local culture and technology can complement each other within the context of physics experiments. This design can be implemented in secondary schools that are studying the concept of sound waves.

2. Design Program

Hardware set-up plays a crucial role in determining the success and accuracy of an experiment. The appropriate program design requires effective integration between the hardware used, careful programming processes, and in-depth investigation into the accuracy of the developed program [13]. Considering the complex interaction between hardware, programming, and program accuracy investigation, this study is expected to provide valuable insights into designing effective and efficient physics experiments.

2.1. Hardware Set-Up

In this experiment, the equipment utilized comprised an Arduino Uno board, a KY-038 microphone sound sensor module, a solderless breadboard, a computer with the Arduino Integrated Development Environment (IDE) installed, a USB-A to B cable, and jumper wires.

In this setup, Arduino exhibits the approximate highest sound frequency identified by the sound detection module. The module transforms sound waves into electrical signals.

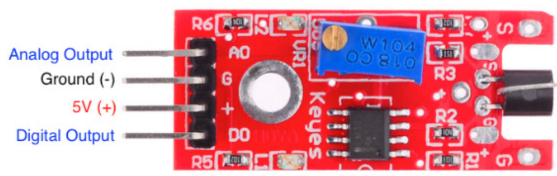


Figure 1. Microphone sound sensor module

The microphone sound sensor module has two outputs, analog output (AO) and digital output (DO), as shown in Figure 1. DO is output as a digital signal, namely LOW or HIGH. AO is output as an analog signal, 0 – 1000. We can only choose one if the sensor is connected to the microcontroller. In this study, the output used is analog. The design experiment aims to identify the frequency of sound Angklung. Fritzing diagram illustrating the circuit construction is shown in Figure 2. The AO of the sound detector module transmits the detected analog audio signal to A0 of the Arduino UNO. Subsequently, the analog signal undergoes sampling and quantization (digitization). Fast fourier transform (FFT) is then executed on the digital data, converting it from the discrete-time domain into result estimates. Arduino IDE Serial Monitor then displays the identified maximum frequency of the estimated results within the discrete time domain.

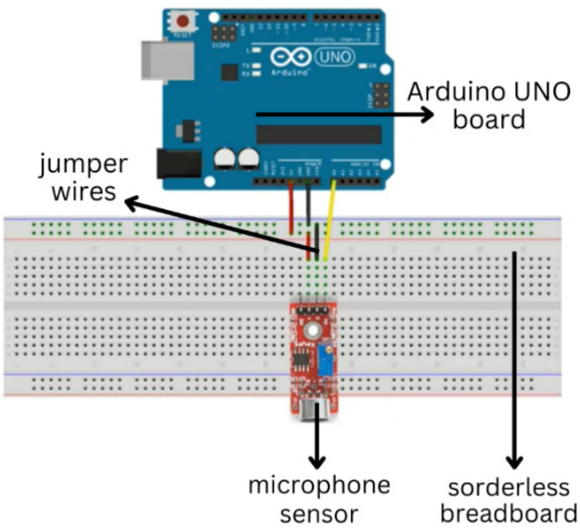


Figure 2. Fritzing diagram of the circuit

2.2. Programming

Arduino programs usually use the C++ language [14].

Connecting the USB to a computer allows the user to program the chip using the Arduino IDE software, which is freely available on the website and can be downloaded at https://www.arduino.cc/en/software/. The user writes the program on the computer, compiles it, and then transfers the program to the memory of the Arduino. Upon turning on the Arduino, the program is executed automatically. The Arduino IDE must be installed on a computer with Windows operating system (OS) to program frequency measurement of sound. We must obtain the Arduino FFT library to allow code programming in Arduino IDE for the audio frequency detector. When opening Arduino IDE, navigate to the Sketch menu, choose Include Library, and select Manage Libraries (Figure 3). Next, enter "FFT" into the search field and proceed to install the Arduino FFT library (Figure 4).

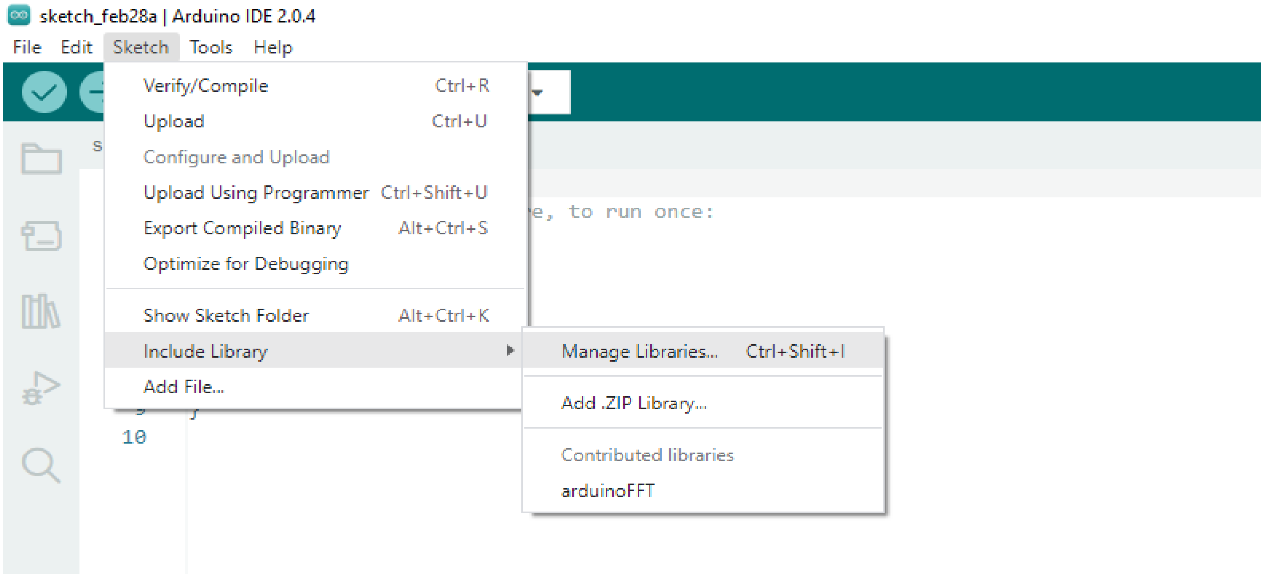


Figure 3. Managing libraries in Arduino FFT Library

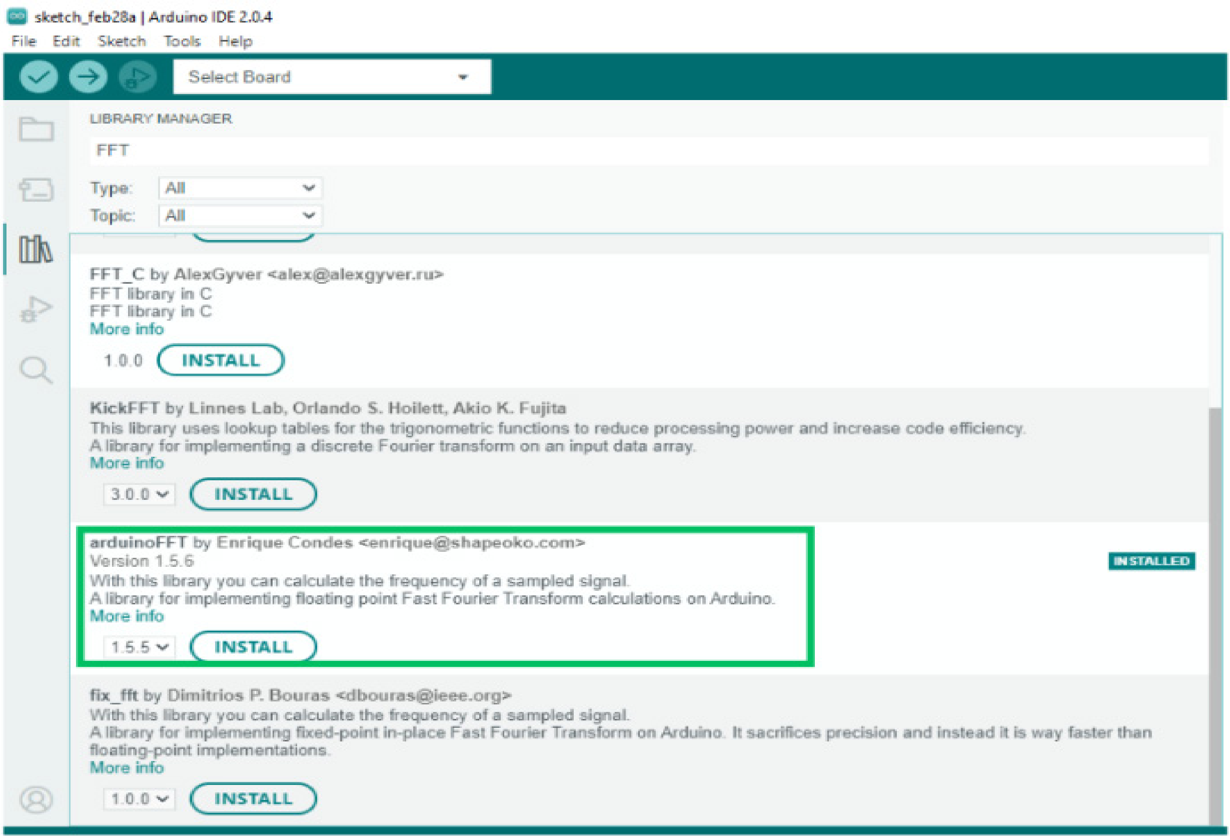


Figure 4. Install FFT Library

The code to program an audio frequency detector using an Arduino UNO is shown in Figure 5. In this setup, to access the sensor, it is only necessary to set the allowable frequency by rotating the variable resistor and then connecting VCC, GND, and OUT to the Arduino UNO.

```
#include "arduinoFFT.h"

#define SAMPLES 128             //SAMPLES-pt FFT. Must be a base 2 number. Max 128 for Arduino Uno.
#define SAMPLING_FREQUENCY 2048 //Ts = Based on Nyquist, must be 2 times the highest expected frequency.

arduinoFFT FFT = arduinoFFT();

unsigned int samplingPeriod;
unsigned long microSeconds;

double vReal[SAMPLES]; //create vector of size SAMPLES to hold real values
double vImag[SAMPLES]; //create vector of size SAMPLES to hold imaginary values

void setup()
{
  Serial.begin(115200); //Baud rate for the Serial Monitor
  samplingPeriod = round(1000000*(1.0/SAMPLING_FREQUENCY)); //Period in microseconds
}

void loop()
{
  /*Sample SAMPLES times*/
  for(int i=0; i<SAMPLES; i++)
  {
    microSeconds = micros();    //Returns the number of microseconds since the Arduino board began running the current script.

    vReal[i] = analogRead(0); //Reads the value from analog pin 0 (A0), quantize it and save it as a real term.
    vImag[i] = 0; //Makes imaginary term 0 always

    /*remaining wait time between samples if necessary*/
    while(micros() < (microSeconds + samplingPeriod))
    {
      //do nothing
    }
  }

  /*Perform FFT on samples*/
  FFT.Windowing(vReal, SAMPLES, FFT_WIN_TYP_HAMMING, FFT_FORWARD);
  FFT.Compute(vReal, vImag, SAMPLES, FFT_FORWARD);
  FFT.ComplexToMagnitude(vReal, vImag, SAMPLES);

  /*Find peak frequency and print peak*/
  double peak = FFT.MajorPeak(vReal, SAMPLES, SAMPLING_FREQUENCY);
  Serial.println(peak);     //Print out the most dominant frequency.

  /*Script stops here. Hardware reset required.*/
  while (1); //do one time
}
```

Figure 5. Code program

2.3. Investigation of Program Accuracy

The Arduino program's accuracy was trialed by measuring the tuning fork with a known frequency. This test is carried out by sounding the tuning fork near the microphone sensor, and the monitor will display the sound frequency generated, as shown in Figure 6.

After testing the Arduino program, the percentage error to indicate the accuracy of a measurement is calculated using equation (1).

$$\%error = \left|\frac{accepted\ value - experiment\ value}{accepted\ value}\right| \quad (1)$$

This design's accepted value is the known frequency value on the tuning fork, and the experimental value is calculated using the Arduino program. The results of calculating the percentage error in sound frequency measurement are shown in Table 1.

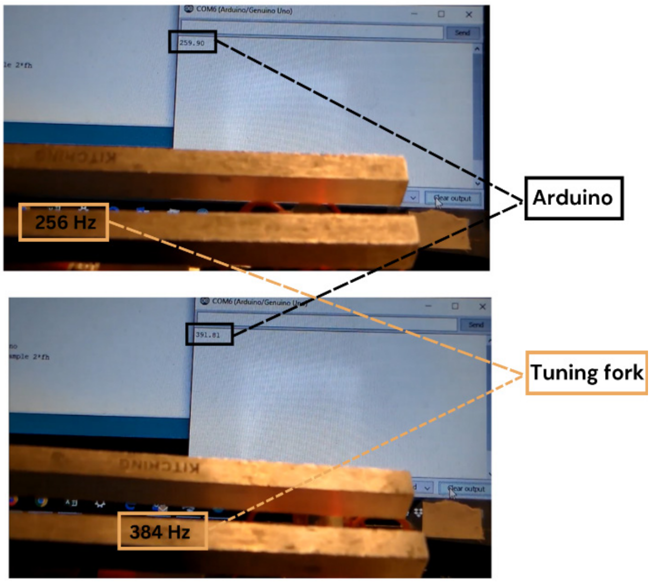


Figure 6. The result of frequency measurements between the tuning fork and Arduino

Table 1. Percentage errors using the Arduino program

Tuning fork (Hz)	Arduino (Hz)	Percentage error (%)
256.00	259.90	1.52
384.00	391.81	2.03
Average		1.77

Based on the calculation of the percentage error shown in Table 1, it is known that the percentage error for the Arduino program to calculate the sound frequency is 1.77%. The Arduino program is running well, with an error percentage of less than 5%.

3. Frequency Measurement of Angklung

After the Arduino program has been declared accurate in measuring sound frequency, the experiment is carried out to measure the frequency of the Angklung sound with various musical instruments, as shown in Figure 7. Angklung has unique tones ranging from pentatonic to diatonic. This study focuses on diatonic Angklung.

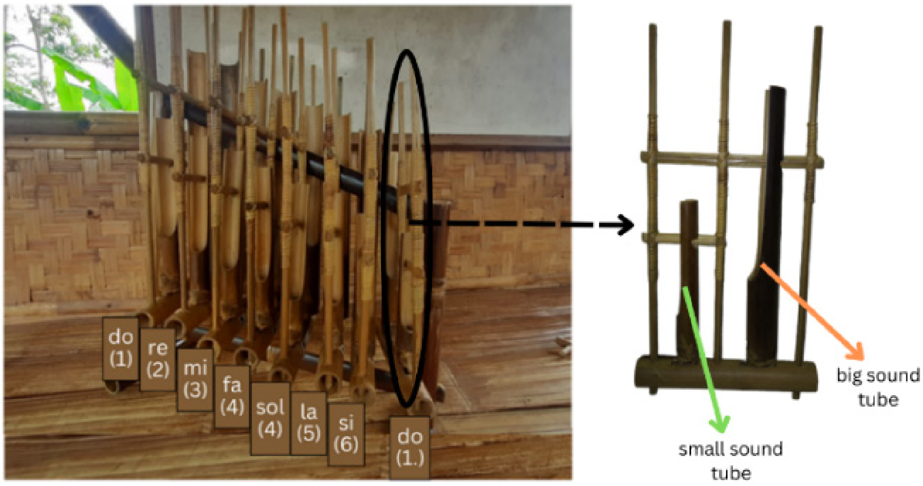


Figure 7. Musical instrument on diatonic Angklung

The design of a physics experiment using Arduino for frequency measurement of Angklung sound is shown in Figure 8. Frequency measurements were carried out on each Angklung sound tube. The small tube (s) are held while measuring the frequency of a big sound tube (*b*) to ensure that the sound is dominant and the frequency measurement is accurate.

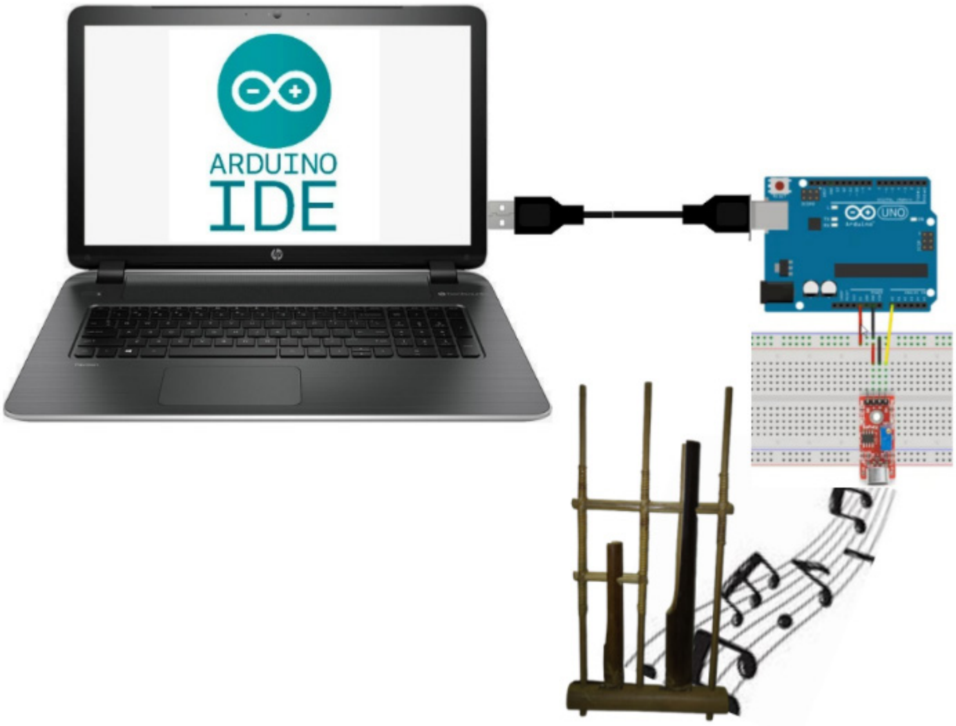


Figure 8. Design experiment of frequency measurement

When Angklung is shaken, it will produce a sound captured by the microphone sound sensor, as the design shown in Figure 8. The analog signal undergoes sampling and quantization (digitization), and the frequency is then showcased through the Arduino IDE Serial Monitor on the computer. The results of the frequency measurement of the big sound tube (f_b) and small sound tube (f_s) are shown in Table 2.

Table 2. The result of the frequency measurement of sound Angklung

Musical instrument	f_b (Hz)	f_s (Hz)
do (1)	268.23	139.68
re (2)	295.65	158.22
mi (3)	336.51	169.51
fa (4)	359.77	188.74
sol (5)	397.34	196.70
la (6)	448.25	236.23
si (7)	485.80	249.87
do ($\dot{1}$)	538.46	276.35

In addition, Marsenne's law found that frequency (f) is inversely proportional to the length of the string (L), as shown by Equation (2).

$$f = \frac{1}{2L}\sqrt{\frac{F}{\rho A}} \dots\dots\dots\dots (2)$$

Measurements of the diameter and length of the tube are conducted to ascertain their impact on frequency. The diameter is gauged using a digital caliper, and the length of the tube is assessed using a ruler, as depicted in Figure 9.

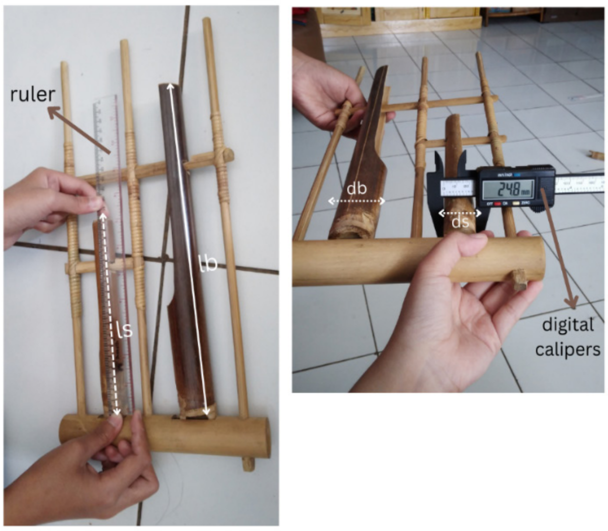


Figure 9. Measurement length of the sound tube (left); diameter (right)

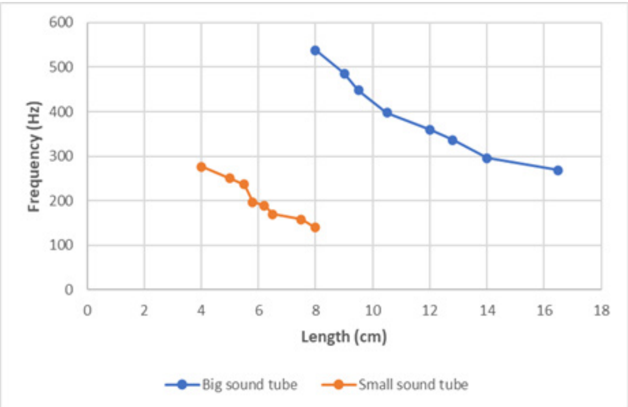
The length is measured using a ruler on the big sound tube (l_b) and small sound tube (l_s). Also, measuring the diameter using digital calipers on the big sound tube (d_b) and the diameter of the small sound tube (d_s). The results of measuring the diameter and length of the tube are shown in Table 3.

A graph plot is carried out to identify the effect of the length and diameter on the frequency of sound Angklung, as shown in Figure 10.

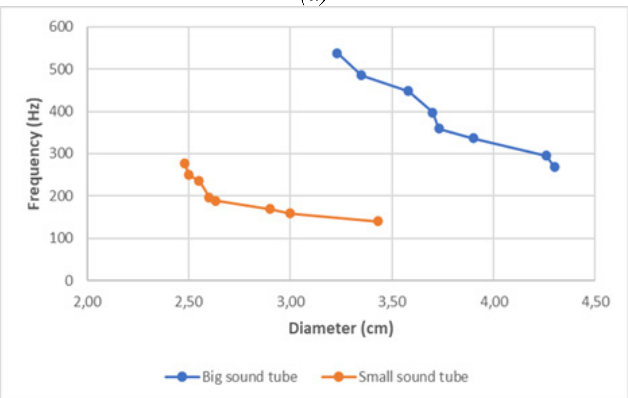
Table 3. The result of the measurement of the length and diameter

Musical instrument	d_b (cm)	l_b (cm)	d_s (cm)	l_s (cm)
do (1)	4.30	16.50	3.43	8.00
re (2)	4.26	14.00	3.00	7.50
mi (3)	3.90	12.80	2.90	6.50
fa (4)	3.73	12.00	2.63	6.20
sol (5)	3.70	10.50	2.60	5.80
la (6)	3.58	9.50	2.55	5.50
si (7)	3.35	9.00	2.50	5.00
do ($\dot{1}$)	3.23	8.00	2.48	4.00

Figure 10 shows a consistent pattern in the relationship between the diameter and length of the Angklung sound. In both cases, the frequency decreases as the length and diameter of the sound tube increase. Conversely, a shorter length of the tube corresponds to higher frequencies. A reciprocal relationship exists between the length and the frequency of sound. This relationship is observed in big and small sound tubes, demonstrating a consistent pattern.



(a)



(b)

Figure 10. Frequency effect (a) length to the frequency; (b) diameter to the frequency

The pitch of the sound is affected by the length of bamboo used for the resonance chamber in *Angklung*. [15]. As the length of the sound tube increases, the pitch interval or frequency range also rises [16]. The same pattern is also shown on the diameter to frequency. The more extensive the diameter is affected, the smaller the resulting frequency. These two observed patterns interpreted that the diameter and length of the tube have significantly impacted the frequency.

Integrating traditional musical instruments into the physics classroom can create a learning environment that resonates with students' everyday experiences, thus rendering the learning process more meaningful. [17], [18]. Previous studies also found that traditional musical instruments were utilized to illustrate sound concepts to students [12], [19], [20].

Experimental activities measuring sound frequency on *Angklung* using Arduino can help students carry out experiments anywhere without in the laboratory. The data obtained help students develop graphic representation skills and analytical thinking to interpret the graph's meaning. Although physics experiment activities using Arduino generally have advantages, such as facilitating experimental activities with affordable equipment and programming that students can do easily, they have some limitations. First, to connect the program code to the Arduino UNO, we need to install the Arduino IDE on the laptop, so the teacher must first give a tutorial to the students. Second, the set-up hardware Arduino UNO and sensors must match so that if inappropriate, it will cause program errors. The teacher must provide the circuit arrangement as clearly as possible to avoid these errors using videos or pictures.

4. Conclusion

Arduino can be used to design various physics experiments with affordable equipment. Using a microphone sensor can help physics experiment activities related to the concept of sound. Arduino is easy for students to use without basic programming knowledge. Teachers can design experiments covering a wide range of topics, allowing students to explore them beyond the confines of the laboratory setting. This experimental activity can be an alternative to train students' science process and analytical, critical, and computational thinking skills.

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