Use of Arduino and flute in teaching waves in a high school class

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Abstract

This work aims to use music as a teaching tool and, alongside it, utilize Arduino as a device to verify the components to be studied. The theoretical framework to be used is based on the Potentially Meaningful Teaching Units, UEPS approach, allowing for the construction of meaningful learning for students through problem-solving situations. A didactic sequence was developed for the study of the theme of sound waves and their components at the high school level. This sequence was applied over a period of four weeks, including an initial presentation of topics related to waves, the construction of an electronic system using Arduino, and the verification of phenomena based on musical notes. The data collection instruments for this research included questionnaires to assess students' prior knowledge, mind maps, and exercise lists. The Arduino programming board, which allows for the digitization of analog and digital electrical signals, was used in conjunction with a microphone module, enabling the integration of electronic physics with wave physics. As a result of this research, there were indications of learning through the interdisciplinary relationship between music and physics, which was made effective through the use of Arduino and the recorder flute.

Keywords: Physics teaching, UEPS, waves, music.

Uso do Arduino e da flauta doce no ensino de ondas em uma turma do ensino médio

Resumo

Este trabalho tem como objetivo geral utilizar a música como ferramenta de ensino e junto a ela, utilizar o Arduino como aparelho de verificação dos componentes a serem estudados. A base teórica a ser utilizada é através da abordagem das Unidades de Ensino Potencialmente Significativas UEPS, permitindo a construção da aprendizagem significativa dos alunos, a partir de situações-problemas. Foi elaborada uma sequência didática para o estudo da temática de ondas sonoras e seus componentes, em nível médio. Esta foi aplicada durante um período de quatro semanas, contando com apresentação inicial dos temas que envolvem ondas, construção do sistema eletrônico utilizando o Arduino e verificação dos fenômenos a partir das notas musicais. O instrumento de coleta de dados dessa pesquisa foram questionários para a verificação dos conhecimentos prévios dos alunos, mapas mentais e lista de exercícios. A placa de programação Arduino, que permite a digitalização de sinal elétrico analógico e digital, foi utilizada junto a um módulo de microfone, o que permitiu trabalhar de maneira a relacionar a área da física eletrônica com a física ondulatória. Como resultado desta pesquisa, foram obtidos indícios de aprendizagem a partir da interdisciplinaridade entre a música e a física, que se fez eficaz através do uso do Arduino e da flauta doce.

Palavras-chave: ensino de Física, arduino, UEPS, ondas, música.

1. Introduction

Physics teaching generally occurs in a boring way, only focused on textbooks, where concepts are presented automatically and continuously. This class style makes it difficult for the student to play an active role in building knowledge and bringing the content closer to their reality, leading to demotivation, which is stated by Moreira (2018) and Séré et al. (2003). According to Bzuneck (2009), motivation is an important process when teaching. Learning must encourage the student to be motivated by the topic and aim to learn more about it, both individually and in groups, and this occurs through the use of different resources within the classroom, through the teacher. These resources must involve methodologies that design a pleasurable activity to be carried out.

Another problem is the unavailability of a space to hold classes in which more complex mechanisms are used, such as a laboratory for experimentation. According to the National Institute of Educational Studies and Research Anísio Teixeira (Inep, 2019), around only 44% of high schools in Brazil had Science laboratories, as of 2019. And when these places are present, another problem what emerges is the lack of equipment and lack of maintenance. Leaving the teacher as the one who provides the materials, and who must adapt to the classroom space.

Taking these, factors into account it is necessary to search for methodological alternatives that help in a substantial number of results that encompass learning. Therefore, this work is justified in that it offers an opportunity not only to learn about Wave concepts, but also promotes a contextualization of a real application of Sound Waves integrated with the use of technology. In this way, knowledge related to the technological aspect is worked on, indirectly, since the student is also introduced to the operating principle of the set used.

The use of Arduino for teaching Physics has been widely documented in the literature, particularly with works that involve the understanding of Mechanical and Electromagnetic Waves, as in the works of Admiral (2020a), Admiral (2020b), Sousa et. al. (2020) and by Silveira & Girardi (2017), where in all these works we realize that the technological resource is a fundamental piece for measuring important wave parameters. This study aimed, to verify learning in the classroom using Arduino models in the study of Waves in a teaching unit in the municipality of Campos dos Goytacazes, State of Rio de Janeiro, Brazil.

2. Theoretical Reference

2.1 Waves

In Physics, Waves are disturbances that propagate in space or in a medium. Waves are classified according to their propagation direction and their nature. For direction, they are classified as transverse or longitudinal. Sound Waves are Mechanical Waves, therefore, they need a material medium for propagation. According to Piubelli et al. (2010) wave as a transmitted signal is observed between two points, with a variable speed, where it transports energy and momentum without there being direct movement of matter. The speed named by Kittel (1978) is described as "group speed" and represents the energy transmission in the medium, thus resulting in propagation. Furthermore, they are also classified as longitudinal, that is, they oscillate parallel to the direction of wave propagation by the Halliday (2016).

When talking about sound waves we are talking about music. According to Bohumil (1996) the music is art of combining sounds and silence simultaneously and successively, with order, balance and proportion within time. To have music, you need something that produces sound and for that we have specific musical instruments, such as the recorder. This type of flute was disseminated through the musician Arnold Dolmetsch and is currently an instrument widely used in musical education, as it is cheap and easy to use (Benassi, 2013).

2.2 Arduino

Arduino is a microcontroller programming board, which has an open source hardware and software that is easy to use. Using a microcontroller on Arduino boards, it is possible to read information and transform it into some action, for example: using a light sensor to activate a lamp (Arduino, 2018).

Figure 1. Illustration of Arduino UNO Ver 3. Source: Arduino, 2018.

The characteristics of Arduino allow the development of simple and cheap projects, thanks to the low cost of the boards and the programming environment being simple and easy to understand. Additionally, Arduino software can run on cross-platforms (such as Linux, Mac and Windows), expanding access across operating systems.

2.3 Ausubel's Meaningful Learning Theory and Potentially Significant Teaching Units (PSTU)

For Ausubel, the most important point when it comes to learning is what the individual already knows. Previous knowledge influences the construction of new knowledge. In this process, the teacher plays the role of mediator of concepts, in order to promote a progressive study and relationships, in which the student has an active role (Moreira, 1999).

The Meaningful Learning Theory is linked to Potentially Significant Teaching Units. According to Moreira (2011), PSTU are teaching sequences that focus on meaningful learning, stimulating the search for answers, through the construction of problem situations for the application of acquired knowledge. This taking into account the student's prior knowledge.

The construction of the PSTU, on a given topic, must follow a sequence that initially externalizes the students' prior knowledge, so that new knowledge can then be contextualized based on previous knowledge. The construction of the complexity of the topic will be progressive according to the resolution of problem situations (Moreira, 2011).

3. Material and Methods

3.1 Search type and target audience

This research is qualitative. According to Moreira (2000), qualitative research aims to understand the students' perspective on a given subject, focusing on the actions they will take with the knowledge in their experiences. In this regard, the teacher's role is to interpret the development of students according to problem situations. The observational experiment is based on a class of students as the target audience, this experimental class presents educational development as they are in the 2nd year of High School in a Comprehensive Education school unit Colégio Estadual Nelson Pereira Rebel, located in the city of Campos dos Goytacazes, State of Rio de Janeiro, Brazil. The application took place during the first two months of school and had around ten to twelve students in the class. It is worth mentioning that there were meetings in which some students were not present. Furthermore, this class already knew Arduino, however, with basic knowledge acquired through activities proposed by the school's Physics teacher.

3.2 Code and circuit construction

The circuit used in this study was created with a microphone module (identification number KY-038, Joy-IT, England). This module is made up of an electret microphone, an amplifier and a comparator that emits light when there is a failure in the module. This module has the ability to measure sound intensity and through the Arduino programming board, the signal produced by the module, both analog and digital, can be digitized (Figure 2).

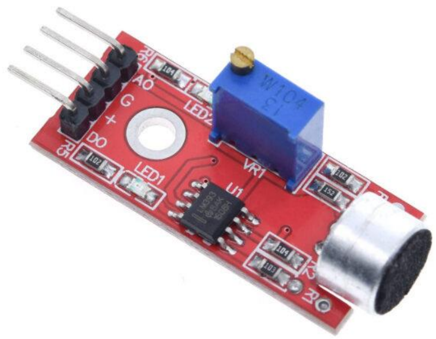


Figure 2. KY-038 Module. Source: https://lojinha.vamuino.com.br/produto/modulo-sensor-de-som-ky-038/

The module shown in Figure 2 was connected to the Arduino via an analog input. Among the components that are part of the module we can highlight the electret microphone, an element that captures sound. It is responsible for converting the mechanical vibrations of the air into electrical signals, through the manifestation of its piezoelectric property. This signal in turn, is amplified by the LM-393 Integrated Circuit and is then sent to the analog port where the reading will be taken. It can also be seen, in Figure 2, a small blue box, which is a potentiometer, through which the sensitivity of the sensor is adjusted.

To build this circuit, three jumpers were used, connected to the analog input, the gate and the power input, respectively. The model of this circuit brought greater mobility to the acquisition of flute waves, as it was able to take the sensor to the exit of the "foot" of the flute (Figure 3).

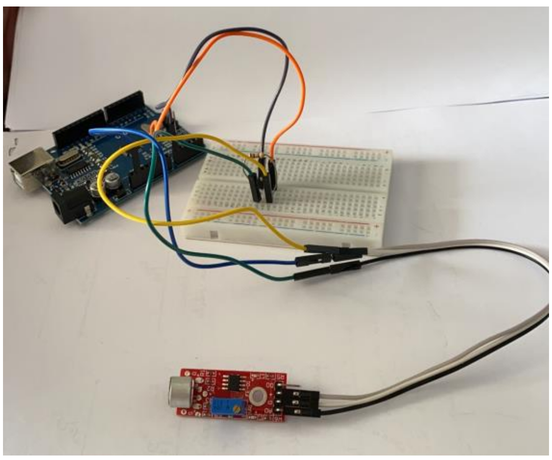


Figure 3. Circuit with the KY-038 sound module. Source: Authors, 2023.

The code used is described in (Figure 4). According to the code, the sensor captures the sound of the flute every 0.5 milliseconds (ms), via the analog input.

Figure 4. Circuit code with the KY-038 sound module. Source: Authors, 2023.

3.3 Didactic sequence and application

The construction of the didactic sequence had the PSTU as a basis, initially prioritizing working with the students' prior knowledge, so that from this, there would be a gradual construction of new knowledge on the topic of Waves. This sequence was divided into four classes.

In the first class, with the aim of externalizing the students' prior knowledge, a questionnaire was carried out on the topic of Waves. With the completion of this, there was a moment of expository class on this topic with a questionnaire (Figure 5). Didactic sequence and application:

What is sound?

____

____

In Physics, there are types of waves, such as Electromagnetic Waves and Mechanical Waves. Try to present at least one characteristic that can differentiate these waves from each other.

____

What do you think would be the relationship between music and these waves?

____

Frequency is an important component when we talk about waves in Physics. What does the word 'frequency' remind you of?

____

When we talk about music, we hear about timbre. What does timbre mean to you?

____

____

Figure 5. Preconceptions questionnaire. Source: Authors, 2023.

For the second class, the Arduino board was introduced, presenting how it works and why it is used. To do this, we used the school's computer laboratory and the Arduino kits provided by the school to build simple circuits. With this, it was presented how the electrical connection works on the breadboard, the resistors, the LEDs and Buzzer components, which is seen in (Figure 6).

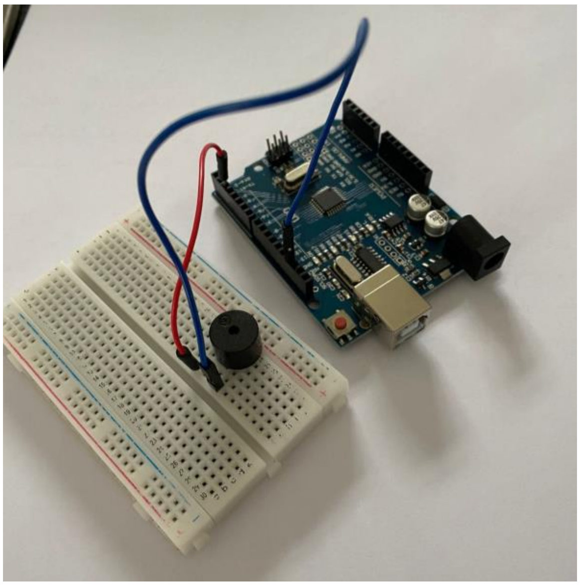


Figure 6. Image of the circuit with the Buzzer. Source: Authors, 2023

At the end of the second class, the students were divided into three groups, each group using a computer available in the laboratory, to assemble systems with LEDs. For this, the Online Tinkercad Autodesk platform was used, so that each group could set up a "traffic light" system with LEDs (Figure 7).

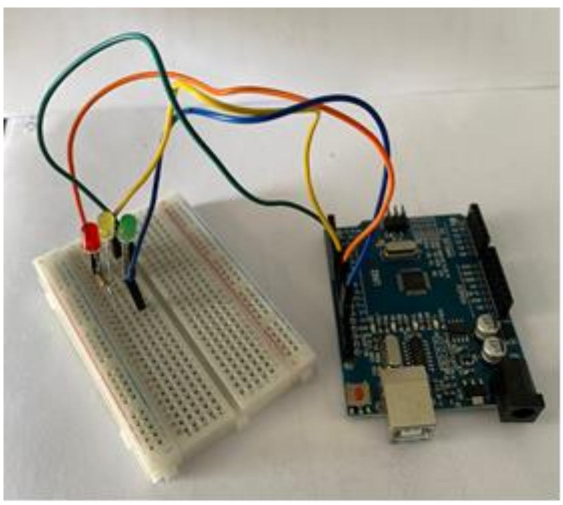


Figure 7. Example image of a circuit with LEDs. Source: Authors, 2023.

In the third class, we worked with Arduino and presented the KY-038 sensor. This was the sensor used in the circuit built by the researcher and supervisor of this study. This circuit was used to capture the sound waves produced by a recorder and a guitar. Using the Arduino IDE application, which is an open development platform, in the Serial Monitor and Serial Plotter tab, it was possible to evaluate the wave formation of the notes formed by these instruments (Figure 8).

The pattern shown in Figure 8 indicates the frequency of the musical note, where these signals were displayed on the serial plotter. The horizontal scale represents time. In Figure 4 where the program code is presented, we can see that near the end, the delay command (0.5 ms), this command indicates the time interval between measurements in ms. Each of the points on the graph in (Figure 8) is separated by the next point with that same time interval.

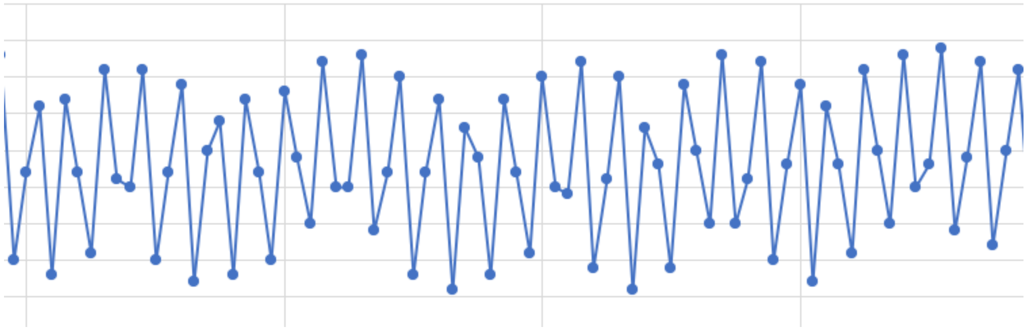


Figure 8. “B” Note Wave. Source: Authors, 2023.

On the vertical axis it presents a scale of the Arduino system itself, at its analog input where it admits a signal varying between 0-5 Volts (V). At this resolution, the system is able to subdivide the signal into 1024 parts (approximately 49 millivolts (mV)), thus, it presents a signal between 0 and 1024 on its vertical scale. In Figure 9 we can see another musical note “D”.

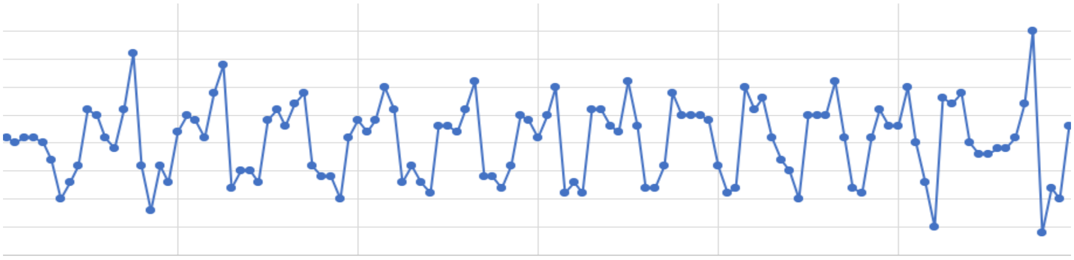


Figure 9. “D” note wave. Source: Authors, 2023.

With the wave formation drawing, the topics of elements of a Wave (crest and trough), frequency (f) in hertz (Hz) and wavelength were recapitulated. Referring us to the topic of low and high notes, and the characteristics of these notes. We end the class with an explanation of the difference between these notes, in terms of wavelength and frequency, in which low waves have a longer wavelength and lower frequency, when compared to high notes, which have a shorter wavelength and frequency “high”.

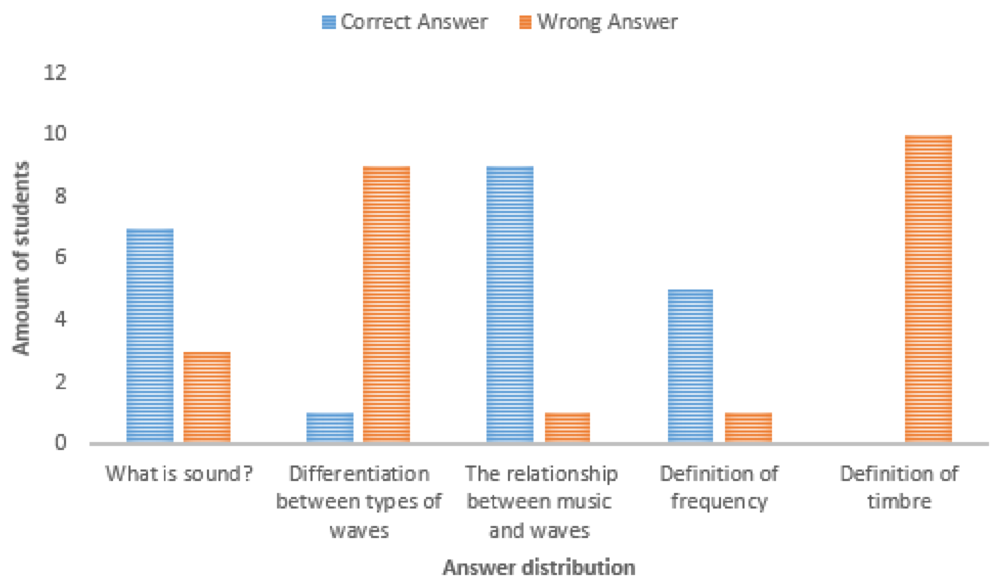
In the fourth and final class, during the first period of class, the students created mental maps on the topic of Waves. It was then explained to the students how writing a mind map works through a model that they sketched on the board, as an example for the students. In the second period of class, a list of exercises on the same topic was applied. This list served as an individual assessment activity, containing five questions involving both discursive and objective questions.

4. Results and Discussion

As in other works in the literature, such as Admiral (2020b), the results of the data collected using Arduino were well compatible with what was expected in theory. In a complementary way to the methodology used by Sousa et al. (2020), also using Arduino, but for a wave on a string, has a very interesting degree of precision in the experimental results. In relation to the experimental results from the apparatus, we can highlight the practicality obtained by displaying the information graphically, and in real time.

Regarding the learning results obtained, the Bardin (2011) analysis was used to evaluate the answers to the first questionnaire, as in the list of exercises, dividing these answers into two categories: correct associations and incorrect associations (Graphic 1).

According to Bardin (2011), this method proposes a qualitative analysis of the research, based on text data. In this process, the researcher defines categories according to textual records that present similar characteristics, resulting in the interpretative analysis of these characteristics. Below, we have an evaluation of the responses obtained through the first questionnaire administered.



Graphic 1. Analysis of the preconceptions questionnaire. Source: Authors, 2023.

From the analysis of the responses (Table 1), it was positively verified that the majority of students were able to associate sound with waves, relate music as something formed by waves and even characterize the frequency as a repetition. Furthermore, the students had no knowledge of the definition of timbre and the vast majority of them were unable to describe what differentiates electromagnetic waves from mechanical waves. Regarding the assessment of the list of exercises, no student got all the questions right, but the majority performed well. With the exception of just one student who did not get any questions correct. In exercise 1, the majority of students got it right, where there was an association between mechanical waves and the material they need to propagate.

Table 1. Categorization of answers from exercise 1.

Exercise 1 - 1 - Select the correct alternative regarding the characteristics of the wave types: a) Electromagnetic waves are Waves that require a medium for propagation. b) Sea waves are mechanical waves and sound waves are electromagnetic Waves. c) Mechanical Waves are those that need a propagation medium. d) The difference between mechanical and electromagnetic Waves lies in the direction of their propagation.	
Test answer: c) Mechanical Waves are those that need a propagation medium.	
Right answer	c) Mechanical waves are those that need a propagation medium. (student 1, student 2, student 3, student 5, student 8).
Incorrect answers	b) Sea waves are mechanical waves and sound waves are electromagnetic waves. (student 4, student 6, student 7, student 9).

Source: Authors, 2023.

In exercise 2, some of the students got the question completely and partially correct. Those who didn't get it right diverted the answer to the property of high and low sounds of musical notes (Table 2).

Table 2. Categorization of responses from Exercise 2.

Exercise 2 - Fill in the gapes: In transverse waves the direction of vibration is ______________ to the direction of wave propagation. In longitudinal waves the direction of vibration is ____________ to the direction of wave propagation.	
Test answer: Perpendicular/parallel.	
Right answer	Perpendicular/parallel. (student 1, student 2, student 5, student 9).
Incorrect answers	High-pitched sound/low-pitched sound. (student 3) Vertical/horizontal. (student 4) Acute/severe. (student 6, student 7) Perpendicular/propagation. (student 8)

Source: Authors, 2023.

Exercise 3 was the only mathematical question on the list. To solve it, it is necessary to understand the wave propagation speed equation (Equation 1).

$$v = \lambda \, . \, f \quad (1)$$

In this case half of the students demonstrated that they knew that there is multiplication in this equation, but they made mistakes in finding the correct frequency result. The frequency result which they all associated with “1800 waves per minute”, would have to be divided by 60 s in order to be converted to the result of 30 Hz (Table 3).

Table 3. Categorization of answers from Exercise 3.

Exercise 3 - A given source generates 1800 waves per minute with a wavelength equal to 8 m. What is the propagation speed of these waves?	
Test answer: v = 240 m/s	
Right answer	–
Incorrect answer	v = 1800 . 8 = 14400 (student 1, student 2, student 5) v = 1800/8 = 225 (student 3, student 6, student 8, student 9)

Source: Authors, 2023.

Exercise 4 was on the topic of timbre in which the class almost unanimously managed to get the correct definition of this term, which already appears to be an advance in this knowledge when compared to the answers to the Preconceptions Questionnaire (Table 4).

Table 4. Categorization of responses from Exercise 4.

Exercise 4 - (ENEM/2015) When you hear a flute and a piano emitting the same musical note, you can differentiate these instruments from each other. This differentiation is mainly due to the

a) sound intensity of each musical instrument.

b) sound power of the sound emitted by different musical instruments.

c) different propagation speed of the sound emitted by each musical instrument.

d) timbre of the sound, which causes the waveforms of each instrument to be different.

e) sound height, which has different frequencies for different musical instruments.

Test answer: d) timbre of the sound, which causes the waveforms of each instrument to be different.

Right answer	d) timbre of the sound, which causes the waveforms of each instrument to be different (student 1, student 2, student 3, student 4, student 5, student 7, student 8).
Incorrect answer	c) different propagation speed of the sound emitted by each musical instrument (student 6). e) height of the sound, which has different frequencies for different musical instruments (student 9).

Source: Authors, 2023.

Exercise 5 (Table 5) was a discursive question that required students to explain the differentiation of low and high notes according to frequency. In addition to presenting an inversely proportional relationship between frequency and wavelength, according to the wave speed equation. In this regard some of the students correctly presented the association of high notes having a high frequency and low notes having a low frequency.

However, they related frequency and wavelength wrongly, placing these characteristics as directly proportional. Highlight is the answer from student 5, with the only answer being completely correct ("Low note = frequency of 280 Hz. High note = frequency of 340 Hz. The low note is C. The high note is B. The longest length of wave is the serious one, as the waves are further apart"). In which he explained the relationship between frequency and the degree of treble or bass, he associated these degrees with the notes and explained the wavelength format in the bass note.

Table 5. Categorization of responses from Exercise 5.

Exercise 5 - We studied sound notes and the differences between low sounds and high sounds. Assuming that the note B has a frequency of 340 Hz and the note C has a frequency of 290 Hz, which of these notes is the bass note? What is the high note? Regarding wavelength (λ), which has the longest wavelength?

Test answer: The low note is the C note and the high note is the B note. The C note has a longer wavelength as it has a lower frequency compared to the B note.

Righht answer	Low sound = C for low frequency. High-pitched sound = Si for high frequency (student 3). The note with the highest bass is C with 290, being smaller than the high note B with 240 (student 4). Low note = Frequency of 280 Hz. High note = Frequency of 340 Hz. The low note is C. The high note is B. The longest wavelength is low, as the waves are separated (student 5). The note B is sharp because it has a higher frequency. The note C is low because it has a lower frequency (student 8).
Incorrect	Note Si with longer wavelength being larger (student 3). The B note is longer (student 4). Si because

answer	it has a longer wavelength (student 8).

Source: Authors, 2023.

5. Conclusions

Based on the results obtained through this application, it was possible to validate the benefits of using Arduino in the teaching and learning process. This platform allowed the visualization of sound waves produced by both the students' voices and the musical instrument. This meant that students could learn and identify the characteristics of a wave in person. It is worth noting that the school's good infrastructure positively boosted practice with Arduino, through the Arduino kits and computers available in the school's computer laboratory. This allowed students to have an active role in building circuits with Arduino.

The proposed didactic sequence allowed working on the students' prior knowledge, correcting erroneous concepts and teaching concepts that they did not yet know. Through the analysis of the answers to the pre-conception questionnaire and the answers to the list of exercises, the students' progress in learning concepts about Waves is seen, comparing them in the first meeting with them in the last meeting.

6. Acknowledgments

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7. Authors' Contributions

Jade Barbosa Nunes was responsible for conducting the research in the school environment, as well as for designing and analyzing the questionnaires. *Tiago Desteffani Admiral* provided guidance in the development of the prototype, directed the construction of the didactic sequence, and reviewed the manuscript.

8. Conflicts of Interest

No conflicts of interest.

9. Ethics Approval

Not applicable.

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