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Proyecto de un dispositivo electrónico en el contexto STEAM para relacionar resultados de mediciones físicas con sonidos, y su análisis a través de la percepción de profesores de Ciencias

Design of an electronic device in the STEAM context to relate results of physical measurements with sounds, and its analysis through science teachers' perception

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RESUMEN

Este trabajo presenta el proyecto y detalles de un sistema electrónico, con aspectos de software y hardware, para generar sonidos asociadas a los valores de mediciones de fenómenos físicos, como temperatura u otros. La propuesta tiene potencial para crear actividades divertidas y motivadoras en el aula, incentivando a los estudiantes a pensar en la asociación directa entre aspectos científicos y tecnológicos. El proyecto tiene un enfoque STEAM (Ciencia, Tecnología, Ingeniería, Artes y Matemáticas) donde una placa de procesamiento Arduino mide el valor de un fenómeno físico con un sensor, calcula una relación matemática para definir una frecuencia de sonido asociada al fenómeno y luego envía una señal de salida para excitar a un altavoz. El sistema electrónico propuesto es sencillo, pero este tema puede no resultar muy familiar para muchos profesores de ciencias y entonces este artículo les explica paso a paso para permitir su efectiva comprensión y posterior uso en el aula. Además, este artículo también presenta una discusión con profesores de ciencias para analizar su percepción cuando se les reta a comprender y analizar el sistema propuesto desde una perspectiva docente, donde se resaltaron preocupaciones acerca de cuestiones como la falta de capacitación y de materiales, pero donde también indicaran positivamente que la propuesta es factible y tiene un potencial docente satisfactorio.

PALABRAS CLAVE

STEAM; Sensores; Arduino; Relaciones matemáticas; Tecnología; Habilidades digitales; Tecnología Educativa; Formación de profesores.

ABSTRACT

This work presents the design and details of an electronic system that uses software and hardware aspects to generate sound frequencies associated with the measurement of physical phenomena, such as temperature or other. It has potential to create fun and motivation activities in the classroom, encouraging the students to think about the association between scientific and technological aspects. It is based on

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a STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach where an Arduino processing board measures a physical phenomenon value with a sensor, computes a mathematical relationship to define an associated sound frequency, and next sends an output signal to excite a speaker. The proposed electronic system is simple, but this subject may not be very familiar to many science teachers and, therefore, this article explains it step by step to allow its effective understanding and later usage in the classroom. Furthermore, this article also presents a discussion with science teachers in order to analyze their perception when they are challenged to understand and analyze the proposed system under a teaching perspective, which emphasized concernments such as the lack of training and materials, but positively indicates the proposal is feasible and has a satisfactory teaching potential.

KEYWORDS

STEAM; Sensors; Arduino; Mathematical relationships; Technology; Digital skills; Educational technology; Teachers training.

1. INTRODUCTION

This work presents an electronic system with educational purposes to express physical measurement results through sounds, which differs from conventional electronic instruments that usually show results numerically in displays. The idea is to propose a system whose understanding, assembling and use can be feasible even for teachers with little experience in the area. It has a multidisciplinary approach that allows the teachers to introduce different topics in the classroom, such as:

1. Sensors.
2. Concepts of measurements.
3. Physical details of the measured phenomenon.
4. Arduino processing boards.
5. Software design.
6. Electronic circuits assembling.
7. Data acquisition and control.
8. Mathematical relationships.
9. Music theory
10. Human earring frequencies.

For example, among the items above, the sensors explanation in the classroom can allow the discussion of interesting subjects such as the measured phenomenon definition, its influence on our daily lives, and sensor types, ways to measure the phenomenon, etc. This type of approach promotes the pedagogical integration of technologies and specific scientific contents, whose association is a strategy that can improve the learning effectiveness (Aliyu et al., 2021; Zha, 2021) and which can meet the idea of TPACK (Technological Pedagogical

Content Knowledge) that analyzes the use of pedagogical practices in educational environments with technology (Koehler, & Mishra, 2009).

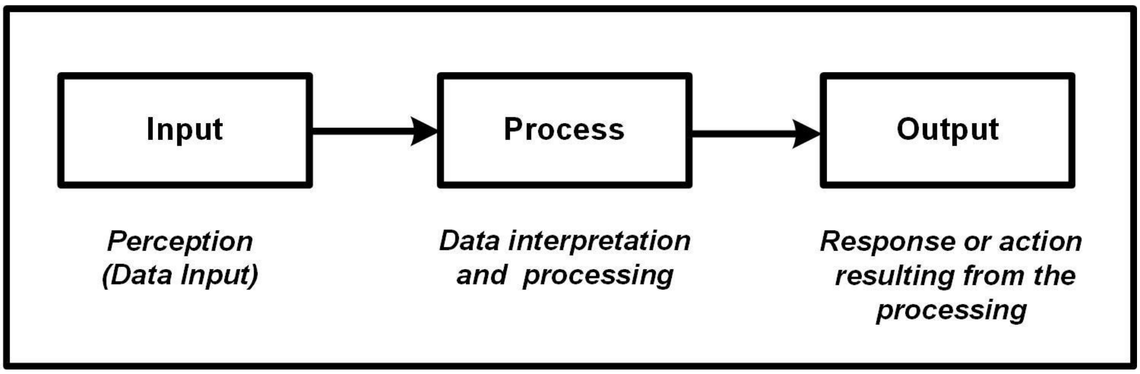
This article also considers interesting to emphasize the presented work could also perhaps be applied in the area of special education for students with visual impairments, where they could analyze a physical phenomenon variation through sounds.

The present work was motivated by other previous correlated works, such as Garrido et al. (2020) that presented the conversion of selected infrared absorbances of well-known molecules into audible frequencies, Munukutla at al. (2022) that presented the conversion of NMR spectra into a collection of associated piano notes, LoPresto (2013) that used musical intervals to demonstrate superposition of waves, and Costa & Fernandes (2019) that used sounds to indicate pH values. However, the present work has a differential that is its flexibility to allow an easy adjustment to allow the measurement of different physical phenomena and the use of different mathematical relationship to compute the sound frequencies according to the measurement results.

This work differential also intends to motivate teachers to change the proposed electronic experiment according to their specific teaching interests, which may represent a challenge for science teachers with few backgrounds in hardware and software. The training of science teachers tends to focus more on pedagogical and scientific content than on technological aspects (Tican, & Deniz, 2019; Weidlich, & Kalz, 2023), and therefore, teaching works based on technology must consider the teachers' knowledge and their emotional willingness to use technology. For example, Badia & Iglesias (2019) presented a study where 26.7% of the interviewed science teachers reported fear or even anger towards teaching with technology. Assuming it as a real problem, this work believes a possible solution to attenuate it can start with the study of a practical system whose main attributes are simplicity, focus on the solving a real problem, and permission for learners to change it constructively according to their needs, and, in this context, the present work includes all these attributes.

For teachers with little technological knowledge, the understanding how these systems work becomes a hard task and consequently they are frequently analyzed as "closed boxes", which was discussed by Dagan (2022) whose work emphasized the importance of teachers developing mental models to try to represent the structure of technological systems and consequently better understand them. In fact, this idea can be inserted in the *General System Theory* that is an interdisciplinary field where a large and complete structure is organized according to an arrangement of smaller elements that relate to each other and compose a system as a whole (Hammond, 2019; Orgill, 2019). In this context, the present work proposes the use of a model called *Input-Process-Output* (IPO) that is shown in figure 1 and defines a system structuration in three basic parts, which allows an objective description of factors such as flow of information, sequence of activities, operational parts detailing, and general system analysis (Chang, & Tsai, 2021; Leyesa et al. 2022; Triantafyllou, & Sapounidis, 2022).

Figure 1. The Input-Process-Output (IPO) model.



For a practical approach, this work uses the IPO model as:

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1. Input: It is a sensor to measure a physical phenomenon.

2. Process: It is a processing unit to compute the mathematical relationship between the phenomenon value and the sound frequency.

3. Output: It is a speaker to generate the sound waves.

The proposed system could measure different *physical phenomena* (P), but this work chose temperature because it is a phenomenon interesting for educational approaches because it can be associated with several physical concepts, has high relevance in the everyday life, is simply to understand, and is easy to measure with electronic systems.

This work processing unit is an Arduino board, which is a small open-source platform used for building electronics projects that require data processing. The speaker is an electronic device called passive buzzer that converts electric signals to audio and has a small size and low cost.

The Arduino boards have general advantages as low-cost, low power consumption, small size, easy interfacing, and have lots of examples on the Internet and in technical books. These advantages make them very interesting for the design of teaching apparatus for science education, which potentials of hands-on Learning focused on application in real-life problems, interdisciplinary approaches that allow the association of several fields, and collaborative work that can promote an exchange of knowledge and social engagement (Budi, 2018; Bashir, 2019; Negrete, 2023).

The next sections will explain and discuss details of the hardware, software, and mathematical relationships, using a practical approach whose goal is to make easier their understanding, even for teachers with only little experience in this technology.

2. MATERIAL AND METHOD

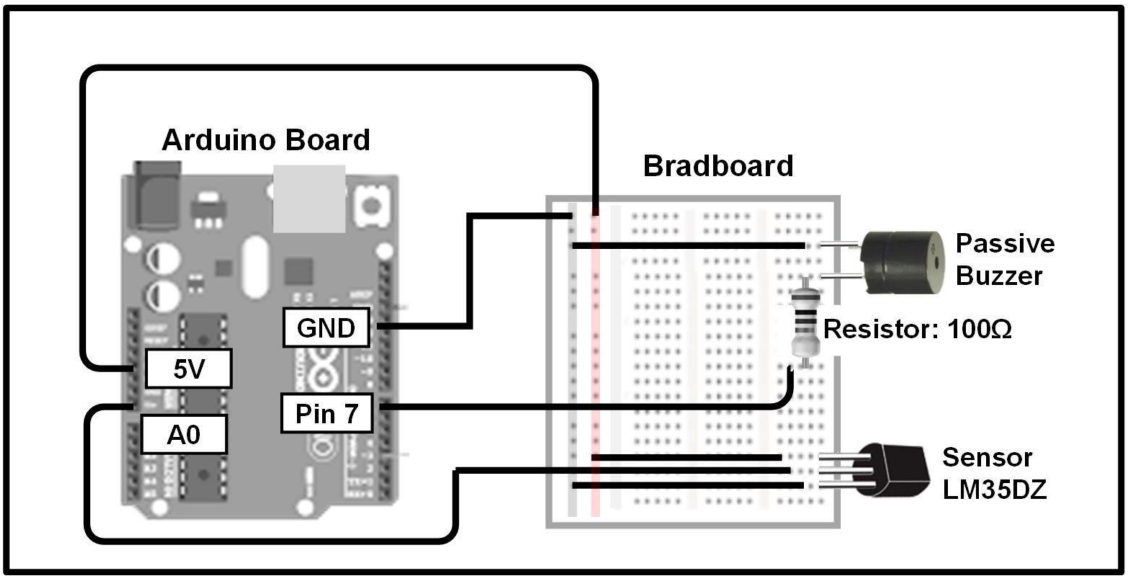
This section shows how to transform concepts above into practices, detailing the aspects of hardware, software, and the mathematical relationships.

2.1. The Proposed Electronic System

Figure 2 shows the proposed electronic system schematic that uses a temperature sensor LM35DZ, which presents low cost and measures temperatures in an interval from 0 to 100 °C. It also shows the electronic circuit

assembled on a device called breadboard or protoboard, which is a physical basis to prototype electronics circuits projects with simple wires.

Figure 2. The electronic system and assembled circuit.



To vary the measured temperature and consequently the generated sound, the students can move the sensor closer to and away from hot or cold objects, or in a more fun way, they can also cover the sensor carefully with their fingers, which causes its forced heating and as soon as the sensor is uncovered, its temperature drops naturally.

The proposed circuit may seem relatively complex for teachers with no experience in electronics, but, in this case, there are alternatives as:

1. The proposed electronic circuit is simple and any person with a minimum electronic background, such as a simple hobbyist, can help this assembling.

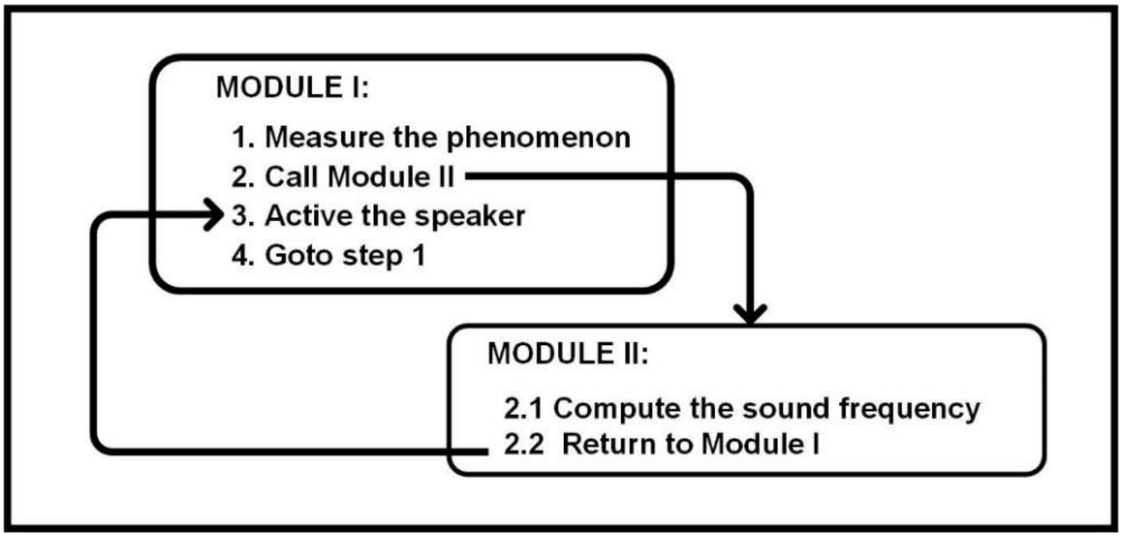
2. Inexperienced teachers can learn about electronic circuit assembling with a self-taught training based on Internet videos, which is an action that deserves a special comment because the self-taught is an ability that becomes more important every day to allow that teachers can keep up to date with technological advances (Carvalho, 2020). Some people may not feel enthusiasm for the self-taught, and therefore, they should look for an emotional change to create a self-motivation, as opposed to a passive behavior (Edwards, 2022). In this context, it is interesting to emphasize the Massive Open Online Courses (MOOCs) relevance, which can offer high-quality courses and meet numerous geographically dispersed students.

3. A third option are the in-service teacher trainings, which may be ideal because they can create a solid basis for the teachers understanding of technological concepts through pedagogically structured programs, which usually encourages teachers to put the acquired knowledge into practice (Schina et al., 2021). Despite its relevance, the in-service teacher training offer, structure, and quality can vary significantly from country to country, or even from different regions in a country, and therefore, the teachers must analyze and find opportunities according to their local reality

(Tümkaya & Miller, 2020; Baecher & Chung,2020). The analysis of a course quality is a very broad topic, but it is possible to check at least basic items, such as the training content and goals, what the student should know after the course, the prerequisites (which is useful to know before starting the course), weekly study time, course duration, cost, certificates, reputation and educational details (Gomes et al., 2022).

The Arduino requires software to operate, and figure 3 shows a proposed algorithmic structure with only two modules, where the first module measures the physical phenomenon, calls the second module to compute a sound frequency, and next sends an output signal to active the speaker.

Figure 3. The modular algorithmic structure.



Finally, figure 4 shows an Arduino program where each module is detailed. the Module I and Module II are referred as “loop” and “function sound”, respectively. Besides, there a module called “setup” that is compulsory in all Arduino programs to perform setup operation, and a “header” for variables and other fundamental definitions. The Module II wasn’t filled because it will be written according to the mathematical relationship selected by teachers according to the models described in the next sections. The teachers can also change the Module I content to measure different other physical phenomena, such as humidity or light, using other sensors. Therefore, both Modules content can be changed freely by teachers, which represents the proposed system flexibility.

Figure 4. The Arduino software.

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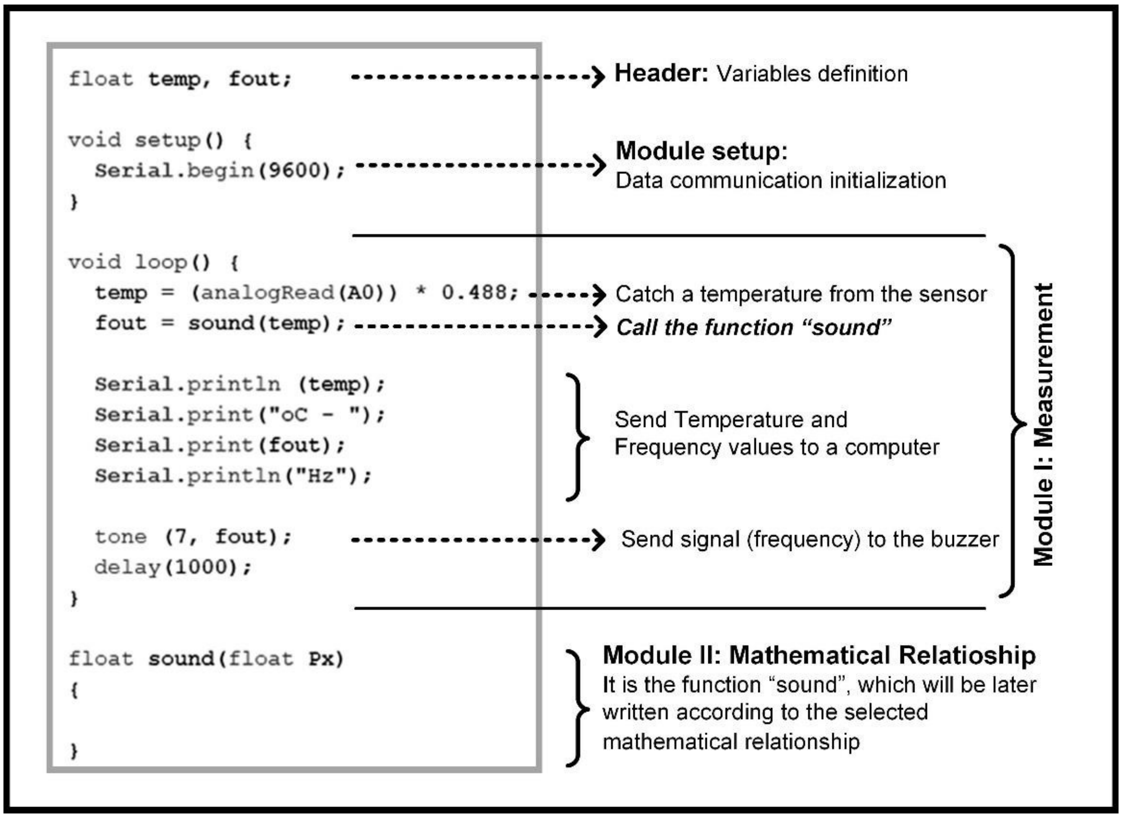

2.2. The Human Audible Spectrum

The relationship between numerical values from measurements and sound frequencies must consider:

1. The human audible spectrum: It represents the human's hearing response that theoretically is from 20 Hz to 20 kHz, with a best audible sensitivity subinterval from 800 Hz to 7 KHz (Alves-Pereira, 2019).

2. The minimum frequency variation: People have a limited ability to detect sound variations when the frequency variation is relatively small, and theoretically the smallest detectable frequency variation is at about 0.3 % for frequencies between 250 Hz and 4000 Hz (Sek, & Moore, 1995; López- Poveda 2014; Yao et al., 2022). This work refers to it as relative resolution (Ar) because the International Vocabulary of Metrology defines resolution as the "smallest change in a quantity being measured that causes a perceptible change in the corresponding indication" (Perea Martins, 2019).

When the phenomenon variation (Δp) is tiny, the mathematically related frequency variation may be tiny too and it may not reach the minimum required variation of at least 0.3 % to allow its perception by a human listener. Therefore, it requires a minimum phenomenon variation to cause a sound frequency variation of at least 0.3 %, which this work refers as *phenomenon resolution* (Pr).

2.3. The linear relationship

The natural human ear response is nonlinear, and therefore the linear relationship doesn't follow it, but it is simpler to explain in the classroom and can

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work well in several teaching experiments, which justify its discussion. The straight-line equation is:

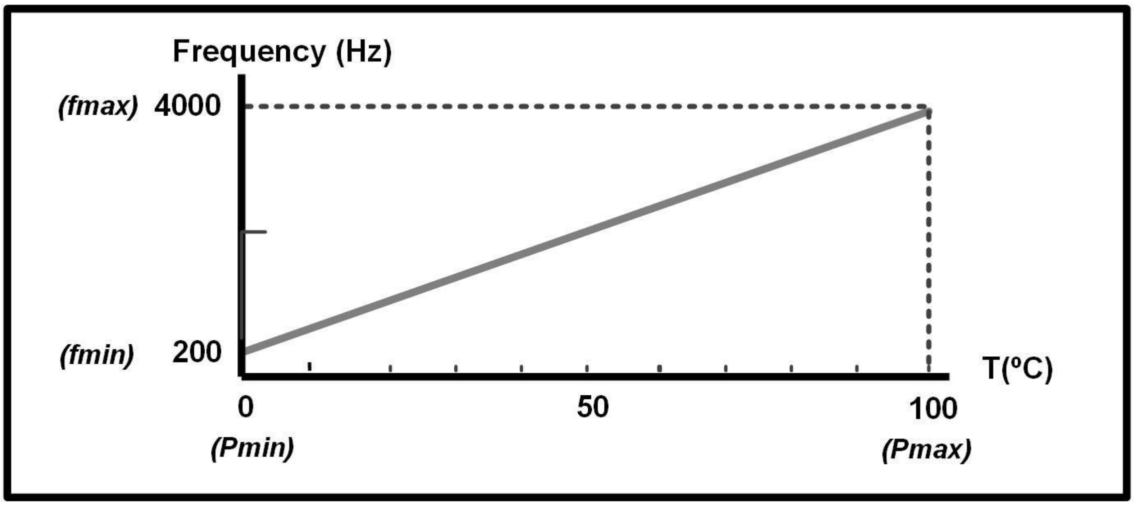
y = mx + C

Where *C* is the y-intercept, and *m* is the gradient computed from two points as

Δy/Δx.

In the present case, the sensor defines the smallest (Pmin) and highest (Pmax) operational phenomenon values, which are 0 and 100 ºC for the sensor LM35DZ. Besides, the system designer fixes the smallest (fmin) and the highest (fmax) operational frequency values, which were empirically fixed at 200 Hz and 4 kHz in this work. Figure 5 shows this relationship, and figure 6 shows the respective function sound.

Figure 5. Temperature and frequency relation



Based on figure 5, equation 1 is rewritten as:

$$fx = \frac{(fmax - fmin)}{(Pmax - Pmin)} Px + C \qquad (2)$$

Where Px is the measured phenomenon, and fx is the sound frequency related to Px.

$$fx = \frac{4000-200}{100-0} Px + 200 = 38Px + 200 \qquad (3)$$

Figure 6. The function sound for the linear relationship.

```
float sound(float Px)
{
  float freq;
  freq = 38 * Px + 200;
  return freq;
}
```

2.4. Analysis of the Sound Variation Perception

The sound variation perception requires a frequency variation of at least 0.3 %, and therefore, it is necessary a temperature variation (Pr) that causes this sound variation magnitude, computed as:

$$Pr = \left|\frac{(38 * Px + 200) * 1.003}{38} - Px\right| \tag{4}$$

Pr follows the figure 5 trend and isn't constant over the measurement interval. For example, for Px at 25 °C, the Pr value is at about 0.1 °C, and the perceptible sound variation will occur only when the temperature changes at least ±0.1 °C and reaches values of either 24.9 °C or 25.1 °C. In the worst case, at 100 °C, Pr is 0.3°C

A frequency variation of 0.3 % may be perceptible, but it is small and usually doesn't attract the students' attention. In this case, the software can be adjusted to work with a smaller range, as indoor temperatures, which will allow greater sound variations. For an indoor temperature interval from 20 °C to 30 °C the mathematical relationship based on equation 2 is:

$$fx = 380\,Px - 7400 \tag{5}$$

Figure 7 shows the function sound for equation 5, but for temperatures (Px) below 20 or above 30 °C, the frequency is fixed at 100 Hz and 4100 Hz, respectively. In this case, Pr is only 0.017 °C for Px at 25 °C, which represents a more highlighted sound variation and tends to attract more students' attention.

Figure 7. The function sound for a smaller range.

```
float sound(float Px)
{
  float freq;

  if (Px < 20)  {freq = 100;}
  else if (freq > 30)  {freq = 4100;}
        else  {freq = 380*Px - 7400;}

  return freq;
}
```

This section has shown the linear relationship is mathematically simple, its software encoding is small, and it ensures a satisfactory sound variation as a function of the temperature variation, and therefore it becomes interesting for teaching approaches.

2.5. A Relationship Based on The Music Theory

There are nonlinear mathematical relationships that follows more realistically the nonlinear human ear response, and therefore are more adequate. A relationship based on the music theory is an efficient way to define an adequate nonlinear relationship between a phenomenon value and a sound frequency because it is based on well-defined criteria that has been used for centuries, with advantages as:

1. Conformity: It generates sounds in sequences more pleasant to human perception, which are the basis of musical instruments design.

2. Educational approaches: It can provide students with a more advanced and critical vision about music, making them understand that music is not just a simple collection of sounds, but an arrangement made with criteria.

3. Technological integration: The music theory can also integrate several technological aspects such as electronic instruments, amplifiers, and music software.

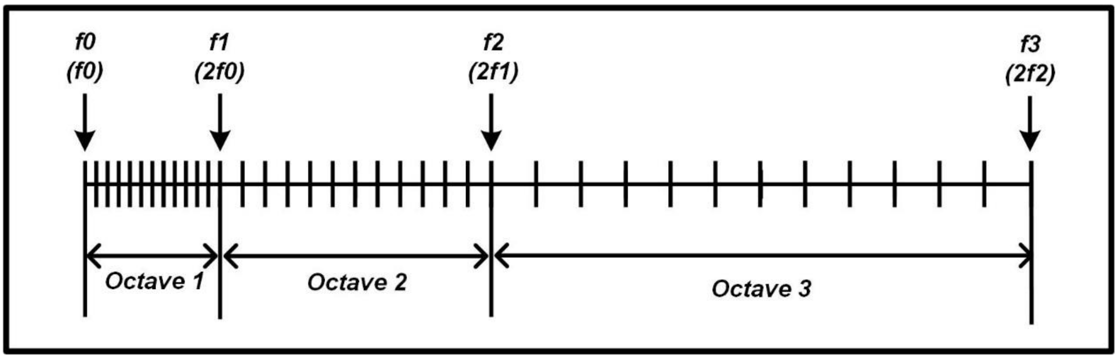
In the present context, there are two fundamental music theory concepts that are detailed as:

1. Consonance: It represents two or more specific sound frequencies whose combination is considered pleasant. The term “pleasant” is merely qualitative and personal, which may seem subjective for exact sciences students, but the music theory has been historically developed under the influence of cultural factors and it justifies the adoption of some “empirical standards”.

2. Harmonic series. It is a series of consonant frequencies. Mathematically, consonant frequencies are related by a fixed small integer ratio, and therefore, if the students define a ratio and a fundamental frequency (fo) then they can calculate the harmonic series.

There are different standardized ratios, and figure 8 shows a popular ratio called *octave* that is 2:1. In this case, two consecutive consonant frequencies, as fa and fb, present a relationship where fb equals 2fa. Besides, each octave was divided by convention into 12 intermediate frequencies.

Figure 8. The Octave division.



The *octave division* (dc) in 12 parts means that the frequency doubles every 12 intermediate frequencies, and it creates a *growth factor* (b) for the nonlinear scale, computed as:

$$b = 2^{\frac{1}{dc}} = 2^{\frac{1}{12}} \cong 1.059 \qquad (6)$$

The factor *b* is the proportional difference between two successive frequencies, and therefore, each frequency (fn) is computed as:

$$fn = fo\ b^{n} \qquad (7)$$

Where: fo is the fundamental frequency, and *n* is the ordinal frequency number

For a frequency interval [fmin, fmax], and that *n* in the interval [Pmin, Pmax], equation 7 is written as:

$$fx = fmin * b^{Px-Pmin} \qquad (8)$$

In the present work, the extreme temperatures are 0 and 100 °C, and the extreme frequencies are 200 Hz and 4000 Hz, and therefore b is:

$$4000 = 200\ b^{(100-0)} \Rightarrow b = 1.03$$

Note, according to equation 6, for *b* at 1.03, *dc* is at about 23. However, it isn't a problem because the division into 12 parts is a conventional value, and not a law. Assuming Pmin is 0, so equation 8 is rewritten as:

$$fx = 200\ (1.03)^{Px}$$

(9)

Figure 9 shows the function sound according to equation 9.

Figure 9. The function sound for the nonlinear relationship.

```
float sound (float Px)
{
  float freq;

  freq = 200 * pow(1.03, Px);

  return freq;
}
```

Besides a smaller Pr value, the relationship based on the music theory relationships advantages are a similarity with the human ear response curve, a constant phenomenon resolution, and a small phenomenon resolution.

3. RESULTS AND DISCUSSIONS

The technological part of this works was satisfactorily, as the programs generated precise sounds according to each mathematical calculation, and it was possible to analyze the sound variation depending on the temperature variation. However, it is important to verify how the teachers analyze this work, according to their teaching viewpoint. Therefore, this human evaluation was carried out through a discussion with a group of ten science teachers, in order to verify qualitatively the main positive and limiting aspects of this work.

3.1. Positive Aspects

The main positive aspects were the hands-on learning, the introduction of physical measurement concepts, and the ludic potential.

3.1.1. The Hands-On Teaching and Learning

All the teachers considered feasible the hands-on activities proposed in this work, and the association of science, mathematics and electronic was considered a way to improve the students' curiosity and to motivate them to think about other STEAM applications. They considered that even teachers with little or no

experience in electronics can use the proposed system with only an initial little help, and later they can transfer these techniques to students so they can carry out their own experiments. It was satisfactory feedback because scientific association with the everyday life doesn't require necessarily the use of modern technologies, but modern technologies compose an interesting educational strategy to explore these applications (Muhazir & Retnawati, 2020), and the support material becomes a fundamental key in this approach (Schoenfeld, 2020).

3.1.2. The Introduction of Sensors and Physical Measurements

Most teacher considered interesting the introduction of physical measurement concepts in the classroom, such as sensors, resolution, measurement interval, etc., which was justified because they allow an interdisciplinary approach with realistic applications, and, besides, this scenario can be innovative for many classes. It was not a consensus, but this work considers this subject has high teaching potential where, for example, the study of a simple mercury-in-glass thermometer allows the discussion in the classroom about several concepts as capillarity, Jurin's law, thermometric scales, thermal comfort for people, temperature influence on plants, global warming, etc.

Terms in the area of metrology, such as precision and accuracy, are often used incorrectly, which Eshach & Kukliansky (2018) justified through the called *intuitive rules theory* that states the people can develop their own understating about some technological or scientific terms, based on their previous life experiences and influenced by external factors such as movies, newspapers, music, TV commercials, or even sellers' catalogs. The intuitive rules theory discussion in the classroom is an interesting subject to improve the students' critical sense, and besides, teachers can show to students the International Vocabulary of Metrology (VIM) that is a free and official guide to define these terms.

3.1.3. The Ludic Learning

The teachers considered the sounds generation according to physical measurements a funny experiment, whose multidisciplinary approach can develop competencies and motivate the students' curiosity. A special moment in this context was the sensor heating with the fingers contact, when some people even challenged the others to see who could achieve a higher sound with the simple touch of their fingers. Remember that a ludic teaching isn't only gamification, and the playfulness in education enables meaningful and creative learnings in a pleasurable way.

3.2. Limiting aspects

The main related limiting aspects were the lack of resources, the lack of training and time, and the lack of curricular insertion. However, the bright side is these factors don't represent insuperable obstacles, and they can represent a challenge to motivate teachers and schools to analyze, discuss, and change their own reality.

3.2.1. The lack of resources

The lack of resources was a critical problem raised by all the teachers because many schools don't have a laboratory equipped with electronic materials to allow

the present work assembling by students, which becomes a barrier. However, an alternative can be the assembling of at least one electronic system for demonstration in the classroom. Despite the experimentation advantage of allowing hands-on activity, the experiment demonstrations may be an alternative and can't be neglected. Even in schools with laboratories, can use demonstration and experimentation as complementary strategies, where students are first familiarized with specific procedures and apparatus through the teacher's demonstration, and later they perform their own experiments. In the past centuries, demonstrations were initially based on empirical didactic experiences, but its popularity and utility motivated several in-dept pedagogical studies in the twentieth century that consolidated them as an efficient educational approach (Deboer, 2012; Trna, 2015). The Arduino boards and the presented system are inexpensive, but a complete educational laboratory with technological resources can include devices as computers, high-speed internet, 3D printers, Arduino boards, robots, measurement instruments, smartphones, sensors, etc. Obviously, it represents a high cost and, besides, it also depends on pedagogical issues such as the laboratory insertion in educational plans, and the teachers' training.

Besides the use of demonstrations, in schools where the required technological resources don't really exist, the teachers can simulate the electronic circuit using specialized software of simulation. There are several simulation software of electronic circuits and, among them, this work highlight the modelling system called "Tinkercad", which includes an efficient and free of charge software for simulation of electronic circuits, that is easy to use, has a very realistic human- machine interface, and doesn't require any installation on the computer because it runs directly in the web browser (https://www.tinkercad.com). Note, details of the Tinkercad use become outside this work proposal, but it is important that teachers know about their existence, and that there are many tutorials and training videos available on the Internet.

3.2.2. The Lack of Training and Time

The teachers showed their lack of technological training as a serious problem, which was a consensus. They considered easy the concepts presented in this work, but the lack of training becomes a complaint with a more generic focus, where teachers have difficulty understanding technological applications in general. Currently, the technological development is rapid and intense, which creates a feeling of not keeping up with this evolution. Usually, the science teachers' training y don't include electronic concepts, and even about software, many classes focus on the use of software applied to solving specific problems, and not on programming languages teaching to allow future teachers to develop their own programs, according to their specific interests (Bers, 2019).

The teachers also expressed their concern about the lack of time to update themselves in relation to the new technologies and to prepare classes with this content. Akşan & Eryilmaz (2011) had already presented that many teachers consider the preparation of instructional material based on technology a tiring and time-consuming task and they didn't feel confidence to do it. More recently, there are studies that show the teacher confidence in using technology for preparing classes has increased (Beardsley, 2021), but it is a problem that still persists (Saubern et al, 2020, Andrzej et al. 2021, Kearney et al, 2022).

Maybe, a way to attenuate the problems above would be a change in the teachers' training with the inclusion of more in-depth computing courses focused on computer programming, or even a bolder training proposal to introduce the called *computational thinking* in the teachers' training. It goes beyond the simple idea of computer programming and includes the solution of general problems through algorithmic analysis and thinking, inducing the development of a human ability where the mental analysis becomes more logical and well-structured. It doesn't try to get humans to think like computers, but is a way to motivate humans to solve problems with logical and creative processes, including a conceptualization that requires multiple levels of abstraction as a peculiar way of analysis (Papert, 1980; Wing, 2006). It is an idea that may seem vague for many people, but it is a concrete approach, whose insertion in the teachers' academic formation is a subject that has been investigated in several countries through practical approaches, with interesting results (Lodi & Martini, 2021; Nordby at al., 2022, Olmo-Muñoz et al., 2023).

3.2.3. The Lack of Curricular Insertion

The teachers also expressed in the absence of a structured curriculum, they may feel insecure about when and how to introduce technological concepts in a consistent way, and without harming the traditional content. The studies about curricula design have been growing exponentially since the 1980s and still remain a contemporary issue (Posillico at al., 2022), and the effective technological insertion in science course curricula becomes a special case that also has been debated for decades because of its particular dynamics (Novita, & Herman, 2021). Note, there are constant appearances, improvements and disappearances of technological devices and systems, such as apps, online resources, interactive simulations, multimedia, sensors, and embedded systems, and therefore, this subject becomes complex.

In general terms, the inclusion of topics in a curricular structure must consider, at least, issues such as:

1. The students' level and age.
2. The teachers' qualification.
3. Methodologies
4. Educational tools.
5. Students' evaluation.
6. Curricular evaluation and reviews.

The issues above can require a very hard work that can vary according each local reality, but this work suggests some basic and practical concernments that can help this task, which are:

1. The curriculum mapping. It checks in which courses the present work could be inserted. If the school doesn't offer specific studies of technology, such as electronics or robotics, then this work suggests general sciences or physics courses could be quite suitable for the present proposal insertion.

2. The goals and objectives learning definitions. What is intended by this insertion? This work suggests that motivating students to associate science and technology may be an inserting goal, and that the objectives can be defined inside two focuses defined as conceptual or specific. The

conceptual objectives focus on the student understanding of "what is" items as sensor, Arduino and programming, while specific objectives include detailed and technical approaches focusing on "how it works".

3. The available time that teachers have available to explain this project. It is an extremely important factor in the insertion, because it can influence the entire context of the curricular insertion, even influencing the goals and objectives definitions.

4. The previous students' knowledge. If students have prior concepts of electronics and Arduino, it will be much easier to approach this topic. Otherwise, the teachers need to introduce some basic concepts, which requires additional time, so this work suggests that these concepts can be explained as the project is presented. For example, when the teachers explain circuit has only one resistor, so they can concomitantly explain details about a resistor, using a level appropriate to each class.

The four steps suggested above don't exhaust the curriculum insertion subject, but at least suggest a beginning.

4. CONCLUSIONS

This work proved that a very simple and cheap electronic system based on hardware and software techniques allows the relationship of numerical physical measurement results with sound frequencies, which is an important teaching approach because it has potential to create motivational environments in the classroom and can also help the teaching of different concepts in a STEAM study. The association between technology and science is a very important issue for both areas, since one can promote advances in the other, and this work presented a satisfactory efficiency to exemplify this association in the classroom. Besides, this work showed the viability of modular software structure for the design of educational electronic apparatus that require data processing, which is an interesting approach for science teachers because it allows them to adjust the system operation according to their specific teaching interests, and therefore, allows these teachers to have a more active action in relation to the development of this type of apparatus and applications. In addition to the presented technological tool for science teaching, this work also verified the teachers' reaction to its use, which highlighted as positive aspects the hands-on teaching and learning, the possibility of an objective introduction of technological concepts in the classroom as sensors and physical measurements, and the playful learning that becomes a motivational factor. Teachers also described concerns about barriers that might be encountered, as the lack of resources, the lack of training and time, and the lack of curricular insertion. The main conclusion regarding these barriers analysis is that they are not limited to the electronic system presented in this work but represent generic problems for the technology insertion in the teaching area, which requires a much deeper reflection and involves different aspects as economic, school management, teacher update, and a wide range of educational issues. In the present work, the teachers understood the presented software when it was explained step by step, but many had considerable difficulty in making small code changes, which allows a conclusion that these teachers have a weak base in relation to software development, which deserves a reflection on how this important topic is inserted effectively in the teachers' training. Usually, the teachers' training is focused on specific aspects

of each area and on pedagogical aspects, without further studies of technology, but it is a reality that must be rethought due to the importance of software and technological applications in education. Finally, this work concludes that the initial design proposal for a low-cost electronic system to relate measurements and sounds was achieved, and that it also allows an interesting analysis of the training and technological knowledge of science teachers.

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