# STEM LEARNING RELATED TO SOUND

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**Abstract:** Generative artificial intelligence - AI, particularly language models, are transforming industries by automating content creation and enhancing human-computer interactions. The STEM education approach in our engineering program is crucial to develop skills and insights that complement and go beyond what language models can achieve. Students must be educated with a highly flexible STEM approach, as AI already can easily handle highly repeatable tasks at a fraction of the cost compared to employee salaries. Without this kind of education, they risk losing their jobs to automation. The aim of this work is to highlight the STEM approach in obtaining and simple processing of sound data using Raspberry Pi.

**Keywords:** STEM, Raspberry Pi, MEMS microphone.

## 1. INTRODUCTION

The increasing prevalence of AI and automation in various industries presents both opportunities and challenges for STEM education. As generative AI models become more sophisticated, they are capable of handling a wide range of repeatable tasks at a fraction of the cost associated with human labor. This shift necessitates a reevaluation of educational priorities, particularly in engineering and technology fields. Pedagogically, this has profound implications on how educators must design curricula and engage with students.

As traditional tasks become automated, the role of STEM education must evolve. Instead of emphasizing technical tasks that can be performed by AI—such as simple data analysis, basic programming, or routine engineering tasks—STEM curricula must now prioritize higher-level competencies such as creativity, critical thinking, and interdisciplinary problem-solving. This shift reflects a need for pedagogies that go beyond imparting technical knowledge, incorporating opportunities for students to engage in collaborative projects, complex problem-solving, and innovative thinking.

AI's rise in automation underscores the need for educators to foster higher-order cognitive skills—those that AI is not capable of replicating, such as abstract reasoning, ethical judgment, and creative problem-solving. Bloom's Taxonomy [1] can serve as a guiding framework for this pedagogical shift. Instead of focusing on basic tasks like remembering and understanding—tasks AI excels at—educators should prioritize activities that develop analyzing, evaluating, and creating skills.

In practical terms, this means that courses on sound data collection and processing, such as those using Raspberry Pi [2] platforms, should encourage students not just to follow pre-programmed routines but to experiment, adapt, and innovate. The sound projects discussed in this paper are a perfect example of this pedagogical approach, where students must move beyond simply collecting audio data. They are encouraged to analyze the data critically, understand its implications, and develop novel applications for it in real-world scenarios, which AI alone cannot accomplish.

STEM education in engineering emphasizes critical thinking, problem-solving, creativity, and collaboration through hands-on, project-based learning. It develops skills in science, math, coding, and engineering design, preparing students for in-demand STEM careers, and enhancing economic competitiveness. The STEM education approach in engineering is even more critical in the artificial intelligence (AI) era. Generative AI, including language models, does not truly "think" in the human sense; it processes data and generates responses based on patterns and algorithms. It lacks consciousness, understanding, and intentionality, relying solely on learned data to produce outputs.

There are many articles discussing the use of Raspberry Pi [2] in student education. Raspberry Pi is an excellent tool for practical learning in programming, electronics, robotics, and other STEM fields. Arduino [3] also plays a significant role in STEM education by providing hands-on experience with electronics and programming. It enables students to build and experiment with their own projects, fostering creativity and practical problem-solving skills. The VEML7700 light sensor has proven to be an effective tool for measuring illuminance levels of light sources. The inverse square law is verified in [4] the sensor was used in Arduino platform. Refraction, diffraction, and energy losses studies using Arduino and Raspberry Pi were conducted in [5]. The setup for measuring the diffraction of light on an optical element, specifically a diffraction grating, in a remote manner based on Raspberry Pi and Arduino is presented in [6].

In this work, we describe the setup for audio recording and what can be done in STEM approach by students on the Raspberry Pi platform. Finally, we provide a short summary.

## 2. SETUP

For microcontrollers lacking analog input or seeking to bypass potential noise issues inherent in analog microphone systems, there is I2S Microphone Breakout, e.g. [7]. Designed for use with microcomputers with I2S peripherals, this breakout facilitates the transmission of digital audio data. Instead of traditional analog outputs, it features Clock, Data, and Word-Select digital pins, eliminating the need for analog conversion.

Compatibility is crucial, as not all microcontroller boards support I2S; however, it pairs seamlessly with hardware that does, including Cortex M-series chips like the Arduino Zero, Feather M0, and single-board computers like the Raspberry Pi. I2S library is also available for Arduinos powered by the SAMD processor [8]. Example codes are accessible from the dropdown menu after installing libraries. Overall sound pressure level and Fourier transformation can be performed to analyse signal; however, this approach is quite restrictive.

In our scenario, Raspberry Pi Zero are employed to harness the full potential of data acquisition and processing. Node-RED [9] can be executed on Raspberry Pi, providing a versatile platform for visual programming and IoT applications. One advantage is its user-friendly interface, enabling quick prototyping and development through drag-and-drop functionality. Additionally, Node-RED's extensive library of pre-built nodes simplifies integration with various devices and services, enhancing flexibility. Moreover, its compatibility with Raspberry Pi's GPIO pins facilitates seamless interaction with hardware components. One can observe that Node-RED operates within a browser, utilizing widely recognizable components. This ensures that students are not confronted with an unfamiliar graphical user interface (GUI), facilitating ease of understanding.

In Fig. 1. The photography of I2S microphones a) which are enclosed in the front panel b) are stacked on top of a Raspberry Pi Zero board (under the microphone plate) c) is shown.

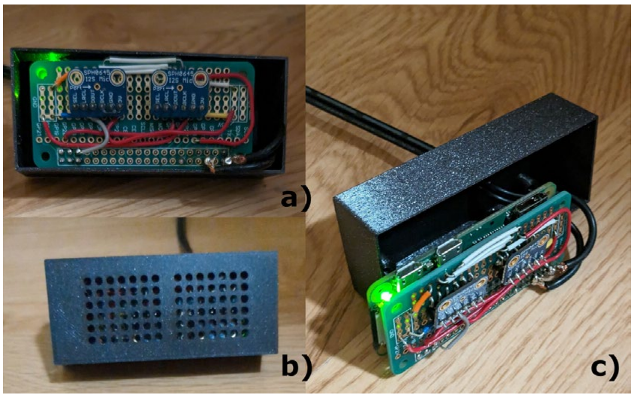


*Fig.1*

## 3. DISCUSSION

Collection of audio data begins by pressing the start button in the graphical user interface in Node-RED. The graphical interface is not shown here. The data collection ends by pressing the stop button or after reaching the time limit, which is set to one minute for compressed files. For uncompressed audio files, the timeout is set to 10 seconds. The audio data is displayed in one graph showing the last second, and another graph shows processed data after applying the Fourier transform. The audio files can be downloaded to a computer for further processing, but the primary goal is to manipulate and process the data on a Raspberry Pi.

Below is one of the possible scenarios of how students could work with the described setup. A few steps could be carried out, but it is better to perform as many as possible steps to show the advantages of the STEM-based approach.

In the subject of Materials and Technologies, students work on developing a printed circuit board (PCB), simulating it, mounting components, soldering them to the PCB, and calculating the probability of failure.

In this subject (Materials and Technologies), the following steps could be taken by analogy. Students could solder MEMS microphones onto the PCB or install other electronic components to eliminate external electromagnetic fields and connect this PCB to a Raspberry Pi. The next step would involve recording audio data. There are several possibilities: one is writing a short program in Python, and another is writing a bash script using built-in bash functions for recording sound. Simple sound processing can be done on the Raspberry Pi again in Python or another language as needed. The goal is not to use the Fourier transform from libraries but to write their own code, which, although is not as efficient as the Fast Fourier Transform. This helps students better understand the mathematical apparatus associated with the Fourier transform. The implementation in any language should not take more than 20 to 30 lines of code (Processing code, see Fig.2 ), so it is not so difficult to realize. On the other hand, students go through the entire process of recording and processing audio signals.

Filtering or other modifications of audio data can be performed using the inverse Fourier transform. Initially, it is not so complicated to program a low-pass or high-pass filter or smooth the audio spectrum in the frequency domain. The goal should be to better understand how these filters affect the resulting signal, even in this simplest approach. This should all be done with an emphasis on processing signals, which do not necessarily have to be audio signals.

Another application could be investigating standing waves on a string. In Physics 1 laboratory exercises, there is an measurement

```
Table data;
float[] amplituda;  // amplitúda zo súboru
int N;  // počet vzoriek

void setup() {
  // Načítanie údajov zo súboru nahravka.dat
  data = loadTable("nahravka.dat", "header, csv");

  // Extrahovanie amplitúdových hodnôt z tabuľky do poľa
  int pocetRiadkov = data.getRowCount();
  amplituda = new float[pocetRiadkov];

  for (int i = 0; i < pocetRiadkov; i++) {
    amplituda[i] = data.getFloat(i, "amplituda");
  }

  // Nastavenie počtu vzoriek pre DFT
  N = amplituda.length;

  // Vykonanie DFT na amplitúdových údajoch
  Komplexne[] vysledokDFT = vykonajDFT(amplituda);

  // Uloženie výsledku DFT do súboru
  ulozDFTVysledok(vysledokDFT, "fourierVystup.dat");
}

// Funkcia na vykonanie Diskrétnej Fourierovej Transformácie (DFT)
Komplexne[] vykonajDFT(float[] data) {
  int N = data.length;
  Komplexne[] vysledok = new Komplexne[N];

  for (int k = 0; k < N; k++) {  // Pre každú frekvenciu k
    float realnaCast = 0;
    float imaginarnaCast = 0;

    for (int n = 0; n < N; n++) {  // Súčet cez všetky časové body n
      float uhol = TWO_PI * k * n / N;
      realnaCast += data[n] * cos(uhol);    // Reálna časť DFT
      imaginarnaCast -= data[n] * sin(uhol);    // Imaginárna časť DF
    }

      vysledok[k] = new Komplexne(realnaCast, imaginarnaCast);  // Uloženie
                                                                 // výsledku
  }

  return vysledok;
}

// Funkcia na uloženie výsledkov DFT do súboru
void ulozDFTVysledok(Komplexne[] vysledokDFT, String nazovSuboru) {
  PrintWriter vystup = createWriter(nazovSuboru);

  // Uloženie reálnej a imaginárnej časti výsledkov DFT
  for (int i = 0; i < vysledokDFT.length; i++) {
    vystup.println(vysledokDFT[i].realnaCast + ","
                 + vysledokDFT[i].imaginarnaCast);  // Zapísanie
                                                   // reálnej a
                                                   // imaginárnej
                                                   // časti do súboru
  }

  vystup.flush();
  vystup.close();
}

// Pomocná trieda na uloženie komplexných čísel
class Komplexne {
  float realnaCast;
  float imaginarnaCast;

  Komplexne(float realna, float imaginarna) {
    realnaCast = realna;
    imaginarnaCast = imaginarna;
  }
}
```

*Fig.2*

on investigating standing waves on a string, where a problem arises with higher harmonic frequencies since the displacement on the string is relatively small, making it difficult for students to read or find the frequency at which the string vibrates.

The proposed setup could be used in this case to record the sound of the vibrating string with subsequent data analysis. The physical processing of the measurement and understanding of the physics would proceed as described in the scripts.

Further development possibilities of the task include installing an operating system on an SD card for the Raspberry Pi, working in the Linux OS environment, debugging code, and solving various interdisciplinary problems which arises through completing task.

The problem could be trivial, hidden in the code, or in a cold solder joint, and finding the cause may not be easy. First, it is necessary to identify in which part the problem is located and then specifically solve it. In physics labs at courses, problems that are not related to physics are often solved, such as connecting electronics, misunderstanding the mathematical apparatus, misunderstanding electrical or electronic connections, incorrect overall approach by the student, and negligence. With a complex task like this, which involves mathematics, programming, electronics, and possibly physics, students should learn how to approach and solve complex problems, focusing on the specific issue because any unresolved error in the initial stages can be very difficult to solve later, is harder to identify, and can affect further stages and overall progress in development and understanding.

## 4. CONCLUSION

As AI and automation reshape STEM industries, the role of students as well as educators is evolving. They must now emphasize creativity, critical thinking, and ethical judgment—skills that machines cannot replicate. Through interdisciplinary projects and hands-on experimentation, students can develop these competencies, preparing them to thrive in a world where AI handles much of the routine work. By maintaining a balance between technology and humanity, STEM education can not only produce skilled professionals but also thoughtful, ethical individuals capable of navigating a complex future.

The process of collecting and processing of audio data is performed on Raspberry Pi in Node-RED graphical user interface and in Python language, preferably. Students in Materials and Technologies subject or similar can make their PCB by soldering MEMS microphones and connecting to a Raspberry Pi for data collection. Students delve into audio signal processing, gaining insights into Fourier transforms and filtering. This task can be extended to physics in which the standing waves can be analyzed. This interdisciplinary approach not only enhances technical skills but also fosters problem-solving abilities crucial for tackling complex issues that may arise during project development. Solving complex tasks is becoming an increasingly urgent issue due to the continuous advancement in automation.

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## REFERENCES

[1] Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H., & Krathwohl, D. R.: Taxonomy of Educational Objectives: The Classification of Educational Goals. Handbook I: Cognitive Domain. (1956) New York: David McKay Company.

[2] Raspberry Pi Website: https://www.raspberrypi.org [online]. Aktualizované 02-10-2024. [cit. 2024-05-31]. Dostupné na internete: https://www.raspberrypi.org

[3] Arduino Website: https://www.arduino.cc [online]. Aktualizované 02-10-2024. [cit. 2024-05-31]. Dostupné na internete: https://www.arduino.cc

[4] JANEK, M.: Student laboratory measurements based on VEML7700 light sensor: AIP Conf. Proc. 2024, 3063, 020006.

[5] JANEK, M.: Refraction, diffraction and energy losses studies using Arduino and Raspberry Pi: J. Phys.: Conf. Ser 2022, 2339 012004.

[6] JANEK, M.: Diffraction measurement - remote experiment: ELEKTRO conference 2022, ISSN: 2691-0616.

[7] Adafruit Website: https://www.adafruit.com/product/3421 [online]. Aktualizované 02-10-2024. [cit. 2024-05-31]. Dostupné na internete: https://www.adafruit.com/product/3421

[8] Arduino I2S library Website : https://www.arduino.cc/reference/en/libraries/arduinosound [online]. Aktualizované 02-10-2024. [cit. 2024-05-31]. Dostupné na internete: https://www.arduino.cc/reference/en/libraries/arduinosound

[9] Node-red Website : https://nodered.org [online]. Aktualizované 02-10-2024. [cit. 2024-05-31]. Dostupné na internete: https://nodered.org

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