Educational Journal of Learning Technology
Vol. 3, No. 3, pp. 192-207, May 2026
https://doi.org/10.58230/edutech.v3i3.85
Received January 21, 2026; Revised February 28, 2026; Accepted April 07, 2026

Development of a Fourier Transform-Based Gamelan Signal Processing Simulation Using Python and GNU Octave to Support Problem-Solving Skills and Independent Learning

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Abstract. Science education today requires integrating technological competencies to prepare students for global competition; however, unsupportive learning habits and limited use of technology contribute to low levels of problem-solving skills and learning independence. This study aims to develop a simulation of gamelan musical instrument signal processing using open-source computational platforms, namely Python and GNU Octave. The research employed a research and development (R&D) approach based on the Borg and Gall model, limited to the initial product development stage. Fourier Transform analysis was applied to convert sound signals from the time domain into the frequency domain. The simulation successfully identified the gamelan's natural frequency at 328 Hz via spectral analysis, with consistent results on both platforms. The developed simulation provides visualization of time-series waveforms and frequency spectra and is intended as a computational learning medium for physics instruction, particularly in wave topics. Although field testing and effectiveness evaluation were not conducted, the simulation is designed to support the development of students' problem-solving skills and learning independence in future implementations.

Keywords: Fourier transform; GNU Octave; Learning independence; Problem-solving skills; Python; Simulation.

1. Introduction

Indonesia is known as an archipelago with diverse tribes and cultures. However, along with the rapid pace of the technological era, students are increasingly unfamiliar with their own culture (Eka Zhoga, 2019). For this reason, it is necessary to innovate learning by integrating existing school-based learning with local wisdom. Along with the times, students' habits have changed; they tend not to learn about their own culture, for example, Gamelan musical instruments. They tend to recognize foreign music more than their own culture (Turmuzi et al., 2022). Learning by linking culture needs to be done. As done by (Herianto & Wilujeng, 2020) that integrates Gamelan local wisdom in science subject e-books. Students not only learn subjects but also come to know the culture of the environment in which they live.

Science education today requires technological skills to prepare for global competition. Learning using technology brings major changes to the learning process, shifting it from teacher-

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centered to learner-centered. Technology provides opportunities for teachers and learners to learn both inside and outside the classroom (Basal, 2015; Pilgrim et al., 2012). Learning with technology can make students more independent, active, and creative, aligning with educational goals. This statement is supported by research by (Wah Chu, 2008), which shows that integrating technology into classroom teaching encourages collaboration and improves the quality of group work and social development skills.

Indonesia currently uses the Merdeka Curriculum. (Wahyuni, 2022) states that the Independent Curriculum aims to overcome the problem of the relevance of education to labor needs. The implementation of the independent curriculum is not without challenges, (Lestari et al., 2023) In his research, he said that implementing the current independent curriculum faces challenges, including that it is still too early, requires more intensive socialization, has limited literacy and limited ability to use technology, and lacks readiness in knowledge, facilities, and infrastructure. Based on the results of interviews with physics teachers at SMA N 1 Bantul, SMA N 1 Kasihan, and SMA N 1 Piyungan, information was obtained that the challenges of implementing an independent curriculum included the difficulty in preparing prerequisite material, a lack of books that accommodate the independent curriculum, and the difficulty of preparing students to learn with differentiated learning. The implementation of the independent curriculum still faces challenges, but the hope is that its presence can strengthen efforts to transform learning and the quality of education in Indonesia. The Independent Curriculum has brought changes to education in Indonesia, including in physics. Physics learning in the independent curriculum can be designed with a more contextual and relevant approach to students' daily lives. The existence of physics is very important in various fields of life, one of which is in the field of technology, which is the basis for the development and innovation of various devices and systems, ranging from telecommunications, transportation, renewable energy, to medical technology (Nugraha et al., 2017).

Another challenge in physics learning was conveyed by (Argaw et al., 2017) which states that physics is considered one of the most difficult subjects in school, and many learners view that only gifted learners can understand physics concepts. A similar view of physics was described in the study. (Angell et al., 2004) that high school students have difficulty conducting experiments while simultaneously using formulas, graphs, and conceptual explanations. Both studies are supported by field-based evidence from interviews, which indicate that activities such as in-class presentations are not optimal for active learning.

However, often the relevance of physics to technological development is not adequately explained. The problem is also conveyed by(Wulandari, 2021) who said that the lack of relevance of physics and technology learning to everyday life, and the use of mathematics are too prominent. In fact, physics is an important basis in the development of modern technology. In physics learning, it should be emphasized how physics concepts can be applied in technology around students. For example, the concepts of kinetic and potential energy are applied in the context of electric cars or renewable energy. By explaining the relevance of physics to technological developments, students will more easily see and appreciate the importance of learning physics in everyday life. This was also conveyed in the research (Bungum et al., 2015) which states that physics learning should emphasize its relevance to the development of modern technology as it is today.

Research conducted by (Brook & Wells, 1988) also explained that students' difficulties were with one of the materials, namely the energy material. Energy material is considered difficult because it has not been given direct practical applications in industry. In the study, students were not encouraged to connect energy changes with the real world from the observation process. The research shows that energy materials often focus only on simple calculations. Research by (Nordine

et al., 2011) showed that integrating the concept of energy with the surrounding environment can improve students' understanding of everyday phenomena. In addition to this research, Handayani (2018) explained that the difficulties students face with the material on effort and energy include applying the dot product, graph-related problems, and applying kinetic energy. It can be said that these students' difficulties arise from not being used to solving problems mathematically. Similar to this research, (Beichner et al., 2007) found that physics learning in the classroom, which is still teacher-centered in its delivery, leads to low problem-solving skills among students.

Problem-solving skills require supporting aspects, one of which is student independence in learning. (Shurygin and Krasnova, 2016) mentioned that good physics problem-solving skills require strong learning independence. (Cheng, 2011) explains that learning independence is the ability to self-regulate, in the sense of learners' ability to understand and master their learning process. When learners can self-regulate, they can take responsibility for their learning process. Learners can identify their learning needs, set learning goals, and seek the resources needed to deepen their understanding of physics concepts. Learning independence also allows students to engage in physics experiments, research, and practicum independently, which is an important step in developing physics problem-solving skills (Puspitasari et al., 2018). Independent learning enables learners to become active learners and engage deeply in the learning process. They can develop critical, analytical, and problem-solving skills that will help them face challenges within and beyond the learning environment. In addition to providing individual benefits, independent learning is relevant in social and professional contexts. In a fast-paced, ever-evolving information age, individuals with learning independence tend to be better prepared for the complex, changing demands of the workplace. They can continue learning, adapt to new technological developments and knowledge, and overcome challenges that may arise in their careers. Nevertheless, learners' independence in learning remains a challenge for teachers in Indonesia. Despite efforts, the level of learner independence in senior high schools remains low overall.

The low learning independence of students is partly due to the teacher-centered learning approach (Wagner et al., 2020). In addition, according to (Dashtestani and Stojković, 2015) Learning habits and unsupportive technology are the causes of low learning independence in students. In line with this, (Nuritha & Tsurayya, 2021) said that low learning independence is because when students learn at school, they still have dependence on teachers, so that in learning, they cannot try themselves and cannot take advantage of learning resources that should be obtained from anywhere. Based on this, it is evident that low learning independence among high school students has implications for success in the learning process.

The low level of learning independence among students is evident in the results of preliminary studies and literature reviews. Previous researchers have examined learning independence. The results of research conducted by (Sanita et al., 2021) which indicates that learning independence at the high school level remains low. Similar research was conducted by (Hapsari, 2016; Kismiati, 2020) It is known that students' learning independence at SMA N 2 Bantul remains lacking, as evidenced by their dependence on the teacher. Learners are still passive in the learning process and only listen to the teacher's lecture. Learners only ask questions and respond when instructed by the teacher. By learning independently, students can choose additional material to suit their needs, enabling them to practice thinking rather than passively receiving knowledge.

The current constructivist learning model has evolved to meet the needs of the times. In the digital era and with increasingly advanced information technology, the constructivist learning model has also adopted a more interactive approach, using technology as a learning tool (Belawati, 2020). An example of a constructivist learning model that is popular today is the flipped classroom.

In this model, learners receive learning materials via online resources, such as videos, presentations, or readings, before attending class. In addition to these models, project-based learning is a common approach within constructivism. In this model, students are assigned projects or assignments requiring problem-solving, research, and critical thinking (Insyasiska et al., 2015). They work independently or in groups to complete the project. Teachers provide guidance and feedback throughout the process, so students can build their own knowledge and develop problem-solving skills. Another constructivist learning model is guided inquiry. In this model, teachers provide questions or problems to learners as a starting point for exploration. Learners are given the freedom to explore their existing knowledge, ask questions, and gather information (Amiasih et al., 2017). Furthermore, learners are asked to analyze the collected data and draw conclusions based on their findings. In this stage, learners construct their own understanding of physics concepts through logical thinking and reflection. Overall, the current constructivist learning model emphasizes students' active role in learning, the use of technology as a tool, and the application of concepts in real-world situations. With an interactive and collaborative approach, this model encourages independent learning and the development of real-world problem-solving skills. Through a combination of technology and innovative approaches, constructivist learning models continue to evolve to meet the needs and challenges of learning in an ever-changing world.

One constructivist learning approach is project-based learning. Project-based learning using simulation based on local wisdom is an alternative that researchers can offer for learning in the current technological era. Learning using simulation has a positive effect on increasing students' learning independence (Zega, 2019). The use of simulations can also be used to instill scientific concepts (Linder & Erickson, 1989). Some studies have successfully used simulation-based learning, one of which is research from (Wang et al., 2017). The results of his research show that the use of simulations or applications can narrow the gap between students with different levels of spatial ability. This study differs from previous studies in several important aspects. Studies that integrate local wisdom, such as (Herianto & Wilujeng, 2020) Generally, gamelan is placed at the level of context or learning narrative. In contrast, in this study, gamelan is treated as a real physical system, with its sound signals analyzed quantitatively using the Fourier transform. Furthermore, unlike simulation-based learning studies such as (Wang et al., 2017) This study, which emphasizes the use of simulation applications for pedagogical purposes, develops open-source computational simulations using two platforms, Python and GNU Octave, to process authentic gamelan sound data. Thus, the novelty of this study lies in integrating local wisdom as a source of real-world physical data, computation-based signal analysis, and the development of open-source simulations within a project-based learning framework.

Based on this, learning through simulations grounded in local wisdom and using the Python programming language and GNU Octave was chosen for this study. Both have the same advantages, namely, free and open source. Both also have libraries that can support signal processing needs. The material used in this article is waves. Based on the identified research gaps, this study aims to answer several key questions, namely, how to develop a gamelan sound-signal processing simulation using Python and GNU Octave during the initial product development stage.

2. Method

This study uses the research and development (R&D) method. This research approach aims to systematically design and develop educational products to meet the criteria of validity, practicality, and effectiveness (Borg & Gall, 1983). The development procedure used refers to the Borg and Gall model, which consists of ten stages, namely: research and information collecting, planning,

developing a preliminary form of the product, preliminary field testing, main product revision, main field testing, operational product revision, operational field testing, final product revision, and dissemination and implementation. However, this study is limited to the initial product development stage, namely the stages of research and information collecting, planning, and developing a preliminary form of the product.

At this stage, the research focused on the design and development of a simulation-based learning media prototype without involving field trials or learning effectiveness evaluations. Therefore, the results of this study emphasize the process and technical characteristics of the developed product rather than empirical measurements of learning impact. The simulation was developed using the Python programming language and GNU Octave open-source software. The gamelan instrument's sound signal was processed using the Fourier transform to convert it from the time domain to the frequency domain. The simulation results were presented as time signals and frequency spectra, designed to support physics learning, particularly in wave material, and to facilitate project-based and computational learning. The coding displays for both are shown in Figure 1.

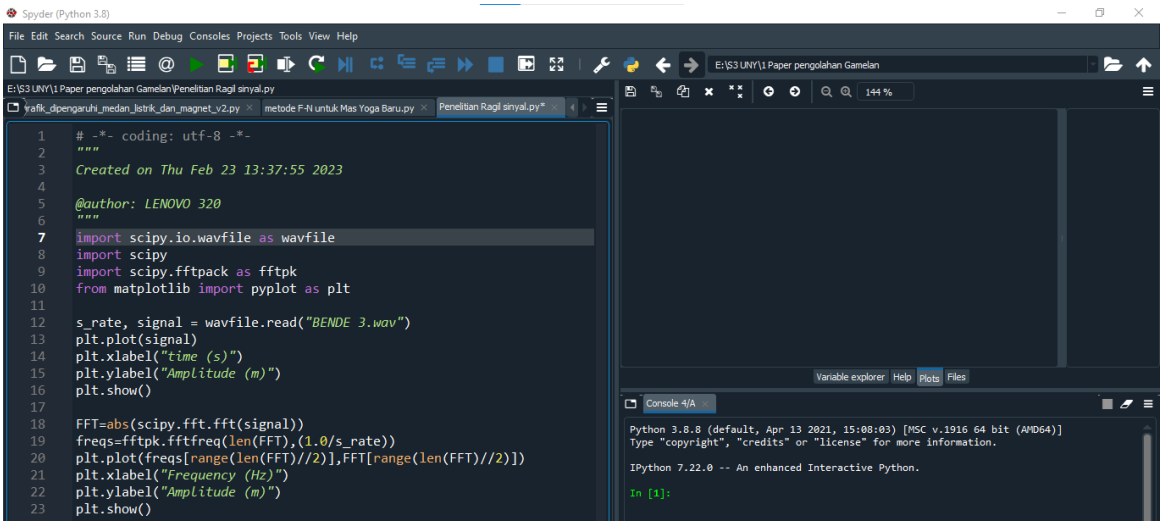


Figure 1. Python Programming Environment Interface (Spyder) for Gamelan Signal Analysis with Fourier Transform (source: my own picture)

Figure 1 shows Python code using the Spyder Anaconda software. Coding in Python starts with importing a library, such as scipy.io.wavfile, to read files in the WAV format. Furthermore, the Matplotlib library is used to visualize data graphically. The next step displays the shape of the Gamelan musical instrument signal over time. Furthermore, to get the spectrum or frequency of Gamelan musical instruments, the Fourier transformation is used by writing fft (signal) as written in the coding. Figure 2 shows the code in GNU Octave. The first step in coding in GNU Octave is the same as in Python: reading the .wav file. In GNU Octave, use audioread to read files; in Python, use scipy.io.wavfile. Next, display the waveform in the time domain. Furthermore, every 1024 data points will be Fourier-transformed. Fourier transformation by writing the coding fft(xn,nf), after which the transformation results are plotted into 2-dimensional form by writing the plot coding.

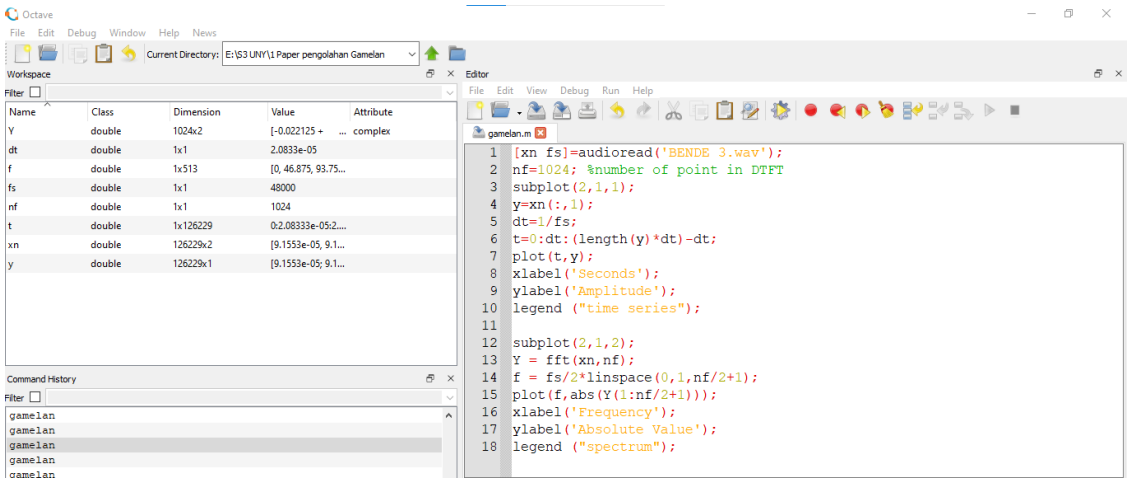


Figure 2. GNU Octave Environment Overview for Gamelan Signal Analysis Using Fourier Transform (source: my own picture)

3. Result

Initial research was conducted on problem-solving skills and student independence in high schools in Bantul Regency. Both aspects were measured using the questionnaire instrument for learning independence (Table 1) and the problem-solving skills instrument (Table 2).

Table 1. Lattice of Learning Independence Questionnaire, 2021 (Sulistyowati, 2021)

No	Aspects of Learning Independence		Indicator	Positive Items	Negative Items	Total
1	Forethought	Individuals design their own learning to meet their needs or goals.	Take the initiative to learn with or without the help of others	2,4	14	3
			Formulate or select learning objectives	8	17	2
2	Performance Control	Individuals choose strategies and implement their learning plan	Confident in learning	12,15	18,20	4
			Disciplined behavior in learning study	6,10	7	3
			Responsible for learning	16,19	1,5	4
3	Self-reflection	Individuals monitor their own progress, evaluating their learning outcomes and comparing them with certain standards.	Self-control	11	13	2
			Evaluate their learning outcomes and compare learning achievements with certain standards	9	3	2
Total Item						20

Table 2. Problem-solving ability assessment grid, 2023 (source: own instrument)

No	Aspect	Indicator	Assessment Technique
1	Understand the problem	Write down the known quantities in the problem	Written test
		Identify problems that must be solved	
2	Planning the solution	Identify concepts, principles, rules, formulas, and laws of physics related to the problem.	
		Determine the correct mathematical equation according to the concepts, principles, rules, formulas, and laws of physics related to the problem.	
3	Implementing problem-solving	Apply appropriate mathematical equations based on the concepts, principles, rules, formulas, and laws of physics related to the problems to be solved.	
4	Evaluate/check back	Rechecking the course of problem-solving that has been done	
		Checking the number of results and units in the answers that have been done	

The low level of problem-solving skills is evident in the results of preliminary studies and literature reviews conducted. Previous researchers have examined problem-solving skills. Such as research conducted in class XI IPA SMA Abu Bakar Yogyakarta by Widaningrum et al. (2020) which indicates that problem-solving skills at the high school level remain lacking. Research on problem-solving skills at SMA N 1 Bantul, SMA N 1 Kasihan, and SMA N 1 Piyungan on class X students using question instruments on the material of Effort and Energy. Preliminary studies show that as many as 80% of students have not been able to write the magnitude and identify the problem (aspect of understanding the problem), as many as 80% of students have not been able to identify concepts and determine mathematical equations (aspect of planning problems), as many as 80% of students have not been able to apply and use mathematical equations related to problems to solve problems (aspect of implementing problem solving). As many as 100% of students have not been able to recheck the course of problem solving and verify the number of results and units in the answer (an aspect of evaluation). The data is summarised in Figure 3 to clarify the distribution of achievements for each indicator.

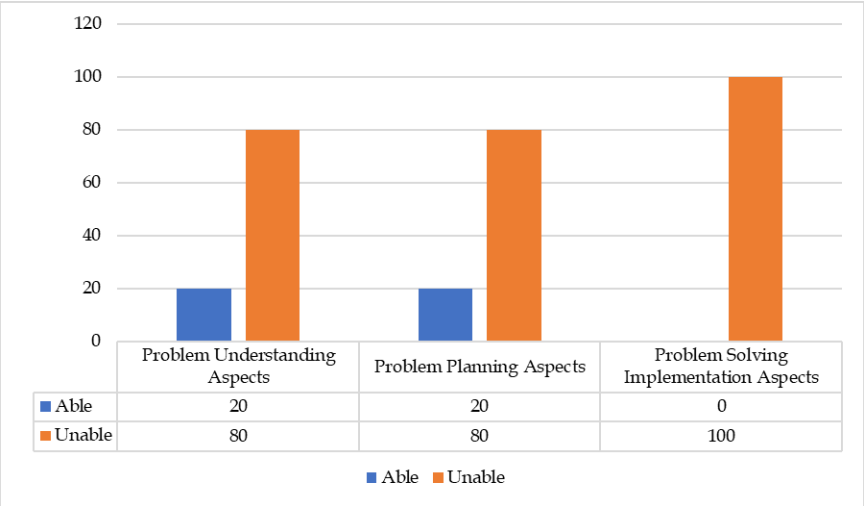


Figure 3. Distribution Graph of Problem-Solving Skills

The low level of learning independence among students is evident in the results of preliminary studies and literature reviews. Previous researchers have examined learning independence. The results of research conducted by Sanita et al. (2021) which indicates that learning independence at the high school level remains low. Research on learning independence conducted by researchers at SMA N 1 Bantul, SMA N 1 Kasihan and SMA N 1 Piyungan on class X students using questionnaires, shows that as many as 19 students (42%) have not been able to design their own learning (aspects of designing) according to their needs or goals, as many as 17 students (38%) have not been able to choose strategies and implement their learning designs (aspects of performance control), as many as 10 students (22%) have not been able to monitor their own learning progress, evaluate their learning outcomes and compare with certain standards (aspects of self-reflection). The data is summarised in Figure 4 to clarify the distribution of achievements for each indicator.

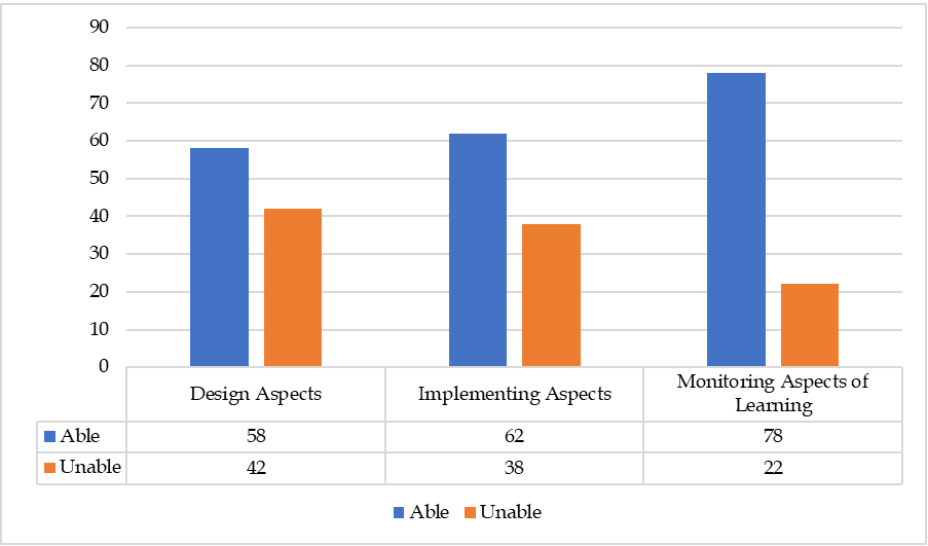


Figure 4. Distribution Graph of Independent Learning

The preliminary study revealed that students have low problem-solving and independent learning abilities, particularly in systematic conceptual and mathematical analysis. To address this issue, a gamelan signal-processing simulation in Python and GNU Octave was developed as a contextual, exploration-based learning medium. The simulation visualizes signals in the time and frequency domains, and Fourier analysis shows a natural frequency of 328 Hz. Although its

classroom effectiveness has not yet been tested, it has strong potential to support analysis, data exploration, and independent learning.

4. Discussion

This study successfully developed an initial-stage simulation of gamelan sound signal processing using Python and GNU Octave, capable of visualizing signals in both the time and frequency domains via Fourier transformation, thereby representing sound waves quantitatively and positioning gamelan instruments as relevant physical objects for computational study in wave and vibration learning. Although the simulation has not yet been implemented or tested for classroom effectiveness, it has strong potential to support constructivist, project-based, and computation-based learning approaches. By allowing students to explore authentic sound data, analyze dominant frequencies, and connect mathematical representations to real physical phenomena, the simulation encourages analytical thinking and structured problem-solving. Overall, it serves as a contextual and exploratory computational learning tool that integrates local cultural elements with physics education.

Problem-solving and learning independence are two very important skills for learners in this evolving era. Problem-solving and learning to be independent are important because the world today is dynamic and complex. Technological developments and social changes affect the way we live, work, and learn. Learners need to adapt quickly, face emerging challenges, and tackle complex problems. In situations like this, problem-solving skills and learning independence become an important foundation for individual success in the future.

One effort to improve students' problem-solving skills and learning independence is to implement a constructivist learning model. Constructivist learning is a learning concept based on an understanding of the learning process that students go through. This statement is supported by (Mayasari *et al.*, 2016) that constructivist learning is one of the alternatives for teachers in training students' abilities in the 21st century. (Dewey, 2008) asserts that learning is most effective when learners are engaged in meaningful experiences. (Vygotsky, 1987) It also emphasizes the importance of providing learners with opportunities for active exploration to develop skills through social interaction. Teachers play an important role in learning activities, namely by creating a non-boring learning atmosphere, attracting students' interest, and instilling character education.

In physics, problem-solving is synonymous with gaining conceptual understanding (Linder & Erickson, 1989). One way to overcome conceptual challenges is through visualizations and simulations that embed scientific concepts. For example, in wave material. In studying wave phenomena, we can use Python and GNU Octave simulations. Scientific visualization is often used in learning, such as by (Ramachandran & Varoquaux, 2011; Weiss, 2017). In this study, project-based learning will be used, with a simulation of Gamelan musical instrument signal processing in Python and GNU Octave. Python and GNU Octave have the advantage of being free and open-source numerical libraries of the SciPy community (Larsen et al., 2017). The following Python programming language is used:

```
import scipy.io.wavfile as wavfile
import scipy
import scipy.fftpack as fftpk
from matplotlib import pyplot as plt
```

```
s_rate, signal = wavfile.read("BENDE 3.wav")
plt.plot(signal)
plt.xlabel("time (s)")
```

```
plt.ylabel("Amplitude (m)")
plt.show()
FFT=abs(scipy.fft.fft(signal))
freqs=fftpk.fftfreq(len(FFT),(1.0/s_rate))
```

```
plt.plot(freqs[range(len(FFT)//2)],FFT[range(len(FFT)//2)])
plt.xlabel("Frequency (Hz)")
plt.ylabel("Amplitude (m)")
plt.show()
```

The above simulation uses the code to model the gamelan's wave signal. Several Python libraries are used in this simulation, including scipy.io.wavfile, scipy.fftpack, and matplotlib. SciPy is used to read wave files with the .wav extension. FFTpack is used for signal processing using the Fourier transform method. The matplotlib script is used to create 2-Dimensional graphs. Graphic plots are also available in the GNU Octave software. The script above starts by specifying the library to use. The next step is to read the file with the WAV extension. The script is written with s_rate, signal = wavfile.read("BENDE 3.wav"). The signal is still in the time domain or time series. A time series is an ordered sequence of values recorded at the same time interval (Deb et al., 2017). Time series analysis can be used to obtain the basic structure and pattern of the data observed in this study, namely, the natural frequency. In addition, time series analysis can be used to predict the economic field, urban governance, and so on. After writing the script to read the signal, I then visualize the signal shape from the Gamelan musical instrument recording. The script is plt.plot(signal), as shown in Figure 5.

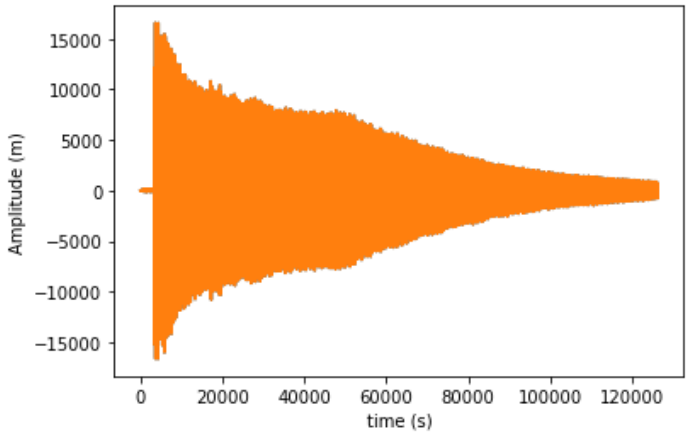


Figure 5. Simulation of Gamelan instrument signal time series using Python programming language, 2023 (source: my own picture)

Figure 5 shows the Gamelan musical instrument signal still in function of time. From time to time, the Gamelan signal data is being recorded less and less. The sampling rate (fs) used to describe the Gamelan signal is 48,000, which means there are 48,000 data points per second. Sampling rate (fs) must meet the Nyquist criteria; the sampling rate value used must be equal to 2 (two) times the natural frequency of the source (Zhao et al., 2020). Using sampling rates that meet the Nyquist criterion reduces aliasing. This aliasing effect is a shift in frequency to a lower frequency than the natural frequency (Jang et al., 2018). The next step is to use the Fourier transform to convert the time function into a frequency function with the script FFT=abs(scipy.fft.fft(signal)). The result of the Fourier transform is shown in Figure 6.

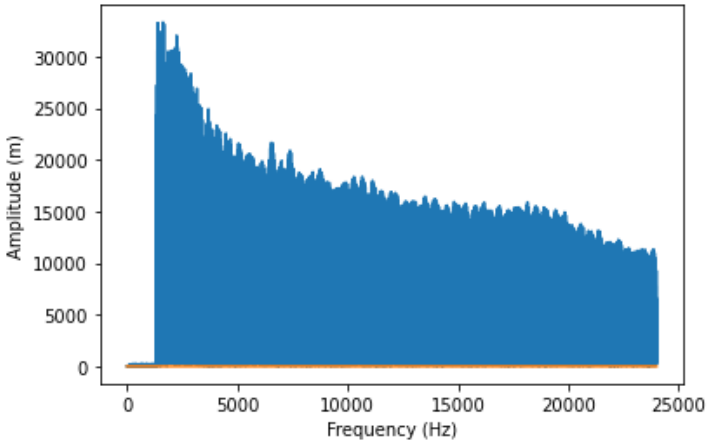


Figure 6. Simulation of gamelan signal spectrum using Python programming language, 2023 (source: my own picture)

Figure 6 shows the signal spectrum as a function of frequency—obtained using the transformation shown in the figure. Analysis using the Fourier transform of Gamelan musical instruments yielded a natural frequency of 328 Hz. Fourier transform analysis is important because it reveals the frequency content of a signal. However, the Fourier transform also has a weakness, namely, when the frequency domain transformation is applied, time information will be lost (Puspasari, 2015). The Fourier transform method is widely used for continuous monitoring of physical conditions, such as heart rate, blood flow, and blood pressure. The Fourier transform $X(\omega)$ of a signal $x(t)$ is defined as equation 1.

$$X(\omega) = \int x(t)e^{-j\omega t}dt \qquad (1)$$

With t and ω being time and frequency parameters. In addition to Python simulations, this research uses GNU Octave to process signals from Gamelan musical instruments. The following is the GNU Octave software script used:

```
[xn fs]=audioread('BENDE 3.wav');
nf=1024; %number of points in DTFT
subplot(2,1,1);
y=xn(:,1);
dt=1/fs;
t=0:dt:(length(y)*dt)-dt;
plot(t,y);
xlabel('Seconds');
ylabel('Amplitude');
```

```
legend ("time series");
subplot (2,1,2);
Y = fft(xn,nf);
f = fs/2*linspace(0,1,nf/2+1);
plot(f,abs(Y(1:nf/2+1)));
xlabel('Frequency');
ylabel('Absolute Value');
legend ("spectrum");
```

The first step in GNU Octave, as in the Python programming language, is to read the file as audio using the command [xn fs]=audioread('BENDE 3.wav'). Next, display the graph using a subplot, as shown in Figure 7.

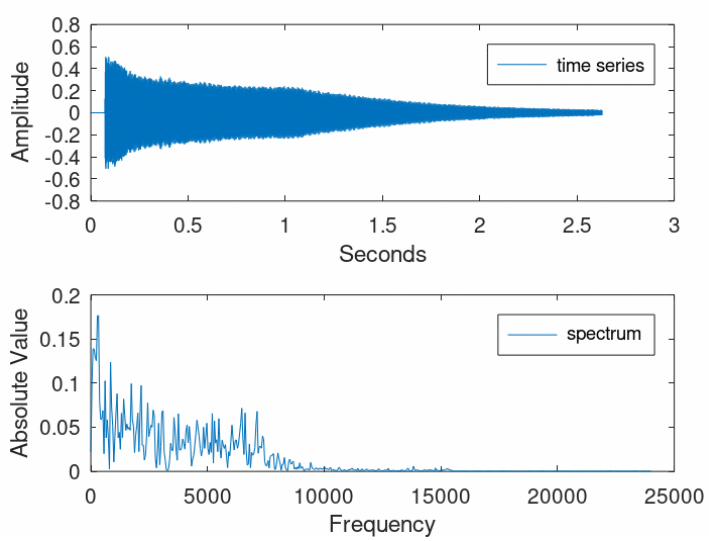


Figure 7. Simulation of gamelan signal processing using GNU Octave software, 2023 (source: my own picture)

Figure 7 shows the time series and spectrum of the gamelan signal. The Fourier transform results showed a natural frequency of 328 Hz for the gamelan, consistent with the Python processing. Algorithm on the fourier transform, the error caused is when N is the value of the power of 2 (Setiawan et al., 2017). The result of the Fourier transform is a complex number consisting of real and imaginary numbers. Then the transformation results are plotted into absolute value form. Mathematically, it can be formulated into equation 2.

$$|z| = \sqrt{[Re(z)]^2 + [Im(z)]^2} \qquad (2)$$

Re and Im are real numbers and imaginary numbers. In addition to using the Python programming language and GNU Octave software, researchers conducted interviews with Gamelan artisans in the Panggungharjo area of Sewon, Bantul. The interview instrument was developed to gather information on the concept of learning Gamelan musical instruments. After conducting the interview, the researcher analyzed the results. The interview instrument is shown in Table 3.

Table 3. Interview Instrument, 2023 (source: my own results)

No	Interview Instrument	Concept
1.	What are the basic materials for making Gamelan?	Chemistry
2.	What is the composition of the Gamelan?	Chemistry
3.	What material has the best tone quality and is in high demand?	Physics and Chemistry
4.	Do the thickness, length, and width of Gamelan instruments affect the sound they produce?	Physics
5.	How to set the tone in Gamelan musical instruments?	Physics
6.	Do Gamelan instruments have limitations in tone?	Physics

Gamelan makers use 3 basic materials: Iron, Brass, and Bronze. According to interview results, the bronze base material is most in demand because it offers a longer tone than other materials. The composition of making bronze Gamelan uses a ratio of 3 kg of white tin and 10 kg of

copper. Other gamelan craftsmen explain the composition of bronze as 78% copper (Cu) and 22% white tin (Sn). The material is then melted together and made into a Gamelan tool. The flat and curved shapes of Gamelan musical instruments affect the high and low tones produced. Based on the interview results, Gamelan musical instruments are mostly related to physics subjects. This shows that Gamelan is an art form that can be used as a learning medium in the classroom. Researchers recommend applying a gamelan musical instrument signal-processing simulation to classroom learning. The concept of science based on local wisdom can help students learn in a context relevant to everyday life.

Through the developed gamelan signal processing simulation, students can engage in several exploration-based learning activities. They can import or record gamelan sound data, observe waveforms in the time domain, and analyze the frequency spectrum using Fourier transforms. Furthermore, they can identify dominant frequencies, compare analysis results across the time and frequency domains, and interpret the physical meaning of the observed spectral peaks. Students can also modify specific parameters in the code or input data to observe changes in the analysis results, thereby encouraging analytical and experimental thinking. Through these activities, students not only understand the theoretical concepts of waves and frequencies but also engage in problem identification, analysis, and planning; apply mathematical procedures; and independently evaluate results.

Despite its great potential, project-based education is not without its problems. Without adequate attention to ways to support teachers and learners, innovative project learning models are difficult to implement. Careful attention should be paid to the design of project questions and related activities, as well as to strategies to improve teachers' implementation of projects. There are some weaknesses in the implementation of the PjBL model, as stated by (Baidowi et al., 2015) dan (Oktavianto, 2017). First, it requires a relatively long time to complete the project. Second, it demands students' independence and responsibility in completing the project. In line with this, (Aini, Lesmono and Wahyuni, 2018) explained that it requires careful preparation in planning the learning process of the PjBL model, so that students are more interested in participating in the lesson, and need to pay attention to the time allocation used in accordance with the level of difficulty of the project that students work on. Although there are challenges in project-based learning, with careful planning, adequate support, and effective management, these problems can be overcome. Teachers need to provide learners with appropriate guidance, feedback, and resources to help them overcome challenges and succeed in project-based learning. Teachers should do project-based learning using programming simulations because it yields strong results in problem-solving skills and learning independence. As the results of research conducted by (Novianti (2017); Pahlawan and Tambusaii, (2019). Research by researchers and previous researchers shows that programming simulations can increase students' problem-solving skills and learning independence.

The developed gamelan signal-processing simulation offers advantages over conventional media by integrating real gamelan sound data with Fourier transform analysis, enabling students to connect abstract wave concepts to quantitative representations of local cultural phenomena through time- and frequency-domain visualizations. Using open-source software such as Python and GNU Octave, the simulation supports flexible, investigation-based learning. It aligns with problem-solving stages, allowing students to identify signal characteristics, determine dominant frequencies, and interpret spectrum results systematically while fostering independent exploration. It also supports project-based learning by engaging students with authentic data and culturally relevant contexts. However, the study is limited to the initial development stage without classroom trials or

effectiveness testing, relies on descriptive data, and has not yet been integrated into an online learning platform, indicating the need for further empirical research and broader implementation.

5. Conclusion

This study developed a gamelan sound signal-processing simulation based on the Fourier transform, implemented in Python and GNU Octave, capable of representing signals in both the time and frequency domains and consistently identifying the natural frequency of 328 Hz. The use of open-source platforms enhances accessibility and flexibility in computational physics learning. At the same time, integrating gamelan sound data provides a contextual and meaningful approach to studying waves and sound. The simulation supports visualization, quantitative analysis, and connections between mathematical representations and real physical phenomena.

However, this research is still limited to the initial product development stage and has not yet included classroom trials or effectiveness testing in improving problem-solving skills and learning independence. Therefore, further studies are needed to evaluate its practicality, develop structured learning modules, and integrate the simulation into LMS or web-based platforms to improve accessibility and implementation in physics learning.

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