Teaching sine wave concept through simulation for elementary school students

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Abstract. In the Natural Science subject for elementary school, one learns about the waves topic which is derived material from sound energy. Students have been taught that waves have periods and frequencies, including the theoretical application of its application in real life. However, the teacher requires a high effort to explain it because it is quite complicated with a short teaching duration. With the help of information computer technology such as an EDA-based software tool, elementary school students can more quickly understand the sine wave material. This paper reveals on how to teach a sine wave material for children with the following topics, i.e., 1) fundamental concept; 2) the introduction of the instrumental tool; 3) introduction of the used Simulator, periods and frequencies measurement using Oscilloscope instruments; 4) Measurement example; and 5) Practicum. These topics are packaged in a new course outside formal schools. The Circuit Wizard simulator was chosen as a teaching tool; we hope to make abstract contents (ex. sine waves) more exact for children and serve many benefits to improve the teaching quality. This paper focuses on the output frequency measurement using Frequency Generator (FG) & analog Oscilloscope pair under the Circuit Wizard simulation. This course can be taken by 4th – 6th grade (10 – 12 years old children).

1. Introduction
In the Natural Science subject, elementary school students in Indonesia have been taught about energy forms, precisely in sound energy topics [1]. The sound material is a Subchapter (minor) of the Energy chapter. Elementary school students already know three sound categories, namely Human’s frequency range or audio-sonic (20 Hz – 20 kHz), infra-sonic (<20 Hz), and ultra-sonic (20 kHz). They also know the signal form (limited to sinusoid form), frequency definition, and period definitions. The elementary school students can find the wave’s frequency (f) by knowing the period (T) first. Problems given to elementary school students are still simple: looking for one of the two parameters (“f” or “T”). There are many web-based calculator programs for converting “f” to “T” or vice versa, as provided by:

- http://www.sengpielaudio.com/calculator-period.htm,
- http://www.calctool.org/CALC/other/converters/freq,
- https://www.sensorsone.com/frequency-to-period-calculator/
- https://www.unitjuggler.com/convert-frequency-from-Hz-to-ms(p).html
- Etc.

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Elementary school students will be facilitated by this web-based tool in solving the tasks. In school, the topic of sound is explained at a glance. Elementary school students can master the sound material and its derivative material through practice in real laboratory; it can be done with a specific trainer kit [2].

The learning process will be more attractive through practice activity than the online calculator’s usage mentioned because it provides real experiences to elementary school students. The actual waveform being demonstrated directly to the elementary can help them understand the abstract contents like period and frequency. Electronic tools (instruments) can accommodate this, namely a Frequency Generator (FG), a tool to generate frequencies, and Frequency Counter or Oscilloscope as a frequency reader. These three tools are only available in vocational high schools and technical college [3,4]. For this reason, virtually approach can be a solution. On the other hand, the constraints of limited lesson hours are also an obstacle. Thus, particular time allocation is needed to discuss the concept of the waves.

This paper proposes a new course that explicitly discusses the frequency and period through a practical approach. Due to the limited time allocation for Natural Science subjects in elementary schools, this course package can be taught outside of compulsory subjects. It can become a reference for new extracurricular material aside from other technology-based extracurricular programs, such as robotics, electronics, basic programming, Etc. The sine wave course is derived from the forms of energy chapter taught in the 4th grade of elementary school students. By this illustration, the reader will know the position of this proposed course. This material will be complicated for students if their cognitive achievement is increased from “Understanding” to “Application.”

Elementary school students will carry out a virtual practicum at the end of the course accompanied by teachers. The virtual approach uses Circuit Wizard software to overcome the limitations of high-cost practical tools, namely FG and Oscilloscope. The Circuit Wizard can provide a virtual world and nice animation [5]. Hopefully, the abstract content (ex. Sine Waves) will be more straightforward for children and beneficial for improving teaching quality. Moreover, the teacher can use this paper to teach the sine waves concept to elementary school students.

### 2. Methods

In this part, we define the subtopic of the sine wave course following its duration. We expect that the course can be finished at least 60 hours; it is divided into ten activities. Students are given a pre-test and a post-test at each meeting by the teacher to know their learning progress, understand the student learning constraints, and measure the elementary school students’ learning outcomes. If this is still not achieved, then the remedial teaching should be performed well by the teacher. The elementary school students should have the initial requirement, at least they can operate the mouse (slide, left-click, and right-click) of a laptop/PC. If elementary school students are not proficient in mouse operation, the teacher can intensively assist these underprivileged students (see table 1).

The content summary for each subtopic will be explained in the Results section.

| Meetings | Subtopic | Description | Duration |
|----------|----------|-------------|----------|
| 1-2      | Fundamental concept | The teacher reviews the forms of energy and sound. Elementary school students are given an overview of the sound applications in everyday life. Then a more detailed understanding of sound definitions; examples of sound energy sources; sound propagation; sound reflection; wave propagation; waveforms; definition of the period; definition of frequency; definition of amplitude; fundamental math division of numbers; basic mathematics of exponents; fundamental math division of exponents; frequency and period formulas; example of tasks/problems and their solutions. | 6 hours |
Table 1. Cont.

| Time | Subtopic | Activity |
|------|---------|----------|
| 3-4  | Instrument | The teacher provides knowledge to elementary school students about instruments to measure the frequency; delivers the knowledge of signal generator devices that can be adjusted for frequency, period, and amplitude (i.e., FG)—then given a photograph of the real instruments following with the instrument’s parts and their use. Elementary school students are given an overview of the Circuit Wizard software; buttons and functions; an analog Oscilloscope and FG in the virtual environment; inserting components in the Circuit Wizard; and how to connect the components. The teacher explains the comparison of the real instrument with the Circuit Wizard’s virtual instrument through the photographs. Furthermore, it also explains how to connect an analog Oscilloscope to FG. Elementary school students are given knowledge on operating the virtual FG and how to measure the frequency read on the virtual analog Oscilloscope. Examples of measurements with different frequencies are also taught in this Subtopic. This week, the elementary school students do a practicum, where they are asked to provide the two instruments needed, and the two are connected. The teacher provides a frequency value that must be generated by the virtual FG. Next, elementary school students are asked to read the frequency measured by the virtual analog Oscilloscope. |
| 5-6  | Software & Wiring | 6 hours |
| 7-8  | Measurement Example | 6 hours |
| 9-10 | Practicum | 6 hours |

3. Results

3.1. Subtopic fundamental concept

Some basic waveforms, as depicted in Figure 1(a), are introduced to elementary school students. However, for this course, only sinusoid waves are taught explicitly for the further materials. The waveform is a continuous thing, so it has a period (T). The frequency (f) of the waveform can be found by Eq. (1). Figure 1(b) illustrates a sinusoid waveform following with the description. As we can see, the Period (T) is the time required to perform one vibration. Amplitude (A) is the height and low of the wave. Frequency (f) is the number of vibrations per unit time (within one second). Where, $f =$ Frequency in Hertz (Hz) and $T =$ Period in seconds (s) [6].

$$f = \frac{1}{T}$$  \hspace{1cm} (1)

Where,

$$T = \frac{1}{f}$$ \hspace{1cm} (2)

![Figure 1](image-url)  

**Figure 1.** (a) Basic waveform, reproduced from [7]; (b) a full wave of Sinusoid (Sine) wave.
3.2. Subtopic instrument
A Frequency Counter or Oscilloscope is needed to measure the frequency and wave period [8]. We can directly know the frequency and wave period in the Frequency Counter because these two parameters are displayed on the Frequency Counter’s LCD. In contrast, the Oscilloscope requires a little bit of calculation by observing the signal on the Oscilloscope’s LCD [9–11]. To produce a wave with a stable frequency, the FG is used (Figure 2a). In operation, the FG is adjacent to an Oscilloscope. There are two types of Oscilloscopes, namely Analog (Figure 2b) and Digital (Figure 2c).

The teacher introduces these instruments [12]-through original photos- accompanied by descriptions of instrument parts, to the elementary school students. There are many buttons on the instrument; this will confuse students on how to operate the instrument. To avoid this, the teacher explains the essential button and selector functions: in FG, namely the power switch, frequency tuning, amplitude tuning, multiplier, and the option for the signal generated form (e.g., Square, Triangle, and Sine). Then on the Oscilloscope, namely the power switch, T/DIV, V/DIV, shift vertically, and shift horizontally. The teacher, not the students, carry out the calibration process.

3.3. Subtopic Software and Wiring
Figure 3 visualizes a worksheet of the Circuit Wizard software. The teacher explains only the necessary menus, buttons, and their functions. The components used for virtual demonstration purposes are “Off-Board” components. To access this feature, the teacher can see the bottom left side of the software, where there are three options, namely Circuit Diagram, PCB Layout, and Bill of Material. In this case, the PCB layout option is selected. To insert components and connect components in the Circuit Wizard is very simple, only Drag and Drop.

Figure 2. Photograph of instruments.

Figure 3. Circuit Wizard worksheet.
Table 2 compares the devices (i.e., Analog & Digital Oscilloscope, SPST switch, and FG) in the real and virtual devices. In this meeting, the teacher will show and explain it to the student. However, the analog-type Oscilloscope was chosen because the digital-type Oscilloscope is not available in Circuit Wizard. Figure 4 illustrates how to connect the FG to the analog Oscilloscope: the red-colored channel (“+” port) is connected to Channel 1 or Channel 2 of the analog Oscilloscope while the black-colored channel (“0” or “ground” port) on the FG is connected to the Oscilloscope’s ground channel. The SPST switch bridges both.

| No | Components              | Real world | Virtual world provided by Circuit Wizard |
|----|-------------------------|------------|------------------------------------------|
| 1  | FG                      | ![Image](image1.png) | ![Image](image2.png) |
| 2  | SPST Switch             | ![Image](image3.png) | ![Image](image4.png) |
| 3  | Digital Oscilloscope    | ![Image](image5.png) | Not Available |
| 4  | Analog Oscilloscope     | ![Image](image6.png) | |

The Virtual Function Generator scale is limited to 0.3 Hz to 3 Hz, and can only be input one digit. Thus, if we want to set the frequency 5 Hz (for example), we can enter the number 0.5 and then set the multiplier of 10. Another example, to produce a frequency of 50 Hz, we can enter the number 0.5 and set the multiplier of 100.

![Image](image7.png)

(a) (b)

**Figure 4.** FG – Analog Oscilloscope connection: (a) basic wiring; (b) wiring in a virtual practicum.

3.4. Subtopic measurement example

The teacher explains how to read the peak-to-peak voltage and frequency on the Oscilloscope screen at this meeting. This part is a bit complicated, so it needs to be explained carefully to elementary school students. Figure 5(a) is part of the Oscilloscope, which is the Oscilloscope’s display. Figure 5(b) is a screen image of an analog Oscilloscope, where the Y (Horizontal) axis represents voltage (V), while the X (vertical) axis represents time. The horizontal centerline is a neutral (zero) reference. For straightforward reading, the signal is usually shifted precisely to the center (zero) position.
Figure 5. (a) Analog Oscilloscope’s display; and its (b) description.

Eq. (3) is used to read the peak-to-peak voltage displayed in the analog Oscilloscope, where the unit is Volt peak-to-peak (Vpp).

\[ V = \frac{V}{\text{DIV}} \times \text{DIV} \]  

(3)

To measure frequency, the first step that must be done is to calculate the period (T) as in Eq. 4. The period calculation result is then converted to the frequency (f) as in Eq. 1.

\[ T = \frac{T}{\text{DIV}} \times \text{DIV} \]  

(4)

The teacher provides an example to facilitate understanding theory and mathematical calculations. They were given a sine waveform, as shown in Figure 6. The analog Oscilloscope scale is as follows: T/DIV = 2 milliseconds and V/DIV = 1V. The first step is to calculate the vertical DIV, which is 4 DIV because there are four squares. The peak-to-peak voltage of the waveform in Figure 6 concerning Eq. (3) is,

\[ V = \frac{V}{\text{DIV}} \times \text{DIV} = 1V \times 4 \text{ DIV} = 4 \text{ Vpp} \]

Calculated from the waveform’s initial period to the end period (one full wave, as illustrated in Figure 1), we get 4 DIV horizontally (four squares). Thus, the period and frequency by using Eq. (4) and Eq. (1), the period and frequency will be,

\[ T = \frac{T}{\text{DIV}} \times \text{DIV} = 2 \text{ ms} \times 4 \text{ DIV} = 8 \text{ ms} \]

\[ f = \frac{1}{T} = \frac{1}{8 \text{ms}} = \frac{1}{8 \times 10^{-3}} = \frac{1 \times 10^3}{8} = 125 \text{ Hz} \]

Figure 6. An example of frequency measurement.

3.5. Subtopic practicum

After the basic concepts are taught well to the elementary school students, they will do a practicum on the 9-10th meeting. Students are asked to provide the two instruments required, and both of them are then connected. The teacher gives the list of frequency values that must be generated by virtual FG. Afterward, elementary school students are asked to read the frequency measured by the virtual analog
Oscilloscope. Firstly, the laptop with the Circuit Wizard software installed is opened; select PCB Layout on the Circuit Wizard to enter the virtual laboratory mode. The whole step is illustrated in Figure 7(a).

1) Provide a virtual analog Oscilloscope and a virtual FG, which can be found in Test Equipment ➔ Virtual Instruments;

2) Connect the two instruments with SPST Toggle Switch;

3) Elementary school students press the “Run” button to start the simulation, then turn “on” the virtual analog Oscilloscope by pressing the power switch and turning “on” the virtual FG. The Sinusoid waveform is selected on the FG. Herein, the signal displayed by the virtual Oscilloscope is sine, as depicted in Figure 1;

4) The two switches are then clicked. Therefore, the positive probe (+) and the ground probe (Gnd) on the two instruments are connected;

5) Enter the frequency value of 1 Hz on the virtual FG;

6) Shifts the T/DIV on the virtual analog Oscilloscope to 1 ms/DIV;

7) Press the Trigger (TRIG) button on the virtual analog Oscilloscope;

8) Immediately click “Pause” the simulation. Thus, the appeared signal can be easily read on the virtual analog Oscilloscope screen. Elementary school students must notice the T/DIV value displayed by the virtual analog Oscilloscope (Figure 7b);

9) The frequency displayed on the virtual analog Oscilloscope must be ensured the same as the frequency generated by the virtual FG, which is 1 Hz:

\[ T = \text{DIV} \times \frac{T}{\text{DIV}} = 1 \times 1 \text{s} \Rightarrow 1 \text{s}, \text{ therefore } f = \frac{1}{T} = \frac{1}{1 \text{s}} = \frac{1}{1} \Rightarrow 1 \text{ Hz} \]

10) Concerning the calculations, it was found that the two instruments were paired: virtual FG generated a 1 Hz frequency, and the virtual analog oscilloscope read the same frequency, i.e., 1 Hz. Furthermore, elementary school students are asked to adjust the frequency on virtual FG according to Table 2: 1.25 Hz, 2.5 Hz, 5 Hz, 10 Hz, 12.5 Hz, 25 Hz, 50 Hz, and 100 Hz.

Table 3 is the example of an entries done by elementary school students, consisting of several parameters: T/DIV, DIV, calculation of “T” & “f.” While Figure 8 is the basis for the frequency calculations results, which are carried out by elementary school students by looking at the number of DIV & T/DIV.

![Figure 7](image-url)  
**(a)** Several steps for practicum; **(b)** reading the period which is displayed by the analog Oscilloscope.
**Table 3.** Observation of the output frequency full-filled by the elementary school students.

| No | FG (Hz) | Oscilloscope | Calculation (T) | Calculation (f) |
|----|---------|--------------|-----------------|-----------------|
| 1  | 1.25    | 250          | T= 3.2 x 250 ms = 800 ms or 800 x 10⁻³ | f= \( \frac{1}{800 \times 10^{-3}} \) = \( \frac{1000}{800} \) = 1.25 Hz |
| 2  | 2.5     | 100          | T= 4 x 100 ms = 400 ms or 400 x 10⁻³ | f= \( \frac{1}{400 \times 10^{-3}} \) = \( \frac{1000}{400} \) = 2.5 |
| 3  | 5       | 25           | T= 8 x 25 ms = 200 ms or 200 x 10⁻³ | f= \( \frac{1}{200 \times 10^{-3}} \) = \( \frac{1000}{200} \) = 5 |
| 4  | 10      | 25           | T= 4 x 25 ms = 100 ms or 100 x 10⁻³ | f= \( \frac{1}{100 \times 10^{-3}} \) = \( \frac{1000}{100} \) = 10 |
| 5  | 12.5    | 25           | T= 3.2 x 25 ms = 80 ms or 80 x 10⁻³ | f= \( \frac{1}{80 \times 10^{-3}} \) = \( \frac{1000}{80} \) = 12.5 |
| 6  | 25      | 25           | T= 1.6 x 25 ms = 40 ms or 40 x 10⁻³ | f= \( \frac{1}{40 \times 10^{-3}} \) = \( \frac{1000}{40} \) = 25 |
| 7  | 50      | 25           | T= 0.8 x 25 ms = 20 ms or 20 x 10⁻³ | f= \( \frac{1}{20 \times 10^{-3}} \) = \( \frac{1000}{20} \) = 50 |
| 8  | 100     | 1            | T= 10 x 1 ms = 10 ms or 10⁻³ | f= \( \frac{1}{10 \times 10^{-3}} \) = \( \frac{1000}{10} \) = 100 |

**Figure 8.** Experimental results done by the elementary school students: (a) 1.25 Hz; (b) 2.5 Hz; (c) 5 Hz; (d) 10 Hz; (e) 12.5 Hz; (f) 25 Hz; (g) 50 Hz, and (h) 100 Hz.

### 4. Conclusion and future work

In this paper, a proposal for a new course has been carefully determined. This course is taught for elementary school students (4th to 6th elementary school level, or 10 to 12 years old children); it is focused on discussing sine waves, which are then divided into several subtopics (i.e., Fundamental concept, Instrument, Software & Wiring, Measurement Example, and Practicum). The teaching process and practicum involve software that provides a virtual laboratory, namely the Circuit Wizard. The
success rate of this proposed course can not yet be measured. Before this program is launched, it is worth to apply to one pilot school first.

In the future, we will implement this course in a real class (little group) to observe the factors that become constraints during the course.

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