

Improve critical thinking skills using traditional musical instruments in science learning

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ABSTRACT

Experiment activity is an essential part of science learning. *Suling* (flute), a traditional musical instrument from West Java, can be used as a learning media for sound wave concepts. Technology-based mobile can be used as an experimental tool is *Phypox*. This study aims to report using a combination of *Suling* and *Phypox* in experiment activities. The designed activity aims to engage students in critical thinking. The instrument for measuring critical thinking consists of five questions based on the critical thinking aspect: interpretation, analysis, evaluation, inference, and explanation. The study used a one-group pre-and post-test design on 32 8th-grade students at one of the junior high schools in West Java Province, Indonesia. The study procedure is a pre-test, discussion of *Suling*'s concepts, introduction to *Phypox* apps, experiment activity, presentation, and post-test. Data analysis uses the normalized gain to compare the pre-and post-test. Experiment activities help students to understand frequency, open organ pipes concepts, and investigate the speed of sound produced by *Suling*. The study found a significant change in the pre-and post-test scores of students after experimenting, so it could be interpreted that the experimental activities using *Suling* and *Phypox* affected critical-thinking students.

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1. INTRODUCTION

Physics is considered to be difficult by many students. In some literature, students view physics as a conceptually complicated, abstract, and only exciting subject for extraordinarily gifted students [1], [2]. However, teachers convince that with a suitable teaching strategy, students can find the physics course is understandable and achieve a good learning outcome [3], [4].

According to previous studies, students' experience relating to concrete, real-life examples in physics concepts may create meaningful learning [5], [6]. Meaningful learning may engage students to think critically [7], [8]. Students' view on physics also affects their performance in physics subject [1]. Creating fun learning activities that allow students to experience physics concept examples related to the environment surrounding students is feasible for attracting students' interest in learning physics.

Local culture can be brought into the physics classroom to build a learning environment that relates to students' daily life, making the learning process meaningful. Existing indigenous knowledge integrated

into science education creates effective hybridization, incubation, skill acquisition, and sustainable development [9]. Besides, integrating local culture into school curricula has an advantage in perceiving national identity [10].

Indonesia is a big country that consists of a lot of ethnic groups. In Indonesia's context, various local culture has potencies to be integrated into science learning. In a previous study, the making process of traditional textile called "Batik" was brought to physics class to show the application of the thermal physics concept [11]. Traditional toys and games also have been used to engage Indonesian students in analytical and critical thinking during the discussion about mechanics [12], [13]. Some studies also show the feasibility of using traditional dance and performance to show the mechanics concept to students [14], [15].

In the west part of Java Island in Indonesia, the influence of Sundanese culture is dominant. The Sundanese culture can be seen through traditional musical instruments called "*Suling*" which most middle school students are familiar with. *Suling* is a woodwind instrument like a flute. Traditional musical instruments can engage students in learning sound wave concepts [16]. The application of the sound wave concept can be seen directly on a musical instrument like *Suling*.

The tremendous development of technology has influenced all aspects of life, including education. Students are more engaged in learning when recent technology is involved [17], [18]. A smartphone is one of the technologies that has developed significantly and is widely used by students. The function of the smartphone has evolved a lot. Nowadays, most smartphones have sensors that can be applied for a physics experiment. A free app available on both Android and iOS called *Phyphox* (an acronym for physical phone experiments) has been developed to support physics learning with smartphone sensors [19]. *Phyphox* has features such as a timer, light sensor, magnetometer, audio scope, audio spectrum, and tone generator. It can be used as a data acquisition tool in physics experiments [20]. It increases access to laboratory activity since not every school has complete experimental devices, but most students have a smartphone. Hence, *Phyphox* has a vast potential to be used as a didactic tool [21].

In the era of the industrial revolution, with significant growth of advanced technology, students need to be prepared with critical thinking skills [22], [23]. Critical thinking involves essential abilities such as reasoning, hypothesis testing, argument analysis, likelihood and uncertainty analysis, problem-solving and decision-making [24]. Nowadays, school curricula, including physics classes, should accommodate critical thinking skills cultivation. Critical thinking skills can increase when the stimulation provided is concrete and has been experienced by students directly, such as in local culture [25]. Integrating technology and local-culture context can be combined in the physics classroom to engage students in learning physics and developing their critical thinking skills.

In this study, a physics learning activity based on the Sundanese local-culture context is designed and implemented in the physics classroom. Traditional music instruments *Suling* and mobile technology *Phyphox* are brought to physics class. Students collaborate to analyze the sound wave produced from *Suling* during the learning process using *Phyphox* on their smartphones. This study aims to investigate soundwave experiments using a traditional musical instrument and their effect on students' critical thinking skills.

2. LITERATURE REVIEW

2.1. Learning media

Learning media is anything related to software and hardware components that can be used to convey the content of teaching materials from learning resources to students individually or in groups to stimulate student learning [26]. Learning media is a tool for teachers to deliver material content to students that are understood more quickly and attracts students to learn more [27]. Science learning media is a tool for a teacher to teach science concepts. Learning media can bring students to interact with phenomena or objects studied directly.

2.2. Analysis of physics concepts in *Suling*

Suling is a wind instrument from West Java, as shown in Figure 1. The main concept in the *Suling* is sound waves, where waves propagate through a certain medium and are mechanical waves classified as longitudinal waves. Sound requires a medium to reproduce and can be heard, one of which is air. When airflow is blown at a certain pressure, the pipe will resonate (make a sound) at a certain tone.

The organ pipe uses an air column as a sound source. Resonance occurs in the air column. When *Suling* is blown, a blowing sound causes the air in the air column to vibrate. The natural frequency of the organ pipe depends on the length of the pipe and the state of the end of the organ pipe, i.e., open or closed. Furthermore, *Suling* is an open organ pipe with the sound wave shown in Figure 2.

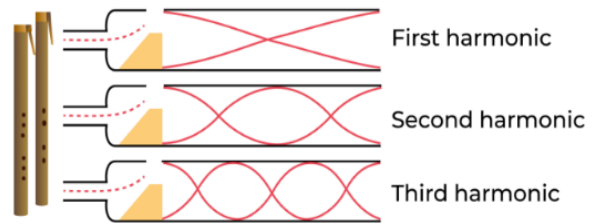
Figure 1. *Suling*

Figure 2. The sound wave in an open organ pipe

Figure 2 shows that the deviation at both ends of the open organ pipe is the maximum and minimum mid-difference. The pressure at the ends of the pipe is minimum, and the pressure at the center is maximum. The length of the air column L shows that in the first harmonic, only half a wavelength occurs, namely a quarter wavelength and a quarter wavelength. Adding them up will get half the wavelength. So, the frequency of the first harmonic is (1).

$$f_1 = \frac{v}{2L} \quad (1)$$

The length of column L in the second harmonic shows quarter, half, and quarter wavelengths so that it becomes one full wavelength when added together. The second harmonic frequency is (2).

$$f_2 = \frac{v}{L} = 2f_1 \quad (2)$$

Where the third harmonic is obtained as (3).

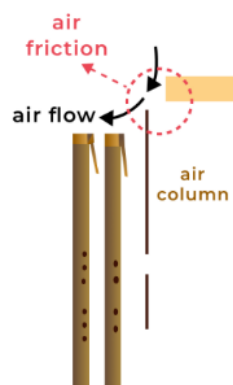
$$f_3 = \frac{3v}{2L} = 3f_1 \quad (3)$$

The next harmonic frequency is an integer multiple of the first harmonic frequency. The harmonic frequency in an open organ pipe was presented in (4),

$$f_n = n \frac{v}{2L} \quad (4)$$

with $n : 1, 2, 3, 4 \dots n$

Figure 3 shows that the sound produced by the *Suling* comes from the air in the pipe column vibrations that rub against the air blown by the player (flutist) in a direction that is not parallel to the direction of the column. The distance between the blowhole and the pitch hole will cause a change in frequency. Therefore, the pitch is related to the concept of frequency.

Figure 3. The sound production on *Suling*

2.3. *Phypox* application as an advanced tool in experiment activity

Phypox is a free application platform available on Android and iOS that is useful for displaying the frequency spectrum [19]. Aachen University developed the *Phypox* app to help conduct science experiments using smartphones. *Phypox* utilizes sensors on smartphones so that there are no additional measuring tools. Today, advanced mobile devices contain sensors that receive data from the environment. Smartphones generally have a barometer, light sensor, magnetometer, gyroscope, accelerometer, and microphone [28].

2.4. Critical thinking skills

Critical thinking is rational and reflective thinking that focuses on deciding what to believe and do [29], cognitive activity related to the use of the mind [30] involves cognitive skills and character [31]. Critical thinking is the ability to prove something, interpret what something means, and solve problems, including interpretation, analysis, inference, evaluation, explanation, and matching [32]. The definition of each aspect, namely i) Interpretation to understand the meaning of something; ii) Analysis to understand more deeply a matter can be through data, and information; iii) Inference to conclude data collection and information; iv) Evaluation to assess the credibility of the conclusions generated; v) Explanation to state the truth, reasons, and evidence; and vi) Matching as the final stage, namely validation. The indicators used in this study are interpretation, analysis, evaluation, inference, and explanation.

3. RESEARCH METHOD

3.1. Research design

This study explores using *Suling* and *Phypox* to wave sound experiment activities in junior high school. A one-group pre-and post-test design was used in the study. Pre- and post-tests were administered before and after students were exposed to the experiment activity.

3.2. Research participant

The research was conducted in a state junior high school in West Java, Indonesia. The participant of this study was 32 8th-grade junior high school on science subjects studying sound waves. The research participant was selected by random cluster sampling. They consisted of 14 male and 18 female students. Based on information from the science teacher, an experiment using a smartphone and traditional musical instruments was the first time at this school. It will become the first experience for teachers and students.

3.3. Instruments

The instruments used in this research are pre-test and post-test to investigate how the experiment activity affects students' critical thinking skills. The instrument consists of five essay questions related to aspects of critical thinking, such as interpretation, analysis, evaluation, interference, and explanation. Each essay question has a maximum score of 5. There were two lectures as an expert have validated the instrument. The question indicators in this study are shown in Table 1.

Table 1. The question indicator in this research

Number questions	Critical thinking aspect	Question indicator
1	Interpretation	Students can interpret the phenomena of sound waves produced on traditional West Java musical instruments.
2	Analyze	Students can analyze that the phenomenon of loudness is related to amplitude, while pitch is related to frequency.
3	Evaluate	Students can evaluate whether blowing the flute loudly or weakly on a musical scale will produce the same frequency.
4	Inference	Students can conclude that the air column length shortens to produce high-frequency sound.
5	Explain	Students can explain how to find the speed of sound in the air by using the phenomenon of the wind instrument

3.4. Procedure

This study was carried out in the second semester of the academic year 2021-2022 for students studying soundwave material. The experimental design begins with a pre-test to measure initial critical thinking skills in students. Then, discussion concepts of *Suling*, where the teacher explains science concepts, will support the experiment activity. Experiment activities will use a mobile app, so students need to be introduced to *Phypox* as an advanced tool. Students were asked to install *Phypox* before the experiment activity occurred. The experiment was conducted in the music room because the media used was *Suling* as a

musical instrument in West Java. Students use a ruler to measure the frequency using the *Phypox* and the length of the column. After completing the experiment, students were asked to present the experiment's results. The final stage is a post-test to evaluate students' critical thinking skills. The procedure of this study is shown in Figure 4.

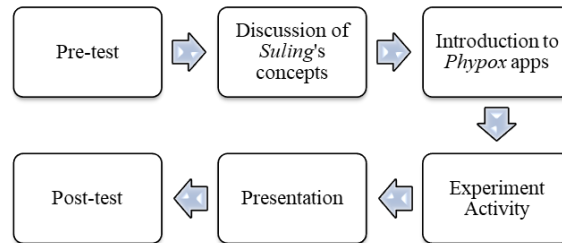


Figure 4. The procedure of the research

3.5. Data analysis

To describe the comparison between the pre-and post-test, use the normalized gain $\langle g \rangle$. The formula for calculating the normalized gain is presented in (5) and the criteria for the normalized gain score are presented in Table 2.

$$\langle g \rangle = \frac{\%post - \%pre}{100 - \%pre} \quad (5)$$

Where, % post is the percentage post-test score and % pre is the percentage pre-test score.

Table 2. Criteria of normalized gain score

Normalized Gain $\langle g \rangle$	Criteria
$\langle g \rangle \geq 0.7$	High
$0.7 > \langle g \rangle \geq 0.3$	Medium
$\langle g \rangle < 0.3$	Low

4. RESULTS AND DISCUSSION

4.1. Result of experiment activity

Experiment activity is the crucial stage in this research. The research object in this research is *Suling*, a traditional musical instrument in West Java, Indonesia. There are two types of *Suling* such as 4-holes as displayed in Figure 5(a) and 6-holes as displayed in Figure 5(b). Students have been taught how to play musical instruments in art science, as shown in Figure 5.

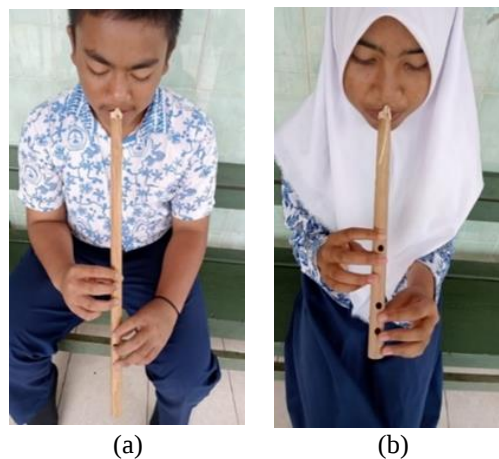


Figure 5. Students playing *Suling* with (a) 6-hole type and (b) 4-hole type

Implementing *Suling* as a tool in the experiment activity is to find the relationship between the period and the frequency and measure the 'speed of sound in the air' from the sound produced by *Suling* with five musical scales called *pentatonic*. The five musical scales are *da* (1), *mi* (2), *na* (3), *ti* (4), and *la* (5). The frequency of each scale is measured using the Audio Spectrum contained in the *Phypox*. The display of *Phypox* as an advanced tool in this experiment is shown in Figure 6. Figure 6(a) is showing audio spectrum, Figure 6(b) is showing recording the voice, and Figure 6(c) is showing frequency result.

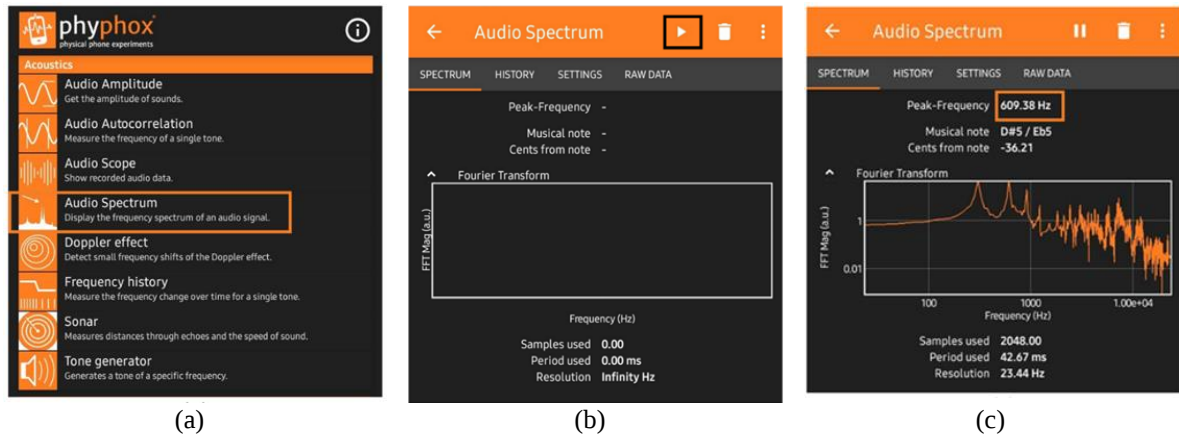


Figure 6. Display of *Phypox* apps in (a) audio spectrum, (b) recording the voice, and (c) frequency result

The experiment activity starts with students measuring the air column length as shown in Figure 7(a). Then, the students played the flute with pentatonic notes (*da*, *mi*, *na*, *ti*, and *la*) sequentially. One student plays *Suling*, and another records the sound from *Suling* using *Phypox*, as shown in Figure 7(b). Then the frequency results are shown in the *Phypox*. Next, repeat the procedure for other musical scales. Students were asked to calculate the speed of sound in the air based on the experimental activity using the graphical method by calculating the slope of the line. The formula frequency in an open organ pipe is (6).

$$f = \frac{v}{2L} \quad (6)$$

The formula can be interpreted as a mathematical equation $y = mx$ same with $f = \frac{v}{2} \frac{1}{L}$. So, the slope of the line (gradient) m is $\frac{v}{2}$. To find the speed of the sound in the air is $v = \text{gradient } m \times 2$. Data analysis was shown in Table 3 and Figure 7.

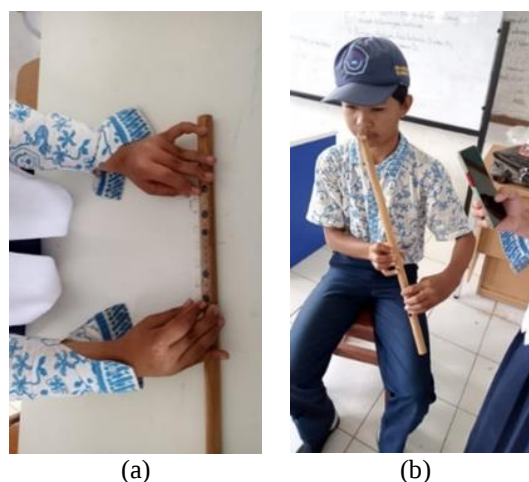
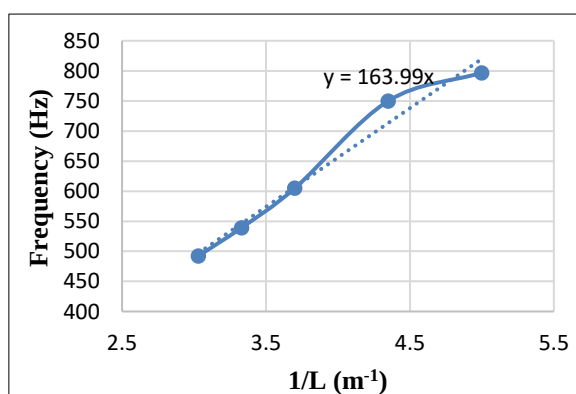


Figure 7. Experiment activities in (a) measuring the length of the air column and (b) implementation of *Phypox* when playing *Suling*

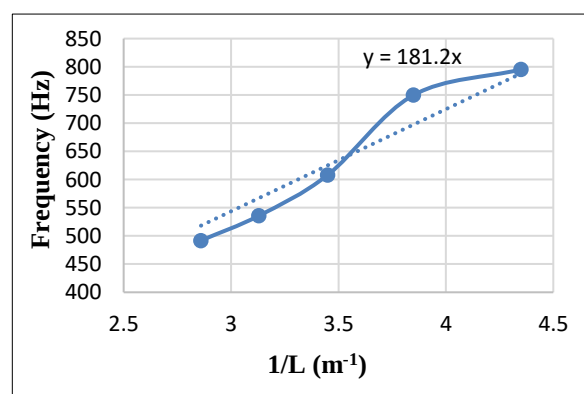
The data obtained from the experiment activity are column length and frequency, and then students are asked to complete the table as shown in Table 3. After the table is complete, students are asked to make a graph as shown in Figure 8. Then, calculate speed of the sound in the air using $v = \text{gradient } m \times 2$. Figure 8(a) shows that the mathematical equation is $y = 163.99x$ with a *gradient* m is 163.99. So, the speed of sound in the air for the *Suling* 4-hole type is $v = 2 (163.99) = 327.98$ m/s. Furthermore, Figure 8(b) shows the mathematical for the *Suling* 6-hole type is $y = 181.20x$. It can be interpreted that the slope of the line (*gradient*) is 181.20. So, the calculations speed of sound in the air is: $v = 2 (181.20) = 362.40$ m/s. Based on the experimental activities that have been carried out, it was found that the speed of sound in the air for *Suling* 4-hole and 6-hole type is 327.98 m/s and 362.40 m/s, respectively.

Table 3. Data processing to find the speed of sound in the air

Number of Instrument	<i>Suling</i> 4-hole type			<i>Suling</i> 6-hole type		
	Fingerstyle	$\frac{1}{L}$ (m^{-1})	f (Hz)	Fingerstyle	$\frac{1}{L}$ (m^{-1})	f (Hz)
<i>da</i> (1)		5.00	796.88		4.35	795.24
<i>mi</i> (2)		4.35	750.00		3.85	749.94
<i>na</i> (3)		3.70	604.84		3.45	608.12
<i>ti</i> (4)		3.33	539.24		3.13	535.96
<i>la</i> (5)		3.03	492.19		2.86	491.88



(a)



(b)

Figure 8. Graphical method of (a) *Suling* 4-hole type and (b) *Suling* 6-hole type

4.2. Effect experiment activity to critical thinking students

The results of students' critical thinking skills were found to have changed before and after using *Suling* and *Phyox* as learning media in the sound wave experiment. The critical thinking aspects selected are interpretation, analysis, evaluation, inference, and explanation because it follows the context of critical thinking based on problems in real life which found by students. The signification difference between the pre-and post-test for each critical thinking aspect can be seen in Figure 9.

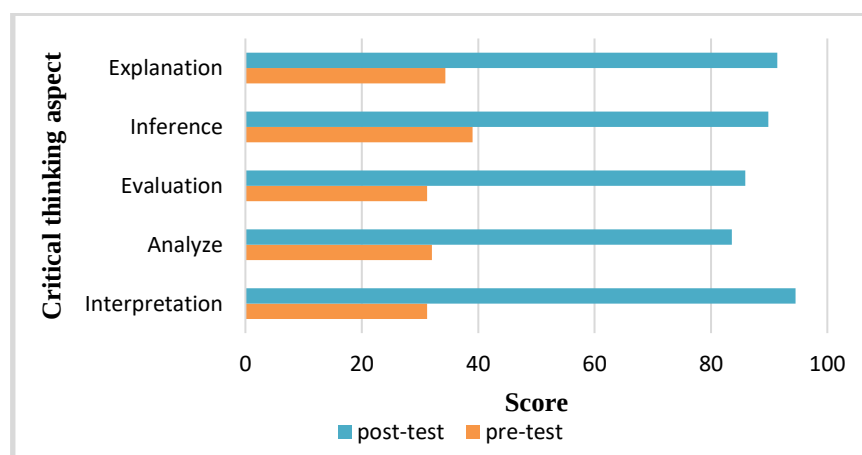


Figure 9. The improvement in scores for each critical thinking aspect

Figure 9 shows that each critical thinking aspect increases. Each aspect is represented by one question in the pre and post-test, which consists of five questions. The questions given are related to everyday life phenomena. The result show that the pre-test scores are still low, which means that students critical thinking skills are still lacking. In general, the average score for each question increased on the post-test. Then the gain score normalization was calculated to determine the increase in each aspect, as shown in Table 4. The table shows that all critical thinking aspect include high criteria and the most significant increase is in the interpretation aspect.

Table 4. Comparison between critical thinking aspects on the pre-and post-test

Number Questions	Critical thinking aspect	Pre-test average (max=100)	Post-test average (max=100)	N-gain score	Criteria
1	Interpretation	31.25	94.53	0.92	High
2	Analyze	32.03	83.59	0.75	High
3	Evaluation	31.25	85.93	0.79	High
4	Inference	39.06	89.84	0.83	High
5	Explanation	34.37	91.40	0.86	High

In the first question, the critical thinking aspect is interpretation. Interpretation means understanding or explaining the meaning of statements, experiences, situations, events, or procedures. In this question, students asked to interpret the phenomena of sound waves produced on traditional West Java musical instruments. The average score on this question in the pre-test is 31.25, and the post-test score is 94.53. The normalized gain score is 0.92 and includes high criteria. From this question was found students can interpret the phenomenon of sound waves on musical instruments in West Java.

Besides, some students' answers have misconceptions about sound filling space instead of propagating. Previous studies have explained that students have misunderstood the concept of sound [33], [34]. Most students have understood that sound propagates through vibrating air particles. However, some students still answered that the air particles also moved when they vibrated. The same case is when a player blew a *Suling*. This is in line with previous study by Hernandez *et al.* about analyzing students' concepts regarding the design of acoustic properties as learning media [35]. The teacher can facilitate students by developing diagrammatic and image representations that can describe the direction of particle oscillation when the vibration source is set to face various directions.

The second question, the critical thinking aspect is analyzed to examine information to find implicit meanings and relationships. In these questions, students asked can analyze that the phenomenon of loudness is related to amplitude, while pitch is related to frequency. The average pre-test score is 32.03, the average post-test is 83.59, the normalized gain score is 0.75, and includes high criteria. It concludes that students can analyze about the relation between amplitude and frequency. In this question, students aim to understand amplitude and frequency differences. These concepts are often reported as a misconception [36], [37].

The third question with the critical thinking aspect is evaluated, assessing the accuracy or objectivity of an argument, method, procedure, or form. In this question, students asked can evaluate whether blowing the flute loudly or weakly on a musical scale would produce the same frequency. Based on the experiments, it was found that if the speed of sound is calculated, it will produce the same number and also understand that the speed of sound does not depend on the amplitude. The average pre-test score is 31.25, the average post-test is 85.93, and the normalized gain score is 0.79, including high criteria. In this question, the student can evaluate the argument about blowing the flute loudly or weakly on a musical scale in *Suling*.

Next, the fourth question with a critical thinking aspect is inference, which means identifying the elements needed to make a rational statement by considering relevant information. The average pre-test score is 39.06, the average post-test is 89.84, and the normalized gain score is 0.83, including high criteria. The result showed an increase from the pre-test to the post-test. The inference has also increased in previous research related to developing critical thinking skills on indicators for inferences is a significant increase [38]. These questions made students conclude that the air column length shortens to produce high-frequency sound. In the discussion after the experiment, students understood that the pitch (related to frequency) caused by blowing air at the end of the open mouth of the bottle would increase when the volume of water in the bottle increased. This concept can lead students to understand the concept of the length of the air column that shortens to produce sound with a rising frequency. This should be observed directly when students take data from playing the flute in the notes *da* (1), *mi* (2), *na* (3), *ti* (4), *la* (5). But some students still do not understand the relationship between the air column length and frequency. This probably happened because the students could not compare how to play the flute from low to high notes by slowly opening holes in *Suling* one by one from the bottom so that the air column is shortened.

The fifth question, the critical thinking aspect is that explanation means providing a supporting statement or reason for any claim, evidence, or other information. The question asked students can explain how to find the speed of sound in air using the phenomenon sound produced by *Suling*. This question has an average pre-test score of 34.37 and post-test score of 91.40. Next, the normalized gain score of 0.86, which includes high criteria. Experiment activity to find the speed of sound in the air can be measured without experimental equipment in laboratory. Using *Suling* as open organ pipes, the measurement of the length air column is the distance from the tip of the top hole being blown to the center of the hole that opens near the hole closed by the fingers when a note is played. The speed of sound in air, which is measured using a *Suling* applies the concept of the frequency of the fundamental tone (first harmonic) as shown in (1). Students understand that when *Suling* is blown loudly or weakly on a certain scale, the frequency displayed in *Phypox* is same. This means that if the speed of sound is calculated, it will produce the same number.

Based on the experimental activities that have been carried out, it was found that junior high school students need a guiding question to the phenomenon so that students make detailed observations on the aspect in question. Characteristics of junior high school students who must be guided by guiding questions to direct them to abstract observations by the stage of development of their reasoning are now in the transition stage from concrete to formal reasoning [39]. Suppose no guiding questions explicitly lead to the phenomenon, even though the phenomenon can be observed directly, should be able to stimulate students' curiosity and critical thinking skills.

5. CONCLUSION

Experimental activities are important in science learning. Using phenomena that exist around students can improve students' critical thinking skills. *Suling*, a traditional musical instrument from West Java, can be used as a learning media for sound wave concepts. Combination of *Suling* as a West Java musical instrument and *Phypox* as an advanced sound wave experiment tool. Experimental activities also help students to understand the frequency concept and investigate the speed of sound in the air from the sound produced by *Suling*. The study found a significant change in the pre-and post-test scores of students after experiment activities, so the experimental activities affected students' critical-thinking.

The limitation of the study is a small sample size where only one experimental class is used. Future research can use a pre-post-test control group design to see the effectiveness of traditional musical instruments in science learning. Besides, not all students are fluent in playing *Suling*. There is a need for prior training on how to play it. Suggestions for further research can use another traditional musical instrument according to the research area to enhance higher order thinking skills.

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