

Exploring Guided Inquiry Learning with PhET Simulation to Train Junior High School Students Think Critically

Erni Yulianti^{1,*}, Nailah Nur Zhafirah¹, and Nurul Hidayat²

¹Study Program of Science Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Malang, Jl. Semarang 5, 65145, Indonesia

²Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Malang, Jl. Semarang 5, 65145, Indonesia
erni.yulianti.fmipa@um.ac.id

DOI:10.20527/bipf.v9i1.9617

Received: 5 December 2020 Accepted: 4 March 2021 Published: 4 March 2021

Abstract

Until recently, not only students in middle high schools but also in a university have difficulties in understanding either mathematical representations or physical concept behind scientific phenomena. Those difficulties are then associated with a low level of critical thinking. For instance, in physics, it seems to be not easy for students to attain proper relation among wave speed, wavelength, and frequency. This improper understanding contributes to students' low critical thinking skill. One of the most effective ways to overcome the problem is to use student-centred learning with interactive, animated, and game-like learning experiences. Guided inquiry learning and a freely App "Physics Education Technology (PhET)" are believed to meet the criteria. This study focused on the students' knowledge construction process to be able to think critically the wave-related concepts. This PhET-assisted guided inquiry learning strategy was addressed to 25 students at a junior high school in Indonesia. The objective is to explore the stages of inquiry learning approach using PhET, especially on training them to attain their critical thinking skill. This is a qualitative study that purely involves in-class observation. The lesson plan and student worksheets were prepared as the research instruments. As the results, we found that the use of PhET in the guided inquiry learning model can help students acquire to learn the concept of wave speed, wavelength, and frequency with critical thinking.

Keywords: Critical thinking; Guided inquiry; PhET simulation; Wave concept

© 2021 Berkala Ilmiah Pendidikan Fisika

How to cite: Yulianti, E., Zhafirah, N. N., & Hidayat, N. (2021). Exploring guided inquiry learning with phet simulation to train junior high school students think critically. *Berkala Ilmiah Pendidikan Fisika*, 9(1), 96-104.

INTRODUCTION

One of the important competencies that must be instilled in students in science lessons is the ability to think critically, especially to solve various difficulties in real life (Forawi, 2016). Therefore, the maximum process of learning science to train students to

enthusiastically participate during the learning process is required. However, the critical thinking skill of high school students is still quite low. This is evidenced by the low achievement of the average category of correct answers of students in answering questions related to critical thinking skills (Fazriyah,

Supriyati, & Rahayu, 2017). The low ability to think in critical ways is because students are not accustomed to active learning that maximizes their thinking potential. This low-level thinking skill may have an unfavourable effect on their next level of education or even in their life. Students must be exposed to learning activities that engage their critical thinking skills in a way that they can analyze their thoughts in designing choices and figuring conclusions. One of the best ways to practice critical thinking skills is through the learning process. Teachers must be able to realize learning that engages students' critical thinking skills (Vieira & Tenreiro-Vieira, 2016). The selection of the right learning model can activate all capabilities owned by students, to improve students' thinking abilities.

The ability to think critically in science and technology also plays an important role in instilling scientific attitudes in students. Learning in class does not merely develop critical thinking skills, but must also be supported by the existence of assessment instruments that reflect critical thinking (Tiruneh, De Cock, Weldelessie, Elen, & Janssen, 2017). One of the various ways is the habit of working on problems that can improve critical thinking. On the other hand, the low ability of students to think critically is because they are not accustomed to getting and working on problems with cognitive levels C4-C6. Therefore, better coaching to improve students' critical thinking skills needs to be done, especially by accustoming students to solve problems with C4-C6 cognitive levels (Wasis, Sukarmin, & Prastiwi, 2017).

At the same time, vibration and wave topics are somehow difficult for students to understand (Awad & Barak, 2018). In conventional learning, teachers tend to only explain the material, write formulas, give examples of questions and give assignments to students. As a

result, in learning students become passive recipients of the information. This is the reason why students are less interested in learning science, especially in the material of vibrations and waves (Jack & Lin, 2017). To learn these materials effectively, experimental observations are required. The use of laboratory facilities for showing students vibration and wave phenomena can provide a pictorial, conceptual, and mathematical understanding (Holmes, Olsen, Thomas, & Wieman, 2017). However, such facilities in some schools are still far from adequate.

Along with the development of science and technology, there is an opportunity to solve the problem. Various applications for the needs of virtual practicums are integrated into supporting practicum activities. The use of this virtual application is seen as being able to increase students' learning motivation so that students' critical thinking skills can be honed. Various programs are presented freely and can be used in learning, one of which is the Physics Education Technology (PhET) program. It is proven to be successfully implemented to help students learn the behaviour of gas (Correia, Koehler, Thompson, & Phye, 2019). The PhET application presents a variety of simulated science material, including vibrations and waves. PhET simulations can be operated using a variety of computer operating systems that are easy to run.

The reason why simulation-based learning can be an effective knowledge construction tool, including to trigger students critical thinking, is due to the strong fundamental theories and evidence-based data from related studies. For example, when students are exposed to any kind of simulation, their sensory skill can be activated in a way to construct new knowledge based on the simulation or experimental activities (Bivall, Ainsworth, & Tibell, 2011).

Other studies have claimed that simulation-based learning gave better conceptual understanding for students when simulation-based learning was conducted in the class (Chang, Chen, Lin, & Sung, 2008).

There are relatively many learning models applied in schools, but not all models are suitable for teaching critical thinking skills. One of the learning models that are suitable for the ability to think critically is the guided inquiry model. The guided inquiry model is based on science process skills, which position students as learning subjects so that learning is more focused on students. The use of guided inquiry models also has the essence in teaching students to acquire knowledge for students in investigating an actual problem, so that students' critical thinking abilities increase during the implementation of the guided inquiry model in learning (Stender, Schwichow, Zimmerman, & Härtig, 2018; Yulianti, Mustikasari, Hamimi, Rahman, & Nurjanah, 2020). The appropriateness of the material chosen in this guided inquiry learning model is very closely related to science. This is also supported by curriculum standards where the learning system is required to use a scientific approach, i.e., students are required to obtain their knowledge in learning. One of the natural science materials that can be applied in learning this model is vibration and wave material. Because in this material students are required to find links between similarities and connect concepts with everyday life. Thus, students are expected to overcome problems on a daily basis with critical thinking. The guided inquiry learning syntax was followed from its well-defined stages from the prominent experts (Kuhlthau, Maniotes, & Caspari, 2012).

As far as simulation-based learning is concerned, some significant studies

have been reported. Some of them can be found in the following references (Chang et al., 2008; Correia et al., 2019; Pucholt, 2020). However, the fundamental exploration of how students construct knowledge in critical thinking viewpoint from the simulation-based guided inquiry learning has not been explored so far. Therefore, in this present study, we employed simulation-based learning using a guided inquiry approach to teach students the concepts of vibration and wave. An exploration of every stage in guided inquiry learning with the assistance of PhET simulation is discussed.

METHODS

This study explores the description of the guided inquiry learning stages using PhET simulation to train students' critical thinking on vibration and wave topics. The subjects of this study were 25 students of SMP Negeri 1 Malang. The lesson plan and student's worksheet were prepared in a way that students will be able to learn to think critically through a guided inquiry learning setting. The syntax for the guided inquiry learning was adopted from the well-known guided inquiry framework by Kuhlthau and coworkers (Kuhlthau et al., 2012). The guided inquiry learning framework starts from (i) open, (ii) immerse, (iii) explore, (iv) identify, (v) gather, (vi) create, (vii) share, and (viii) evaluate. Also, PhET simulation was introduced during the stage (iii) "explore" until (vi) "create". Every stage of the guided inquiry was carefully done and observed to describe students critical thinking.

RESULTS AND DISCUSSION

Table 1 shows the learning activities for every stage of guided inquiry learning. Before the *open* stage, a *pre-opening* stage was introduced. It is consisting of introducing the learning objectives to students, arranging groups, and getting the worksheets delivered to

the students. In our class, it was familiar to have a short prayer (making du'a) before starting the lesson. It was done in this *pre-opening* stage. The students' learning activities in every stage is also depicted in Table 1.

Table 1 Guided Inquiry Stages During Learning and Instruction.

Stage	Students Learning Activity
<i>Pre-Opening</i>	• Understanding the learning objectives • Arranging positions in a group • Receiving worksheets from the teacher
<i>Open</i>	• Apperception to stimulate student's curiosity • Answering teacher's questions • Initiating observation
<i>Immerse</i>	• Observing the demonstration(s) • Writing questions individually based on the demonstration(s) • Building background knowledge
<i>Explore</i>	• Exploring various sources to find interesting ideas related to the questions • Using PhET simulation
<i>Identify</i>	• All the questions are gathered • Identifying inquiry questions • Selecting inquiry questions
<i>Gather</i>	• Discuss in group • Data collection using PhET simulation • Analyzing data
<i>Create</i>	• Discuss in group • Write a conclusion from PhET simulation • Preparing creative presentation

Stage	Students Learning Activity
<i>Share</i>	• Using PhET simulation • Presenting the results • Knowledge sharing • Learn for other students • Understanding the teacher's clarification
<i>Evaluate</i>	• Conclude the goals of learning • Writing up the reflections

At the *open* stage, students were asked to answer questions from the teacher. This stage can facilitate students to be able to think critically on aspects of answering questions because this stage can open students' thinking and stimulate curiosity about the material to be studied in class as a whole. This stage is also able to inspire students to want to follow the next stages of learning. In this stage, a teacher asked simple questions like "Have you ever played swings?" and "What did you feel when you were on the swings?". The students were required to write the answers in the worksheets. One of the sample student's answers that reflect their ability to think critically in the level of basic clarification was "I felt it drifting back and forth and felt the movement repeat itself".

At the *immerse* stage, students are asked to pay attention to the demonstration from the teacher. This stage can facilitate students to be able to think critically on aspects of formulating questions because students are guided to connect with the materials and explore fascinating ideas through questions made before the new materials (Almuntasheri et al., 2016). The demonstration was done by students under the teacher's guidance using a rope. One end of the rope was held by a student to maintain its fixed position. Meanwhile, the other end was moved up and down by another student to create a sinusoidal wave. At the same time, a rubber bracelet was placed at an arbitrarily

chosen point between the two ends. From that observation, students are required to write questions. Two examples of the questions that reflect student's critical thinking in the level of formulating evidence-based questions were "Why the rubber does not move horizontally?" and "Does the force exerted through the hand influence the frequency of oscillation?". These two questions are scientifically important and reflect that the students were able to think critically. The questions would provide crucial explanations on the core concepts of the energy transfer during the oscillation.

At the *explore* stage, students were asked to read books and any other format of sources to answer selected questions. This stage can facilitate students to be able to think critically on aspects of answering questions because students must explore many kinds of information to obtain creative ideas and help to develop students' inquiry questions. Learners must explore ideas and gather facts. Students are guided to explore and observe various sources to understand the information that has been found, then students write down the information that has been found on the students' worksheet. Also, PhET simulation was introduced to the students so that they can play around to recreate similar observation to get more understanding and critical thinking. In this stage, one student assumed that the answer to the question "Why the rubber does not move horizontally?" is "...because a wave can travel due to energy transfer, but it does not include the transfer of mass of particles". This is one of the good examples of the student's critical thinking during the *explore* stage.

At the *identify* stage, students' questions were identified and selected. Only inquiry-related questions were chosen to be discussed in the group setting. This stage can facilitate students to be able to think critically on aspects of choosing important inquiry questions. The selected questions were designed to

be in line with the simulated experiments that would be done by students. The PhET simulation display can be seen in Figure 1, Student responses on worksheets; formulating physical quantities can be seen in Figure 2, and Student responses on the worksheet: connecting physical quantities can be seen in Figure 3.

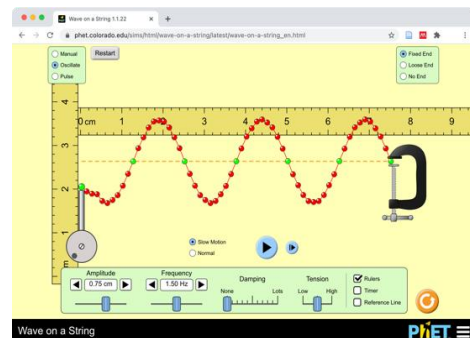


Figure 1 PhET Simulation Display

1. Hubungan A dengan f , λ , dan v ! 1. Relationship of A with f , λ , and v .

a) Variabel bebas = A a) Independent variable = A
 b) Variabel terikat = f, λ b) Dependent variable = f, λ
 c) Variabel kontrol = f, λ c) Control Variable = f

Amplitudo (A)	Frekuensi (f)	Panjang gelombang (λ)	$f \cdot \lambda$
0.5 cm	1 Hz	1.3 cm	1.3
0.5 cm	1 Hz	1.3 cm	1.3
0.5 cm	1 Hz	1.3 cm	1.3

• Bandingkan nilai A dengan f , λ dan $f \cdot \lambda$ • Compare the values of A to f , λ , and $f \cdot \lambda$.

A tidak mempengaruhi f, λ ataupun $f \cdot \lambda$ ($\neq$)
 ↓
 konstanta nilainya
 A does not influence f, λ , or $f \cdot \lambda$, regardless the values of f, λ , and $f \cdot \lambda$.
 f, λ , or $f \cdot \lambda$ is constant

2. Hubungan f dengan λ , dan $f \cdot \lambda$! 2. Relationship of f with λ , and $f \cdot \lambda$.

a) Variabel bebas = f a) Independent variable = f
 b) Variabel terikat = λ b) Dependent variable = λ
 c) Variabel kontrol = λ c) Control Variable = λ

Frekuensi (f)	Panjang gelombang (λ)	$f \cdot \lambda$
0.5 Hz	2.5 cm	1.25
1.5 Hz	0.85 cm	1.25
2.5 Hz	0.5 cm	1.25

• Bandingkan kolom f dengan λ ! • Compare the values of f and λ .
 Semakin besar ($\dots$) f , maka semakin kecil ($\dots$) λ . The greater f , the smaller λ .
 • Tuliskan secara matematis hubungan antara f dan λ !
 Write the mathematical relationship between f and λ .
 λ dipengaruhi oleh f λ depends on f
 $\lambda = \frac{v}{f}$ $v = \lambda f$

Figure 2 Student Response on The Worksheet; Formulating Physical Quantities. The Blue-Coloured Fonts are The Translation of The Corresponding Texts

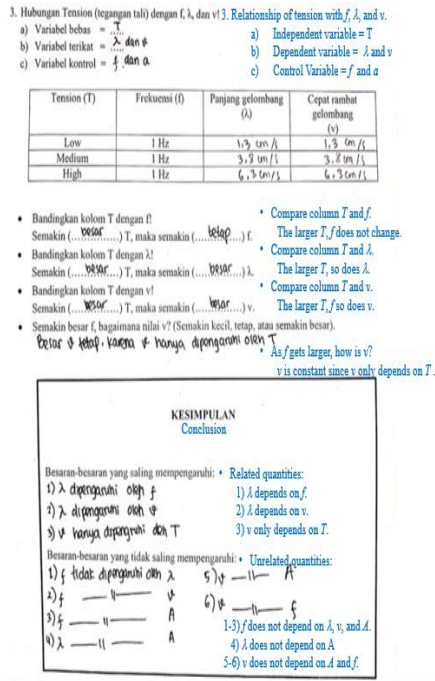


Figure 3 Student Response on The Worksheet: Connecting Physical Quantities. The Blue-Coloured Fonts Are The Translation of The Corresponding Texts

At the *gathering* stage, students were asked to conduct an animated experiment according to the given procedure using PhET simulation. The students were divided into several groups. This stage can facilitate students to be able to think critically on aspects of observing because this stage is designed to assist students in gathering information from PhET experiments. This information involves students in learning an investigation. Also, at this stage students were asked to write down the observation results. The PhET simulation display (from <https://phet.colorado.edu/>) of wave material can be seen in Figure 1. The main goal of these simulated experiments using PhET was to enable students to find the relationship of wave quantities, i.e., amplitude, tension, frequency, wavelength, and wave speed. The data collections completed by a group of students can be seen in Figures

2 and 3. More importantly, students were working in groups to also answer some critical questions given in their worksheets. These questions were set to help students' response to the selected questions previously. The students' answers to the worksheets are also provided in Figures 2 and 3.

In the *create* phase, students made conclusions based on their group simulated experiments using PhET. This stage can facilitate students to be able to think critically on aspects of concluding arguments. The conclusion could be expressed by students in the same worksheet (see Figure 3). Also, students were required to design creative presentations.

Lastly, at the *sharing* stage, students were asked to present the results of their group discussions in front of the class. This stage could facilitate students to be able to think critically on the integrated advanced clarification aspect. It is because this stage was arranged in such a way that students were able to share the results of what they have developed during the gathering and creating phases. Students should be able to critically choose the best words and descriptions to communicate and to present their finding and knowledge to other peers. This is also important to develop students' communication skills in expressing their creative ideas. Also, the teacher was able to directly give feedback to the students. In this stage, clarification was provided by the teacher.

At the last stage, namely, *evaluate*, students were asked to conclude that day's learning and wrote down reflections about the whole learning process that had been implemented. This stage could facilitate students to be able to think critically on aspects of deduction because at this stage students were guided to think individually about the learning content and achievements that have been experienced during the inquiry process. Students' reflections occurred

when the whole new process is in their minds and reinforces the learning content and creates good habits to learn how to learn through the inquiry process.

From the use of the PhET simulation applet, students could analyze the relationship among variables in wave phenomena, i.e., tension, amplitude, wave speed, wavelength, and frequency. It could be seen that students were able to understand quantities using the PhET application and look for relationships between quantities that do and do not influence each other. Students were able to write systematically the relationship between several quantities and determine the independent variables, control variables, and the dependent variable contained in the worksheet related to the quantities that exist. It appeared that all stages of guided inquiry and several aspects of critical thinking. All the stages of the guided inquiry with the help of PhET simulation may trigger students' critical thinking in various levels.

Most students were interested in and paid attention to learning starting from the *pre-opening* to the end. The real observation and simulated simulation help students to learn in an inquiry manner. Also, the use of teaching materials that are simple and close to the daily lives of student can increase students' attractiveness towards learning. It is in line with the previous report (Yulianti, Mustikasari, et al., 2020). More details about the stages that arise in the learning of vibration and wave material can be seen in Table 1.

Furthermore, our results are supported by other findings. It is reported that students' understanding and conceptual development, including critical thinking, can be fostered by the use of virtual based experiments (Pucholt, 2020). Developing students' critical thinking is vital to their higher-order thinking skills (Yulianti, Pratiwi, et al., 2020). The use of PhET was claimed to be very effective to teach Dutch

secondary schools' students the concept of quantum wave phenomena (van den Berg, van Rossum, Grijzen, Pol, & van der Veen, 2020). However, they stated that students' wave-particle duality understanding is restricted by the lack of understanding of classical wave concepts. Therefore, our results can be further used by teachers to help students properly understand the characteristics of vibration and wave both in classical and quantum physics. Furthermore, other researchers also reported the theoretical framework that explains the use of guided inquiry with physical and virtual laboratories in science classes (Husnaini & Chen, 2019). The role of simulation and/or laboratory activities in fostering students' understanding and critical thinking lies behind the theory that sensory-motor processing is strongly influenced students' learning (Bivall et al., 2011). Besides, some researchers found that the employment of real laboratory and virtual simulation produced similar effects on students' achievements (Olympiou & Zacharia, 2012). Other experts have observed that simulation-based learning is better than that of physical laboratory for students' conceptual understanding from graphical and mathematical representations (Chang et al., 2008; Hidayat & Yulianti, 2021). In this regard, our results support the second opinion that the application of the integrated guided inquiry model of the PhET application can improve students' achievement in particular their critical thinking skills.

CONCLUSION

The integrated guided inquiry model of the PhET application can be applied to the learning of vibration and wave and can facilitate students to train their critical thinking abilities. This descriptive study will benefit other researchers to further explore other aspects of students' critical thinking based on the guided inquiry learning

model. We have shown the critical thinking levels of students in every aspect of the guided inquiry, mainly by the use of the PhET simulations. With critical thinking, students were able to gain a correct conceptual understanding of classical wave phenomena which furthermore will make them easier to learn more advanced topics, such as quantum physics in the future.

REFERENCES

- Awad, N., & Barak, M. (2018). Pre-service Science Teachers Learn a Science, Technology, Engineering and Mathematics (STEM)-Oriented Program: The Case of Sound, Waves and Communication Systems. *Eurasia Journal of Mathematics, Science and Technology Education*, 14(4), 1431–1451.
- Bivall, P., Ainsworth, S., & Tibell, L. A. E. (2011). Do haptic representations help complex molecular learning? *Science Education*, 95(4), 700–719.
- Chang, K. E., Chen, Y. L., Lin, H. Y., & Sung, Y. T. (2008). Effects of learning support in simulation-based physics learning. *Computers & Education*, 51(4), 1486–1498.
- Correia, A. P., Koehler, N., Thompson, A., & Phye, G. (2019). The application of PhET simulation to teach gas behavior on the submicroscopic level: Secondary school students' perceptions. *Research in Science & Technological Education*, 37(2), 193–217.
- Fazriyah, N., Supriyati, Y., & Rahayu, W. (2017). The Effect of Integrated Learning Model and Critical Thinking Skill of Science Learning Outcomes. *Journal of Physics: Conference Series*, 812.
- Forawi, S. A. (2016). Standard-based science education and critical thinking. *Thinking Skills and Creativity*, 20, 52–62.
- Hidayat, N., & Yulianti, E. (2021). Real Time Measurement for Spring-Mass System: The Graphical and Mathematical Representations. *Jurnal Penelitian Pendidikan IPA*, 7(1), 74–79.
- Holmes, N. G., Olsen, J., Thomas, J. L., & Wieman, C. E. (2017). Value added or misattributed? A multi-institution study on the educational benefit of labs for reinforcing physics content. *Physical Review Physics Education Research*, 13(1).
- Husnaini, S. J., & Chen, S. (2019). Effects of guided inquiry virtual and physical laboratories on conceptual understanding, inquiry performance, scientific inquiry self-efficacy, and enjoyment. *Physical Review Physics Education Research*, 15(1).
- Jack, B. M., & Lin, H. (2017). Making learning interesting and its application to the science classroom. *Studies in Science Education*, 53(2), 137–164.
- Kuhlthau, C. C., Maniotes, L. K., & Caspari, A. K. (2012). *Guided Inquiry Design®: A Framework for Inquiry in Your School*. ABC-CLIO.
- Olympiou, G., & Zacharia, Z. C. (2012). Blending physical and virtual manipulatives: An effort to improve students' conceptual understanding through science laboratory experimentation. *Science Education*, 96(1), 21–47.
- Pucholt, Z. (2020). Effectiveness of simulations versus traditional approach in teaching physics. *European Journal of Physics*, 42(1).
- Stender, A., Schwichow, M., Zimmerman, C., & Härtig, H. (2018). Making inquiry-based science learning visible: The influence of CVS and cognitive skills on content knowledge learning in guided inquiry. *International Journal of Science Education*, 40(15).

- Tiruneh, D. T., De Cock, M., Weldeclassie, A. G., Elen, J., & Janssen, R. (2017). Measuring Critical Thinking in Physics: Development and Validation of a Critical Thinking Test in Electricity and Magnetism. *International Journal of Science and Mathematics*.
- van den Berg, E., van Rossum, A., Grijzen, J., Pol, H., & van der Veen, J. (2020). Teaching Particle-Wave Duality with Double-Slit Single-Photon Interference in Dutch Secondary Schools. *Research and Innovation in Physics*.
- Vieira, R. M., & Tenreiro-Vieira, C. (2016). Fostering Scientific Literacy and Critical Thinking in Elementary Science Education. *International Journal of Science and Mathematics Education*, 14(4), 659–680.
- Wasis, W., Sukarmin, S., & Prastiwi, M. S. (2017). Cognitive Process Analysis of PISA, TIMSS, and UN Science Items Based on Revised Bloom Taxonomy. *Advanced Science Letters*, 23(12), 12068–12072.
- Yulianti, E., Mustikasari, V. R., Hamimi, E., Rahman, N. F. A., & Nurjanah, L. F. (2020). Experimental evidence of enhancing scientific reasoning through guided inquiry model approach. *AIP Conference Proceedings*, 2215(1).
- Yulianti, E., Pratiwi, N., Mustikasari, V. R., Putri, A. P., Hamimi, E., & Rahman, N. F. A. (2020). Evaluating the effectiveness of problem-based learning in enhancing students' higher order thinking skills. *AIP Conference Proceedings*, 2215(1).