**Implementation of ICT-based Inquiry Learning Model for Enhancing Critical Thinking Skills in Mechanical Waves Characteristics**

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| **Abstract** | ***Article Info:****Recieved:* 12/07/2023*Revised:* 18/08/2024*Accepted:* **Creative Commons License**20/08/2024 |
| *Critical thinking skills are essential in 21st century education. However, students’ critical thinking skills remain underdeveloped. To align with contemporary advancements, curricula now demand integration with 21st century skills, including critical thinking and technology. This study aims to investigate the implementation of ICT-based inquiry learning model for enhancing critical thinking skills in mechanical wave characteristics. This study employed a pre-experimental research method, utilizing a one-group pretest-posttest design. The participants consist of 34 eleventh-grade students from a high school in Bandung district, selected through convenience sampling. The instruments used were critical thinking skills test. The improvement of critical thinking skills was analyzed using N-Gain. The results showed that students’ critical thinking skills increased an average N-Gain value of 0.35 in a moderate category and there is a significant difference between the pretest and the posttest shown by the Wilcoxon signed rank test, which is p value < 0.05. Thus, the ICT-based inquiry learning model can enhance students’ critical thinking skills on mechanical wave characteristics.***Keywords**: *Critical thinking, ICT, Inquiry learning, Learning model, Mechanical wave* |

# Introduction

The nature of education is evolving and students increasingly require 21st century skills to be mastered both now and in the future. As a result, 21st century abilities must be incorporated into and improved upon in order to adequately prepare students for ever-more complex lives and carreers [[1]](#_References_1). Critical thinking skills are one of the 21st century’s competencies. Making decisions about what to believe or do is the main goal of critical thinking, which is logical, analytical thought [[2]](#_References_1). Critical thinking skills are essential to modern education in the 21st century since students will undoubtedly require them when dealing with a range of issues [[3]](#_References_1). All academic subjects can be used to develop critical thinking skills and physics is one of them [[4]](#_References_1). Thus, the development of students’ critical thinking skills is one of the 21st century talents that physics education is accountable for supporting [[5]](#_References_1).

 Based on a preliminary study conducted at one of the high schools in Cimahi City, students’ critical thinking skills are still lacking, particularly when it comes to mechanical waves. This is demonstrated by a students’ average test score of 65 and 69% of students are still below the minimum qualifying criteria.

The question used is not about asking students to think critically, but about evaluating students’ knowledge of the concepts and formulas they have learned. Based on observation result, out of the 29 students there are 20 students with low grades with a minimum score of 24/100. The result indicates that students’ critical thinking skills remain poor and the success of teaching physics on mechanical waves has not been attained to a sufficient level. The results of the preliminary study are in line with the research carried out by Feti and Harto [[7]](#_References_1) which found that the critical thinking skills of students in physics learning were in the lowest category with 55.6% of students having low critical thinking skills and 30.6% having very low critical thinking skills [[6]](#_References_1). In addition, a study conducted by Syifa also found that students’ critical thinking skills are still low, so efforts are needed to enhancing them through learning innovation.

 Based on interviews between teachers of physics subjects and students, information indicating that classroom learning activities have not adequately honed critical thinking skills was discovered. Physics learning is still focused on understanding physics concepts and their formulas and less attention is paid to other skills. Besides, the use of technology is rarely done and only maximizes student worksheets or books borrowed by the library. The most commonly used learning model is the discovery learning model with lecture methods, question answers, and occasional demonstrations. Students presented expectations of learning physics in the classroom that is more modern, more practice, more innovative learning methods, and explain theory using media and tools. The results from interviews on field studies are consistent with what Mayasari mentioned that when students were in school, they did not learn the skills necessary for the twenty-first century [[8]](#_References_1). Students get more information, record the material provided by teacher, and work on subjects found in books or from the teacher, which makes them passive and less involved in learning. This is the reason why students are less facilitated to train a variety of skills [[9]](#_References_1).

 Alternative approaches to the aforementioned issues can be taken care of by implementing instructional strategies that encourage and promote students’ critical thinking skills. Since Physics is the science that is identical to observation and experimentation, physics learning is designed to be student-centered and to use learning stages that can equip students with the competence to meet the demands of success and support their lives. This allows students develop a mature and full understanding of physics as well as critical thinking abilities [[5]](#_References_1). Regulation Number 22 of 2016 issued by the Minister of Education and Culture of the Republic of Indonesia states that inquiry-based, problem-based, project-based, and discovery learning are among the suggested instructional approaches. Of the four models, the inquiry learning model becomes a learning model in which students study like scientists. In this model of inquiry, the role of the teacher is limited to telling the concept directly to the student, but the student gains an understanding of the concept from the activity and the learning experience of finding the concept. This will be remembered by the student for a long time as learning becomes more meaningful [[10]](#_References_1). Through inquiry-based learning, students become more engaged and apply their aptitude for methodical, critical, logical, and analytical search and investigation to develop their own notions derived from self-assurance [[11]](#_References_1).

 Physics learning especially the inquiry model with its research, is not independent of experimental and laboratory activities, but not a few schools have insufficient laboratories to carry out experiments [[12]](#_References_1). According to observations at one of the schools in Cimahi City, the school does not have a physics laboratory and there is only an science laboratory, and then the laboratory equipment is incomplete. However, this can be solved using information and communication technologies integrated into learning. There is a lot of promise for information and communication technology to raise learning standards [[13]](#_References_1). ICT integration into learning is needed to bridge the gap between theory and practice [[14]](#_References_1), especially in abstract physics and one of them is mechanical wave topics [[15]](#_References_1).

The curriculum used in Indonesia, the “kurikulum merdeka” also requires learning to be associated with 21st century skills and technology [[10]](#_References_1).

 The ICT-based inquiry learning model becomes a learning model that serves as a solution to the challenges of 21st century skills, one of which is critical thinking skills and the need to integrate information and communication technology into learning. ICT-based inquiry learning is the development of a learning model in which the teaching and learning process is integrated with technology at every stage [[5]](#_References_1). The difference between the inquiry learning model and the ICT-based inquiry learning model lies in its syntax, where in the inquiry models are orientation, conceptualization, investigation, conclusion, and discussion. While ICT-based inquiry learning model syntax are online orientation, problem identify in e-resources, exploration using ICT tools, report findings, and closure. Therefore, in the ICT-based inquiry learning model, ICT is at the level of integration because ICT is not separated from learning by the use of ICT in each learning syntax. Research by Fuji *et al*., [[5]](#_References_1) suggests that ICT-based inquiry learning models are valid, practical, and effective to enhance 21st century skills with an average N-Gain of 0.63. In addition, research conducted by Ismadi and Esther [[16]](#_References_1) found that an ICT-based learning model can improve the critical thinking skills of students with an N-Gain score of 0.84 and are in the high category. Therefore, ICT-based inquiry learning models have the ability to improve students’ critical thinking skills. Based on the problem and the result of previous research, a study was conducted on implementation of ICT-based inquiry learning model for enhancing critical thinking skills in mechanical waves characteristics.

# Methods

Quantitative research is the research methodology used in this investigation. Because there is no control group and the samples are not chosen at random, this research design is pre-experimental with a one group pre-test – post-test. The research design can be seen in Figure 1.



Figure 1. One Group Pre-test - Post-test Research Design

In Figure 1 O1 represents the pre-test before implementation of the ICT-based inquiry learning model, X denotes the intervention (learning with the ICT-based inquiry learning model), and O2 signifies the post-test after implementation of the ICT-based inquiry learning model.

The whole 11th grade intake at one of the high schools in the Bandung district during the second semester of the 2023-2024 school year serves as the research’s population. The samples in this study were determined using convenience sampling. The participant involved in this study was an XI grade in one of the high schools in Bandung district of 34 students. This is the basis of consideration in selecting participants: 1) Students have never done learning using the ICT-based inquiry learning model, 2) Students’ haven’t learned about mechanical waves, 3) The physics teacher and the school give permission to do research.

The instrument is an assessment of critical thinking skills related to mechanical waves. The pre-test and post-test consist of the same set of nine essay questions designed as an instrument to measure critical thinking skills aligned with Ennis’ indicators. The questions that have been prepared consist of 1 elementary clarification question, 2 basic support questions, 2 inference questions, 2 advanced clarification questions, and 2 strategy & tactics questions.

The material on mechanical waves includes concepts such as mechanical wave properties, identifying wave parameters like amplitude, wavelength, wave frequency, wave period, wave velocity, characteristic of mechanical waves including wave reflection, wave refraction, wave diffraction, and wave interference, as well as their applications in life. The validity and reliability of the instrument of assessment employed in this study have been guaranteed by the validation of these questions by experts and field testing. N-Gain is used to analyze the pre-test and post-test results in order to measure of improvement students’ critical thinking skills.

# Results and Discussion

 In order to improve students’ critical thinking skills regarding mechanical wave features, an ICT-based inquiry learning model was implemented over the course of two meetings, totaling two hours of lessons (2 x 45 minutes). Before conducting the first meeting, the student performs a pre-test in advance to find out what knowledge the student has before giving treatment. Then, after two meetings, the student performs a post-test to determine the students’ knowledge after receiving treatment. The core activities begin with the division of students into five groups and the distribution of LKPD to each group. Learning on core activities is carried out in accordance with the ICT-based inquiry learning model, including online orientation, problem identify in e-resources, exploration using ICT tools, report findings, and closure. On the first syntax, online orientation, the stage introduce the topic and sees the physics phenomenon of the wave that exists on the internet. Students read the article on the LKPD about the earthquake news. On the LKPD available QR Code that students need to scan using mobile phones to produce news article that need to be read. At the second meeting, students watched videos consisting of mechanical wave reflections, mechanic wave refraction, mechanic wave diffraction, and mechanic wave interference. The video was stored in Google Drive and the video appeared on the phone as students scanned the barcodes available in LKPD. The application of QR Code technology (Quick Response Code) to student worksheets makes students skilled in the use of technology and makes it easier for students to access their learning resources [[17]](#_References_1).

 On the second syntax, problem identify in e-resources, the stage where students identify problems or brainstorm the phenomena they have discovered. At this meeting, students’ are asked to ask scientific questions from their reading or viewing results. Then, students’ make a temporary answer or hypothesis from the scientific question they have already written. Elementary clarification is trained when students formulate their questions and hypotheses. The third syntax, exploration using ICT tools, students use their own phone to conduct experiments. The experiment is a virtual experiment using PhET (Physics Education Technology). PhET was chosen because research suggests that an inquiry model integrated with technology, namely the PhET virtual lab, can be implemented in vibration and wave learning and can facilitate students’ to train their critical thinking skills [[18]](#_References_1). Furthermore, the use of PhET simulation media is chosen because PhET can motivate students’ to learn physics, free, and interactive [[19]](#_References_1). In the first meeting, the simulation was played of the introduction of waves using sound waves, whereas in the second meeting, simulations were played of wave diffraction and wave interference using water waves. The exploration phase is the longest stage carried out because students’ are not used to using mobile phones in learning instead of looking for answers to questions. Students’ are also new to PhET, so teacher introduce them in advance so that students are not confused and become familiar with the tools they will use during learning.

Teacher guides students’ by demonstrated the PhET simulations in front of the classroom using a laptop and projector. Students’ will match experiments on mobile phones with on laptop. The basic support skills are trained when students’ conduct experiments in accordance with the steps available in the LKPD. The learning strategy and tactics and inference skills are trained when students discuss with students’ group to make answers and evaluate the problem solution. Advanced clarification skills are trained when students’ define terms and identify assumptions or hypotheses that have already been written by students at a previous stage.

On the fourth syntax is report findings, students’ present the results of the experiment in front of the class. Teacher guide the course of the presentation and condition groups that are not presenting to appreciate group that move forward. After the presentation of the exploration results is completed, students’ are invited to ask questions, comment and/or answer and discuss their group experiments. When no one asks, then the teacher asks an example and encourages the other students’ to ask. For groups that are not present in front of the classroom, the results of the video are shared on social media, i.e. Instagram. Instagram can be accessed using a smartphone and can be used to share physics material [[20]](#_References_1). Others who watched the video were allowed to comment, either in the form of questions or suggestions, so there was an online exchange of thoughts or discussion on the social media. Strategy and tactics are trained when students’ interact with others by presenting their answers in front of the classroom and on social media. Basic support is trained as students’ observe and evaluate the reports presented and corroborate answers with the answers of other groups.

On the last syntax, closure, the teacher verifies the students’ concepts and answers. Then, students and teacher jointly draw conclusions from the learning process that starts from orientation to drawing conclusions based on the results of the experiments that have been carried out. The technology used in this phase is a laptop, projector, and Power Point. It is to make it easier for students and teacher to review the learning that has been done because by power point students become concentrated and not sleepy [[21].](#_References_1) Inference and advanced clarification skills are trained when students conclude concepts and answers based on their learning results.

 N-Gain is calculated using the result of students’ critical thinking skills pre-test and post-test results to assess how much their critical thinking skills have improved. The test instrument consists of 9 essay questions tailored to Ennis’ indicators of critical thinking, including elementary clarification, basic support, inference, advanced clarification, strategy and tactics [[2]](#_References_1). Students’ answers for each question are assessed based on a prepared scoring rubric. The minimum score assigned for each question is 0, while the maximum score is 4. Subsequently, these scores are summarized and analyzed to explain how the adoption of the ICT-based inquiry learning improved students’ critical thinking skills (Table 1).

Table 1. Recapitulation of Pre-test and Post-test Scores of Critical Thinking Skills Test

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Test | Xmin | Xmax | $$\overbar{X}$$ | X Ideal | <g> | Category |
| Pre-test | 1 | 19 | 6.38 | 36 | 0.35 | Moderate |
| Post-test | 9 | 25 | 16.79 |

 The pre-test results on Table 1 , the minimum score obtained for critical thinking skills was 1, the maximum score was 19, and the average score obtained was 6.38. Meanwhile, in the post-test results for critical thinking skills, the minimum score obtained was 9, the maximum score was 25, and the average score was 16.79. The average N-Gain obtained is 0.35, categorizing it as a moderate improvement.

Out of 34 students’, 26 students’ showed a moderate improvement in critical thinking skills, 7 students’ showed a low improvement, and 1 student did not show any improvement in critical thinking skills. Based on the calculation of n-Gain, the results indicate an overall improvement in students’ critical thinking skills. The analysis of students’ critical thinking skills for each indicator can be seen in Table 2.

Table 2. Average of N-Gain for Each Indicator

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Critical Thinking Skills Indicators | Pre-test | Post-test | N-Gain | Category |
| Elementary Clarification | 0.26 | 2.18 | 0.5 | Moderate |
| Basic Support | 0.34 | 0.96 | 0.13 | Low |
| Inference | 0.15 | 2.06 | 0.1 | Low |
| Advanced Clarification | 0.6 | 2.9 | 0.58 | Moderate |
| Strategy and Tactics | 0.97 | 1.4 | 0.06 | Low |

By using SPSS software the researcher find a normality test and a difference test to see if there was a significant difference in the critical thinking skills before and after learning. Table 3 shows the normality test results for students’ critical thinking skills.

Table 3. The Results of Students’ Critical Thinking Skills Normality Test



Based on Table 4 the significance value is 0.000 < 0.05, it may be inferred that the data is not normally distributed. The Wilcoxon Signed Ranks test is the difference test that was employed in this case.

Table 4. The Results of Students’ Critical Thinking Skills Wilcoxon Signed Ranks Test



Based on the significance value (2-tailed) 0.000 < 0.05 shows that there is a significant difference. In this case, H0 is rejected and H1 is accepted. This suggests that there is a substantial difference in the pre-test and post-test scores, indicating that the ICT-based inquiry learning model can significantly alter critical thinking skills. The improvement of each student’s critical thinking skills indicator is the subject of the following discussion.

Students’ skills in elementary clarification improved with an N-Gain value of 0.5, which in the moderate category. The question to test elementary clarification is about wave reflection in technology. In the pre-test, students answered questions using their prior knowledge from the fluid mechanics material that had been covered before the pre-test session. Students also mention “radar” when answering, but it is suspected that this term is familiar to them because of its association with submarines. During the post-test, students were able to correctly answer questions applying wave reflection in technology by providing simple explanations of the names of devices or technologies used and how they function. Out of 34 students, 10 students showed a high improvement in elementary clarification skills, 14 students showed moderate improvement, 5 students showed low improvement, and 5 students did not show any improvement in elementary clarification skills. This indicates that learning with the ICT-based inquiry learning model can assist students in enhancing their elementary clarification skills and understanding the characteristics of mechanical waves, specifically wave reflection and its application in technology.

Figure 2 shows the comparison of the number of students in the elementary clarification skills improvement category.

Figure 2. Elementary Clarification Skills Improvement and Basic Support Skills Category

Students’ skills in basic support improved with an N-Gain value of 0.13, which falls into the low category. To test basic support, there are two questions: one involves identifying wave parameters based on provided images and data, and the other analyzes wave refraction by determining the accuracy of statements (true or false) and correcting the wrong statements based on the provided images. Although the results showed an improvement in basic support skills in the low categories, there were some students who experienced improvements in the high and moderate categories. For the first basic support question, out of 34 students, 1 student showed a high improvement in basic support skills, 8 students showed moderate improvement, 14 students showed low improvement, and 11 students did not show any improvement in basic support skills.

Figure 2 shows the comparison of the number of students for the basic support skills improvement category in the first basic support question. For the second basic support question, out of 34 students, 17 students showed low improvement in basic support skills and 17 students did not show any improvement. Figure 2 shows the comparison of the number of students for the basic support skills improvement category in the second basic support question.

The possible factors contributing to the low improvement in basic support skills include students’ inability to use reasoning to analyze, evaluate, and re-evaluate based on their knowledge to find solutions to the questions [[22]](#_References_1). Students has not familiar with and often confused with terms such as “reflection”, “refraction”, “diffraction”, and “interference” because these terms are similar and can cause confusion among students’. The student also failed to calculate to find and ensure the accuracy of their identifications. Some students’ only write down the formulas without being able to apply them to the questions. Students’ are unable to solve calculation-based questions, indicating the need for practice exercises specifically focused on solving wave parameter calculations. This targeted practice will optimize students’ understanding of the material [[23]](#_References_1). Practice exercises can be conducted during regular class hours by extending the scheduled time, or outside of class hours through supplementary sessions like tutoring or assigning practice problems as homework.

Students’ skills in inference improved with an N-Gain value of 0.1, which falls into the low category. To test inference skills, there are two questions: one involves concluding comparison and explanation of diffraction experiments, while the other requires students to infer wave interference events based on a story and accompanying images presented in the question. For the first inference question, out of 34 students, 14 students showed a high improvement in inference skills, 3 students showed moderate improvement, 2 students showed low improvement, and 15 students did not show any improvement in inference skills. Figure 3 shows the comparison of the number of students for the inference skills improvement category in the first inference question.

Figure 3. Inference Skills Improvement Category

For the second inference question, out of 34 students, 3 students showed a high improvement in inference skills, 6 students showed moderate improvement, 7 students showed low improvement, and 18 students did not show any improvement in inference skills. Figure 3 shows the comparison of the number of students for the inference skills improvement category in the second inference question.

he factor contributing to the low improvement in interference skills is that students only describe differences and explain what is visible in the images, resulting in pre-test and post-test answers being similar.

Students’ skills in advanced clarification improved with an N-Gain value of 0.58, indicating moderate improvement. To assess advanced clarification skills, there are two questions: one involves analyzing concepts of mechanical waves, and the other requires identifying assumptions about wave velocity by conducting further clarification using data provided in the question. During the pre-test, students’ answered that the assumption stated in the question was incorrect, but they did not correctly write down the wave velocity. In the post-test, students’ were able to further clarify the assumptions in the question and calculate and determine the actual wave velocity correctly. For the first advanced clarification question, out of 34 students, 7 students showed a high improvement in advanced clarification skills, 16 students showed moderate improvement, 3 students showed low improvement, and 8 students did not show any improvement in advanced clarification skills. Figure 4 shows the comparison of the number of students in the advanced clarification skills improvement category in the first advanced clarification skills question.

Figure 4. Advanced Clarification Skills Improvement Category in Advanced Clarification Question

For the second advanced clarification question, out of 34 students, 29 students showed a high improvement in advanced clarification skills, and 5 students did not show any improvement. Figure 10 shows the comparison of the number of students in the advanced clarification skills improvement category in the second advanced clarification skills question.

Students’ skills in strategy and tactics improved with an N-gain value of 0.06, which falls into the low category of improvement. To test strategy and tactics, there are two questions involving applying the utilization of mechanical wave characteristics in life situations. In the question, students are asked to decide on a course of action regarding the solution and reasons for practicing drumming well without disturbing others. In the pre-test, students answered correctly, but their response did not relate to the characteristics of mechanical waves. Furthermore, their reasoning was not associated with waves either. In the posttest, only a few students connected their answers to the characteristics of mechanical waves. For the first strategy and tactics question, out of 34 students, 2 students showed a high improvement in strategy and tactics skills, 9 students showed moderate improvement, and 23 students did not show any improvement in strategy and tactics skills. Figure 11 shows the comparison of the number of students in the strategy & tactics skills improvement category in the first strategy & tactics question.

Figure 5. Strategy and Tactics Skills Improvement Category

For the second strategy and tactics question, out of 34 students, 1 student showed a high improvement in strategy and tactics skills, 10 students showed a high improvement in strategy and tactics skills, 10 students showed moderate improvement, and 23 students did not show any improvement in strategy and tactics skills. Figure 5 shows the comparison of the number of students in the strategy & tactics skills improvement category in the second strategy & tactics question. The factors contributing to the low improvement in the strategy and tactics indicator include students merely mentioning actions needed without explaining the reasons why these strategies and actions were chosen as solutions to the problem. Additionally, another factor is the difficulty students face in understanding physics concepts, analyzing questions, and linking them to the material being studied [[24]](#_References_1).

# Conclusion

According to the research results, it is evident that the critical thinking skills of students showed improvement following the implementation of the ICT-based inquiry learning model, having an N-Gain of 0.35, which is classified as moderate. In addition, pretest and posttest scores showed a significant difference from the Wilcoxon signed rank test, which is p value < 0.05. The results show that learning the characteristics of mechanical waves is successful and the ICT-based inquiry learning can be considered a viable instructional model for schools to enhance students’ critical thinking skills, especially in mechanical wave characteristics.

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