Building Critical Thinking Skills Through the ADI Model with STEM and Formative Assessment

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Abstract. Improving your critical thinking will help you master the concept of shaft materials. Critical thinking skills develop attitudes and perceptions that help create positive classes, recognize the meaning of knowledge, and develop positive thinking skills. However, the ability to think critically in physics class is still low. The purpose of this study is to implement an ADI model, including stem and formative assessment, to improve students' critical thinking skills. This study used a mixed method approach with embedded design. Data collection took place in three stages: Applies to pre-learning, during (intervention) and post-learning. The study was conducted at SMA Negeri 1, Putussibau, Class XI in even semester 2020/2021. The study subjects for this study were 27 of her students. The tools used are an interview sheet and a critical thinking ability test with a confidence level of 0.614. A qualitative analysis is conducted to see how students think about the concept of sound and light waves, find learning difficulties, and enhance the results of the quantitative analysis. Analyze quantitative data to answer the question of how to improve students' critical thinking skills before and after learning the ADI model using STEM and formative assessment. Results showed that critical thinking ability increased from a mean score of 13.77 to 34.37 after using her ADI model with STEM and formative assessment. There is a big difference in critical thinking skill scores before and after applying the learning. However, improvement in student critical thinking is still in the low category, with an N-gain of 0.23. Based on the strong categorical effect size value of 15.7, this indicates that the study of students' critical thinking skills with the ADI model using STEM and formative assessment with online learning during the COVID-19 pandemic can be comprehensively applied. Means The critical thinking indicator with the highest rate of increase is the completed indicator. A recommendation for further research is that the implementation of his ADI model using STEM can be done in a real classroom, in a face-to-face class with an added artistic dimension, and for other physics topics.

Keywords: Argument-Driven Inquiry · STEM · Formative Assessment · Critical Thinking

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1 Introduction

The topic of waves is always close to students' daily lives [1]. The role of waves that are closest to students, for example in multimedia learning devices during the COVID-19 pandemic [2]. The topic of waves is part of the core idea of the NRC curriculum development design [3]. Students who can master the topic of waves well can help study materials that are closely related to waves, such as the concepts of light, electricity, and magnetism [4]. Students still have difficulty mastering the concept of waves because of their abstract nature [5]. Some wave concepts were found. Students, including on the material of mechanical waves, wave propagation, representation of traveling waves, and superposition, to arrive at the concept of sound and light waves [6–8].

Improving your critical thinking skills will help you master the concept of shaft materials [9]. This is because critical thinking skills have a positive impact on students' conceptual acquisition [10]. Critical thinking skills foster attitudes and perceptions, so they can support the creation of positive classes, renew the meaning of knowledge, and develop positive her thinking skills [11]. If someone has good critical thinking skills, they can participate as consumers of science [3]. Critical thinking skills can help you solve life's problems [11]. Critical thinking skills make students eager to learn and therefore interested in mastering concepts [12].

Critical thinking skills depend on cognitive abilities [13]. I sometimes wonder how true my ideas are and whether they contradict others. This is a question of critical thinking. Maynes (2015) calls it prejudiced reasoning. That is, the tendency to find arguments that are stronger than those believed to be [14]. A learning presence that provides an opportunity to share arguments drawn from the results of critical thinking certainly helps students master the concepts [15].

In Indonesia, students' low critical thinking ability has been noted in some cases [16, 17]. Several studies have been conducted in Indonesia to improve critical thinking. In general, physics educators use learning models. This is because studies [18–21] have found that inquiry-based learning improves critical thinking skills. Therefore, the ADI model is a combination of inquiry-based learning and scientific reasoning, and thus research studies using the ADI model can be explored [22]. Additionally, the ADI model helps students master the concept of absenteeism [23].

The ADI learning model allows students to have data-driven discussions [24]. Application of the ADI model influences students' critical thinking skills [25]. ADI's learning model from multiple studies in each lesson runs on lab-scale problems [26, 27], but current learning needs to be able to solve environment-scale problems and students' future careers. There are [28, 29]. Solving large-scale problems involves STEM approaches [30]. This follows the recommendation that ADI learning models should accompany current learning approaches, namely his STEM approach [31].

The main purpose of STEM in schools is to solve social and economic needs, and people need to become wealthy, productive and knowledgeable citizens [32]. The student is asked to demonstrate her STEM discipline understanding in a project-based context setting [30]. The presence of the ADI STEM model not only completes classroom learning, but also influences subsequent careers and environments for students [33, 34]. This model requires the ability of students to think in terms of solving real-world problems.

To visualize this, we need a model that opens our minds by communicating the arguments we are thinking to each other [35]. The sheer number of arguments presented makes it difficult for students to conclude what is the most important thing they need to understand. Learning goals are important in this case. The right kind of assessment using the ADI STEM model, namely formative assessment, is necessary to enable students to achieve their learning goals [36].

The purpose of formative assessment is to be a short test used by teachers and students as a tool in the learning process [37]. Formative assessment is used for two main purposes, namely providing students with feedback and information on teaching needs for teachers [38]. Students are asked challenging questions with reflection to get high-quality feedback [39]. Formative assessment can be delivered formally or informally [38]. Formative assessment can cover content, science process skills, or learning activities [40].

The ADI model with STEM is combined with formative assessment because formative assessment can be used in the STEM approach [40]. It is hoped that the ADI model with STEM and formative assessment has an impact on students' critical thinking skills. Based on this explanation, it is rational if researchers want to know how students' critical thinking skills are by applying the ADI model of learning with STEM and formative assessment.

2 Method

The approach used in this study is a mixed method with an embedded experimental model design [41]. The qualitative data in this design is attached to the experimental design as shown in Fig. 1.

Data collection was conducted in three phases before, during (intervention), and after implementation of the ADI learning model using STEM and formative assessment. The study was conducted at SMA Negeri 1, Putussibau, Class XI in even semester 2020/2021. The subjects of this study were students in class XI IPA 2, a total of 27 students. The material presented covers core competencies 3.10 and 4.10 dealing with sound and light

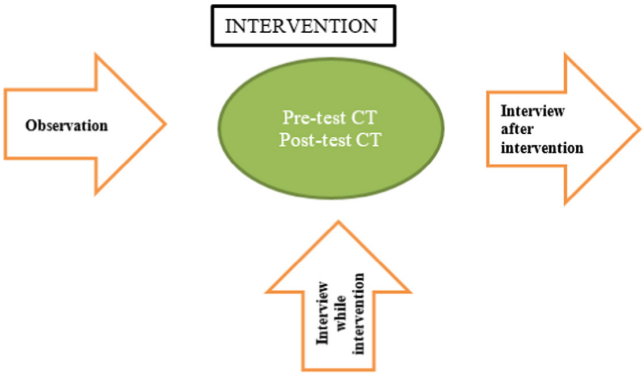

Fig. 1. Embedded experimental model [41]

Table 1. Validity dan Reliability Test

Questions	Validity	Evidence	Reliability	Evidence
question 1	0.278	Valid	0.614	Reliable
question 2	0.724	Valid		
question 3	0.531	Valid		
question 4	0.731	Valid		
question 5	0.662	Valid		

*$t_{tabel} = 0.210$
*$r_{tabel} = 0.6$

waves. Measures students' critical thinking skills using descriptive written tests. A given test has been validated and piloted by two experts. Validation and Reliability The critical thinking tests are shown in Table 1.

An interview form was created to ask questions of the students during and after the implementation of the study. A learning interview sheet is used to clarify student activities and activities that require follow-up. A post-learning interview sheet contains guidelines to see how they are responding to learning and what difficulties they are experiencing.

Data analysis in this study consisted of her two parts: qualitative and quantitative data. Qualitative data analysis with data reduction, coding and data interpretation. Qualitative analysis is done to see how students think about the concept of sound and light waves, find learning difficulties, and enhance the results of quantitative analysis. Before and after learning her ADI model using STEM and formative assessment, analyze quantitative data to answer the question of how to improve the student's critical thinking skills. Statistical tests are used to present quantitative data such as descriptive statistics, normality tests, other tests, N gains, and effect sizes using SPSS.16 and the Microsoft Excel application.

Learning is online as the school is using the Covid-19 Pandemic Emergency Curriculum. Learning with the MINT integrated ADI model and formative assessment in SMAN 1 Putussibau is done virtually via Google Meet and WhatsApp groups. Implementations occur four times a month. After each meeting, the student will work on her LKS, which includes step-by-step instructions for her STEM Integration ADI model. Here are her three worksheets: a STEM worksheet, an internship worksheet, and a reasoning worksheet. At the end of the lesson, students are asked formative questions via Google Forms.

3 Results and Discussions

A. Result

The learning of the STEM and AF integrated ADI model is carried out in class XI IPA 2 and SMAN 1, for the 2020/2021 school year. Learning is carried out through virtual Google Meet and WhatsApp group meetings because it is still in the COVID-19 pandemic. Meetings were held four times during 1 lesson hour, online according to the

published online lesson schedule, and once outside of learning hours (implementation of STEM projects with several students). There are 3 types of worksheets used during learning, namely STEM worksheets, practicum worksheets, and argumentation worksheets. Formative tests are given at the end of each learning meeting. The final STEM project made by students is in the form of an emergency lamp named "Letari". The first meeting begins with the delivery of learning objectives; what will be done when learning for the final test is presented at the first meeting. At the second meeting, students did a virtual practicum through the web provided in the practicum worksheet. The third meeting discussed the results of the work that students had done regarding the solutions in the STEM LKS. In the fourth meeting, students held discussions and conveyed arguments to each other. Meetings outside of learning hours aim to create a "Letari" tool with students at the end of each meeting, always giving a formative assessment.

The description of students' critical thinking skills after applying the ADI model learning with STEM on sound and light waves is carried out through several stages, namely statistical description, normality test, difference test, calculation of N gain, calculation of effect size, and analysis of student answers per question. Statistical descriptions before and after the learning are applied are presented in Table 2.

The statistical description in the table shows that there has been an increase in the mean, maximum, and minimum values of students' critical thinking skills before and after the learning is carried out. The increase in critical thinking skills after the implementation of learning using the ADI model with STEM and formative assessment can be seen in the increase in the mean value from 13.77 to 34.37. The data from the normality test of students' critical thinking abilities can be seen in Table 3.

The results of the normality test of one of the data sets, namely the pretest data sets that were not normally distributed, were carried out using a different test using non-parametric statistics, namely the Wilcoxon test.

The Wilcoxon difference test was used to determine whether there were differences after the implementation of the ADI model of learning with STEM and formative assessment. The data presentation of the Wilcoxon test results is presented in Table 4.

Table 2. Description of Statistics of students' critical thinking ability

Statistic	Pretest	Posttest
N	27	27
Mean	13.77	34.37
Median	8	32
Standard deviation	1.206	1.417
Minimum	0	12
Maksimum	40	68
Range	40	56
Skewness	0.408	0.717

Table 3. The results of the normality test of students' critical thinking abilities

Sapiro wilk			
	Statistik	***Df***	***Sig.***
Pretest	0.897	27	0.012(Not normally)
Posttest	0.940	27	0.125(normally)

Table 4. Wilcoxon test results of students' critical thinking skills

Category	**N**	**Mean ranks**	**Sum of rangks**
Negative ranks	2 (post < pre)	7.75	15.50
Positive ranks	21 (post > pre)	3.98	335.50
Ties	4 (post = pre)		
Total	27		
Z	−4,069 (post > pre) 0.000 (ada perbedaan)		
Asymp.sig(2-tailed)			

Based on the Wilcoxon test results in the table, we can conclude that there are differences before and after the implementation of the ADI model of learning with STEM and formative assessment. The magnitude of the increase in critical thinking skills after learning the ADI model with STEM and formative assessment is calculated with the N-gain value by comparing the pretest and posttest mean values. The results of the N-gain calculation are presented in Table 5.

Based on the results of the N-gain calculation, it was found that there was an increase before and after learning the ADI model with STEM and Formative Assessment in the low category with N-gain 0.33. The results of the effect size values are presented in Table 6.

The effect size results in the table show that the relationship between pretest and posttest data is strong. This means that the application of the ADI learning model with STEM and formative assessment in improving students' critical thinking skills is recommended to be widely applied.

Table 5. The results of the N-gain calculation of students' critical thinking skills

PAspect	**Value**
Mean pretest	13.77
Mean posttest	34.37
Normalized gain Score	0,23 (Low category)

Table 6. Effect size value of students' critical thinking skills

Data	N	Mean	Deviation standard	Effect size
Pretest	27	13,77	1.206	15.7 (strong category)
Posttest	27	34.37	1.417	

Table 7. Student's Answer to Question Number 1

Question	Pretest Answer	Posttest Answer
Question 1. After it rains, on several occasions we often see rainbows. Is the rainbow in the sky caused by light interference? Give an example of light interference!	Student 1 (Point 2) The earth's sky is blue; pool water is colorful; the occurrence of Newton's rings	Student 1 (point 5) This event is usually referred to as the concept of dispersion, which is the event of reducing polychromatic light (white) into monochromatic light (me, ji, ku, hi, bi, ni, u) on a prism through refraction or bending. This proves that white light is composed of harmoniously different colors of light with different wavelengths. For example, the sky looks blue, and the light passing through broken glass looks colorful.
	Student 2 (point 3) The occurrence of a rainbow is caused by the refraction of light that starts with white and then breaks down into many colors, which is called light dispersion.	Student 2 (point 5)The rainbow event is an example of light dispersion, where the light that was originally white is refracted to produce various colors. Some light interference events such as the color of soap bubbles or when flashing a keyhole in a door.
	Student 3 (point 1) the occurrence of Newton's rings	Student 3 (point 3) The appearance of rainbow colors also occurs due to diffraction, which causes polychromatic light. An example of a light interference event is that pool water looks colorful.

Question 1. (gives a simple explanation) consists of focusing, analyzing, asking, and answering questions about an explanation or statement. The following is a presentation

of the questions and some of the students' answers before and after learning is applied, which is presented in Table 7.

Based on the student's answers in Fig. 2, we can see the differences in the answers of each student before and after being given learning. These questions lead students to ask about the phenomenon of the occurrence of rainbows that they often observe. Before learning that the student's ability was still lacking, it was seen that the points obtained were still low. However, after learning the students' points increase, the students' answers become clear and complete, so that they can get the maximum points. In this question, the correct percentage value of students before and after learning is also different. The average correct percentage value before learning is 9.63%, while the correct percentage value after learning is 16.3%.

Question 2 (building basic skills) consists of considering the source's beliefs and observing and considering an observation result. The following presentation of questions and answers of students before and after learning is applied is presented in Table 8.

In this question, students are asked to be able to use their understanding of wavelength and healing time through any information that is known in the question. It was found that the results of students' critical thinking skills on this indicator did not increase. It was assumed that the student researchers only did plug and chug on the known equations in the problem without knowing their meaning. This is due to the lack of students' livelihoods for sources that can help them answer questions. The hope is that, from existing sources, students can build knowledge. This question is too difficult for students to answer, as evidenced by the low percentage of students getting it correct, among other indicators. The increase before and after learning is also not too far away. Before learning, the average percentage of students is 25.2%, and after learning is applied, the results are 45.2%.

Question 3 (concluding) consists of activities of deduction, induction, and making and determining the value of consideration. The following is a presentation of student's questions and answers before and after the implementation of learning in Table 9.

It can be seen that there is an increase in students' answers that are not correct until they can answer well after being given learning. Students finally know that the difference between light and heat is in the spectrum. This problem asks students to be able to compare heat and light waves. The results of students' answers to this question show the highest increase compared to other indicators. The average percentage of students correctly before learning is 10.4%, while after learning, the average percentage of students is 30.4%.

Question 4 (providing further explanation) consists of identifying terms and definitions of considerations as well as identifying assumptions. The following is the presentation and student answers before and after learning is given in Table 10.

In question 4, it can be seen that the student's answers were initially incorrect and became appropriate after learning was applied. Problem 4 asks students to identify how headphones work to overcome the noise received by workers. There was an increase in this indicator after learning was applied. Judging from the correct presentation, the average student before learning was 12.6%, while after learning it increased to 42.2%.

Table 8. Student's Answer to Question Number 2

Question	Pretest	Posttest
Question 2. Echolocation is a form of vision used by most bats, toothed whales, and dolphins, as well as some birds. The animal emits a sound pulse that is reflected from objects; the reflected pulses are then detected by the animal to study its environment or interact with other animals. The echolocation wave emitted by the whale has a frequency of about 200,000 Hz. (a) What is the wavelength of the whale's echolocation? (b) If an obstacle is 100 m from the whale, how long after the whale emits the reflected wave does it receive it?	Student 1 (point 1) a) 200.000 Hz b) 3 s	Student 1 (point 2) v = b/p = 200.000/100 = 2000Hz Wave propagation speed = lamda = v/f = 2000/200.000 = 0,01 Velocity consept = s = v × t = 2000 × 0,01 = 20 Hz
	Student 2 (point 1) (a) The wavelength emitted at 200000 Hz is 167087. (b) the barrier is 100 m away when the whale's reflection is 26 cm..	Student 2 (point 1) a). 200.00: 100 = 2.000 s b) 200,000 Hz The recommended wavelength is 167,087. While the barrier is 100 m away. The bounce time received by the whale is 26 cm.
	Student 3 (point 1) A. Wavelength = 1000 m B. Time = 100 ÷ 200.000 = 0,05 s	Student 3 (point 1) SONAR (Sound Navigation and Ranging) is the use of the principle of sound wave reflection for navigation systems. Sonar can generally be used for ultrasonic sounds whose frequency is > 20000 Hz. In addition, another reason is that ultrasonic waves also have a short wavelength, and the propagation of waves is also relatively small. This causes small objects to be detected.

Question 5 (setting strategies and techniques) consists of determining actions (predictions) and interacting with other people. The following is a presentation of student's questions and answers before and after learning is applied in Table 11.

It was found that before learning, the students answered incorrectly because they thought that the loudest sound was in the position of the child closest to the source. This question asks students to be able to predict in which position the loudest sound is heard by the child playing on the swing. There was a significant increase where initially

Table 9. Student's Answer to Question Number 3

Question	Pretest	Posttest
Question 3. Standing in front of the fire, we can feel the heat and light. How are heat and light emitted? What is the difference between the two?	Student 1 (point 1) The light emitted by the sun comes from the thermonuclear fusion reaction that occurs in the star's core. By convection, the energy from the fusion reaction is transferred to the surface.	Student 1 (point 4) Heat transfer concept Thermal radiation enters visible light.
	Student 2 (point 2) Temperature is defined as heat. Light is light.	Student 2 (point 3) The heat from the fire can be felt by the body because the heat of the fire propagates through radiation. While the propagation of light in free space is carried out by electromagnetic waves,
	Student 3 (point 2) Heat and light were emitted from the blazing fire. The difference is that heat can be seen from our current temperature/radiation from what is in front of us, while the light from the fire can be seen by our eyes, namely fire that emits light.	Student 3 (point 4) The concept of displacement through radiation Because fire has heat and conducts radiation. Thermal radiation, which is included in the form of visible light, is also bright and has light.

students' understanding was wrong to be right and better. The average correct percentage before learning is 11.1%, while after learning it becomes 37.8%.

B. Discussions

The learning steps of the ADI model with STEM and formative assessment are carried out through virtual learning. Virtual learning was chosen with the consideration that normal learning could not be carried out due to the COVID-19 pandemic. The ADI learning steps are implemented in seven steps, namely identifying tasks and questions, collecting and analyzing data, generating temporary arguments, arguing, writing investigative reports, peer reviews, and report revision [32]. The existence of a STEM approach that is applied with the ADI model makes learning not only completed in the classroom environment but can be broader, namely in the community environment [42]. Not only with the STEM approach, the ADI model is also equipped with formative assessment, the importance of formative assessment is to help students learn and focus on learning objectives [43].

The linkage of each learning step with improving critical thinking skills is the first, namely when filling out the STEM LKS, students are challenged to complete and provide

Table 10. Student's Answer to Question Number 4

Question	Pretest	Posttest
Question 4. The traditional method of protecting the hearing of people working in high-noise areas is by blocking the noise level. With relatively new technology, headphones have been developed that do not block out environmental noise. However, it reverses the sound electronically and then feeds it into the headphones along with noise from the environment. How can the addition of noise actually reduce the sound level? What is the underlying concept of this?	Student 1 (point 1) Provide hearing protection if it is not possible to reduce the noise.	Student 1 (point 3) The concept of interference is a combination of two waves with different frequencies and phases that meet and interact with each other in the same medium. For example, in two coherent sources, which have variations in the strength or weakness of the waves.
	Student 2 (point 2) The headphones use the controller's noise-canceling feature, which is a slightly advanced technology that is equivalent to putting your hand to your ear to block out incoming noise. Noise-canceling headphones can reduce overall noise by up to 80 decibels.	Student 2 (point 4) The concept that underlies this is the concept of interference. Sound wave interference is the combination of two waves with different frequencies and phases that meet and interact with each other in the same medium. For example, in two coherent sources, which have variations in the strength or weakness of the waves.
	Student 3 (point 1) That is to make our brains work to focus on and recognize which sounds we want to hear and which voices we don't want to hear. So that the brain only focuses on the sound in the headphones, so that we don't hear too much noise from outside, because the focus of the sound we hear is in the headphones.	Student 3 (point 3) Interference concept Because the brain will focus on what it wants to hear only so that what it doesn't want to hear automatically becomes small.

solutions that will be presented to other students. The solution to the student's thoughts is the result of the student's critical thinking skills. The aspect of critical thinking ability that is applied is "applying gained solutions" [44]. Students will try to analyze problems comprehensively to design solutions. The ability to analyze also includes aspects of critical thinking [45].

The second link is when students do the virtual practicum. Practicum conducted by students is about the relationship of frequency, wavelength, and string tension on the sonometer and identification of diffraction patterns on the lattice through a virtual

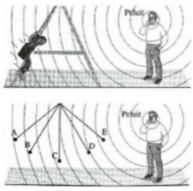

Fig. 2. Swing game simulation

lab. Doing virtual practicums makes students interested and motivated in learning [46]. Virtual practicums in several studies have been proven to be effective in improving students' critical thinking skills [47, 48]. Virtual practicums equipped with practical worksheets were also found to be able to improve critical thinking skills [49].

The third link is in argumentation activities, where students are given worksheets with argumentative questions. Based on the questions given, students are asked to give a claim of agreement or not with the given statement. Student consent must be accompanied by evidence. Several studies have found a close relationship between scientific argumentation and students' critical thinking skills [50, 51]. Through argumentation, critical thinking can be conveyed [52].

The fourth linkage is when students convey their arguments to each other in the forum. Students are encouraged to express their ideas while learning. The ability to convey their thoughts is one aspect of critical thinking, namely explanatory, where students can interact with each other regarding their understanding of a problem [45].

There was an increase in critical thinking skills after the implementation of the ADI model of learning with STEM and formative assessment. Based on the average score of students before and after learning, it increases to 34.37. There is a difference after applying the learning with a Wilcoxon significance value of 0.00. The calculation of 0.23 is an increase in the low category. The improvement of critical thinking skills through the ADI model with STEM and formative assessment is in line with research that has been carried out on the ADI, STEM, and formative assessment model variables on students' critical thinking skills [50, 53–57]. The calculation of the effect size found a value with a strong category, namely 15.7. That is, the application of the ADI model with STEM and formative assessment of critical thinking skills is recommended to be widely practiced. Students with the highest critical thinking improvement results when interviewed provided information about actions that could help increase critical thinking. The action is to focus on the main idea of a question. Understanding the main idea can help develop reasoning that can improve critical thinking skills [58]. Not only focusing on the main idea, courage in arguing is also important in improving critical thinking skills [51]. When interviewed, the students with the highest improvement admitted that they tried to be brave in conveying the arguments they understood.

Table 11. Student's answer to question number 5

Question	Pretest	Posttest
Figure 2 shows the various positions of a child moving on a swing. An observer blows his whistle in front of the child. In what position will the child hear the highest frequency of the sound of the whistle? Describe your reasoning!	Student 1 (point 1) The frequency of sound from a sound source heard by an observer will increase if the sound source approaches a stationary observer.	Student 1 (point 3) is in position C. This child will swing the swing in front of the person who blows the whistle. Because position C in the middle will definitely receive the sound blown by the person who blew the whistle.
	Student 2 (point 1) Position E. Because the distance from the sound source to the listener is closer, so that the resulting frequency is not widely spread.	Student 2 (point 4): Position C. Because sound is a wave, and waves occur gradually and stop gradually, In this event, the whistle that was sounded initially had a low frequency, and the more it sounded, the frequency would increase, and the frequency would decrease again if the whistle stopped blowing. So in that question, the frequency increases in the middle of the whistle, and the one in the picture above, position C, is the most middle position, and in that position, the highest frequency that the child will listen to..
	Student 3(point 1) E, because the closer we get to the source of the sound, the clearer the sound will be heard.	Student 3 (point 5) Point position from C-A. because when the child's position approaches the origin of the sound, the sound will be blocked so that the sound is less loud, while when the child's position is away from the sound source, the sound will sound loud because the sound is absorbed and has a propagation path ear.

4 Conclusion

There was an increase in critical thinking skills from an average value of 13.77 to 34.37 after the ADI model was applied with STEM and Formative Assessment. There is a significant difference between the results of critical thinking skills before and after

learning is applied. However, the improvement of students' critical thinking skills is still in the low category. Based on the value of the effect size, which is in the strong category. Students' critical thinking skills through the ADI model with STEM and formative assessment can be widely applied. The critical thinking indicator with the highest increase is the "concluded" indicator. Aspects that must be considered in developing students' critical thinking skills are daring to convey ideas, growing motivation, trying to give explanations, and daring to argue.

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