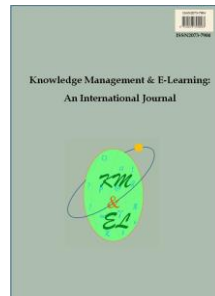

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Assessment instrument of graph representations on sound wave topic: Development and measurement implementation

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Abstract: Sound waves are one of the important topics studied in physics. However, students' graph representation is still low, leading to their low concept understanding of physics learning. Therefore, it is necessary to optimize the learning process to improve students' graph representation by providing a valid and reliable graph representation test instrument. This study aims to (1) develop a graph representation test instrument on sound wave topic and determine its psychometric characteristics and (2) describe students' graph representation abilities in implementing measurements. The development followed the ADDIE procedure combined with the modified Wilson, Oriundo, and Antonio procedure. The analysis included content validity, item analysis (Rasch model), paired samples t-test, descriptive analysis, and calculation of effect size coefficient. This development produced two packets of graph representation test instrument on the sound wave topic that is considered feasible to use in the test. The results of the measurement implementation show that students have low graph representation before and after learning. This research is expected to provide a new instrument to be implemented in learning and open new insights related to physics learning.

Keywords: Assessment; Assessment instrument; Graph representation; Sound wave; Physics education

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1. Introduction

Sound waves is one of the physics topics studied by high school and university students. The phenomenon of sound waves is easy to present in the classroom, making this topic suitable for study. In addition, the topic of sound waves in physics discusses the Doppler effect, which is very important for understanding relativity and astronomy and is closely related to the discussion of waves (Leccia et al., 2015; Moriconi, 2006; Nolte, 2020). The position of sound wave topic makes mastery of concepts in the topic essential to encourage student success in learning physics. Although students' concept mastery has a vital position, students still experience many difficulties with sound waves. Many students still experience misconceptions about sound waves and have low concept mastery (Eshach et al., 2018; Saparini et al., 2021; Silaban & Jumadi, 2022).

Difficulty in learning sound waves can be caused by several factors, one of which is the low representation ability of students. Representation ability is the ability of students to utilize their perceptions to form, interpret, and associate a representation in order to understand and communicate the understanding of science concepts (Daniel et al., 2018; Volkwyn et al., 2020). Nieminen et al. (2012) and Van Heuvelen (1991) stated that representation is important in learning physics concepts and quantities. Some studies also concluded that representation ability benefits students' concept understanding (Küchemann et al., 2021; Pande & Chandrasekharan, 2017). These studies show that students' failure to understand physics concepts can be influenced by their representation ability.

Sound wave learning involves different types of representations to express concepts. One type of representation involved in learning sound waves is graph representation. Graphs in physics help connect physical phenomena and mathematical equations (Pospiech, Michelini, et al., 2019). Graphs on the subject of sound waves are often used to explain the character of sound frequency, sound superposition, and the Doppler effect (Aygün & Aydın-Güç, 2019; Azalia et al., 2022; Dias et al., 2016). The utilization of graphs in the presentation of the sound waves concept indicates the need to utilize graph representation ability to understand the concept of sound waves.

Graph representation is one of the representation abilities that is very important to learn. Graph representation ability plays a role in bridging the ability of mathematical representation and pictorial representation, helps in representing data, and helps uncover complex pattern problems (Pospiech, Geyer, et al., 2019). Using graph representations in physics can also help students think like physicists and help develop knowledge in physics (Nixon et al., 2016). These views show that graph representation is one of the supports for other representation abilities. The relationship among these representation skills can mean that low graph representation abilities of students can inhibit students from using other types of representation, which can further inhibit students from understanding concepts. Furthermore, research has also shown that as one type of visual representation, graph representation can help students illustrate relationships between information, help information to be accessed perceptually, and reduce information stored in working memory (Mößner, 2015). The reduced working memory load is due to the imagination effect that arises when students use visual representation (Ignatova et al., 2023). Further, visual representation has also been shown to help students with low visuospatial abilities (Bobek & Tversky, 2016). These arguments show that graph representations can facilitate students in understanding scientific concepts.

Various arguments regarding the effect of graph representation ability on understanding the concept of sound waves are reinforced by various findings regarding students' graph representation abilities. Pebriana et al. (2022) and Furqon and Muslim

(2019) found that more than 70% of their research respondents in Indonesia have poor graph representation ability. In addition, Rangkuti and Karam (2022) also noted the difficulties experienced by students related to graph representation. Furthermore, Kassiavera et al. (2019) found that only 25.2% of students answered correctly on the graph representation test questions. Similar findings were reported by Asriadi Am and Istiyono (2022), who found that 80.72% of students involved in their research needed higher and deeper graph representation. These findings indicate that students still need to improve their graph representation ability. Given that the sound waves topic involves graphs in expressing various concepts, students' low graph representation ability can inevitably hinder students from understanding the sound waves topic.

Students' low graph representation ability requires improvement to encourage students' concept understanding. Studies have been conducted to find the right way to improve students' graph representation skills. Some ways that have been empirically proven to be optimal for improving students' graph representation include the involvement of graphing when learners conduct experiments or science investigations (Matuk et al., 2017), the provision of graph-based materials (Weigel & Angra, 2023), the implementation of active learning (Weigel & Angra, 2023), collaborative learning (Gardner et al., 2024), application of reflection on graphs (Gardner et al., 2024), problem-based learning models (Rahmasari & Kuswanto, 2023), local wisdom-based learning (Rahmasari & Kuswanto, 2023), the use of modeling with the help of Excel or Spreadsheet (Malone et al., 2018), Augmented Reality (AR) based media (Hidayatulloh et al., 2021), and interactive graph visualization technology (Donnelly-Hermosillo et al., 2020). These methods will not be effective without good assessment practices. Assessment is proven to have a positive influence on students' skill attainment (Sotiriadou et al., 2020), provides diagnostic information about students' abilities (Bleckmann & Friege, 2023), provides feedback to students regarding their ability achievements (Black & Wiliam, 2018), provides feedback to teachers regarding the learning process (Black & Wiliam, 2018), and can even affect student learning (Wilson, 2018). Good assessment practices cannot be carried out without providing a valid and reliable assessment instrument.

The vital role of assessment and graph representation in learning has attracted various researchers to develop assessment instruments to measure graph representation ability. Research by Pramudia and Agustin (2018) developed an assessment instrument for thermodynamics topic based on graph representation. The analysis carried out in the development was only limited to validity and reliability analysis. Slightly different, Bunawan et al. (2015) developed a graph representation test instrument on the topic of geometric optics and analyzed the quality of the instrument using classical test theory. Research by Armanto et al. (2021) successfully developed a test instrument on graph representation ability on linear motion topic and analyzed it with the Partial Credit Model. The instrument developed by Boote (2014) is scoring rubrics, which were developed to measure student's ability to interpret graphs and validated based on expert judgment. Another assessment instrument is a performance assessment instrument in the form of true-false questions to measure students' understanding of graphs, which was analyzed using item response theory (IRT) (Ring et al., 2019). Finally, there is a performance assessment instrument in the form of pretests and posttests, which was developed to measure students' graph interpretation and analyzed for three types of validity in the form of construct validity, convergent validity, and discriminant validity (Peterman et al., 2015). Based on some of these instrument developments, only a few graph representation assessment instruments are developed for specific learning materials, especially sound waves. In fact, the subject matter is closely related to students' representation skills (Nitz et al., 2014). Furthermore, the instrument analysis carried out on these instruments is still

partial; for example, it is only a validity analysis. A broader analysis is needed to produce an accurate and reliable instrument for measuring students' abilities.

The critical role of graph representation in learning, the low graph representation ability of students, the student's low concept mastery of sound wave topic, and the limitations of previous research indicate the importance of developing an assessment instrument of graph representation ability for physics learning on the topic of sound waves. In this study, researchers will develop an assessment instrument of graph representation on sound wave topic. The developed instrument is analyzed using modern test theory and classical test theory. The purpose of this research is (1) to develop a graph representation assessment instrument on sound waves topic and determine its psychometric characteristics and (2) to describe the profile of students' graph representation ability in measurement implementation. The instruments developed in this study are expected to be used to capture valid and reliable data that can be used to improve the quality of the learning process, which can then enhance students' graph representation ability.

2. Research methods

2.1. Research design and development procedure

To fulfill the objectives of this study, we conducted development research. We use ADDIE research design (Branch, 2009) as the primary study framework. Researchers focus on instrument development and instrument implementation in learning assessment activities through this ADDIE design. ADDIE research design generally consists of 4 steps: Analysis, Design, Development, Implementation, and Evaluation. ADDIE is a research design that is often used in development research in the field of education in general. Since this research aims to develop an assessment instrument, there needs to be specific steps to develop the instrument. In this study, Wilson, Oriundo, and Antonio's modified development model (Istiyono et al., 2014), consisting of 3 main steps, including instrument design, test piloting, and test preparation, was combined with the ADDIE design to produce a more specific research procedure.

The instrument design stage consists of several steps. This stage begins with the problem analysis process. Some of the problems we found have been identified in the introduction. Problem analysis is done to identify problems and to find the right solution to the problem. After identifying the problem, the next step is determining the test's purpose. The test's purpose in this study is to measure the development of students' abilities during the learning process. This goal was chosen because the previous instrument had not been developed to assess students in the learning process. The consequence of this test objective is that the test instrument developed consists of 2 packets of formative test instruments to assess students before and after learning. After the test objectives are determined, the competencies and subject matter to be tested are determined. The competencies and subject matter to be tested are graph representation ability and sound wave topic. Both of these are essential components in physics learning and are closely related. The next step is writing the test grid as a guide for writing the test instrument. Writing the test instrument is done in the next step, and the instrument is written based on the test grid. After the instruments are prepared, scoring guidelines are also prepared. Experts conduct a content validity assessment after the scoring guidelines and instruments are ready. Experts conduct content validity assessments to ensure the developed instruments measure students' graph representation abilities. If there are

problems with the instrument, researchers would revise the instrument based on the results of the expert assessment on the next step.

The following two stages, pilot test and test preparation, can also be divided into more detailed steps. The test piloting stage includes pilot-testing the instrument and analyzing the characteristics of the instrument items. Pilot testing of the instrument is conducted to collect student data, which can then be analyzed to determine the psychometric quality of the test items. The psychometric quality of the test items is known through the psychometric analysis. The details of the analysis method are explained in the following subsection. The last stage is the preparation of tests, where quality items are compiled for use. After the instrument has been developed and deemed feasible, it is arranged to be used in the implementation of learning. These two development designs result in a development procedure, as presented in Fig. 1.

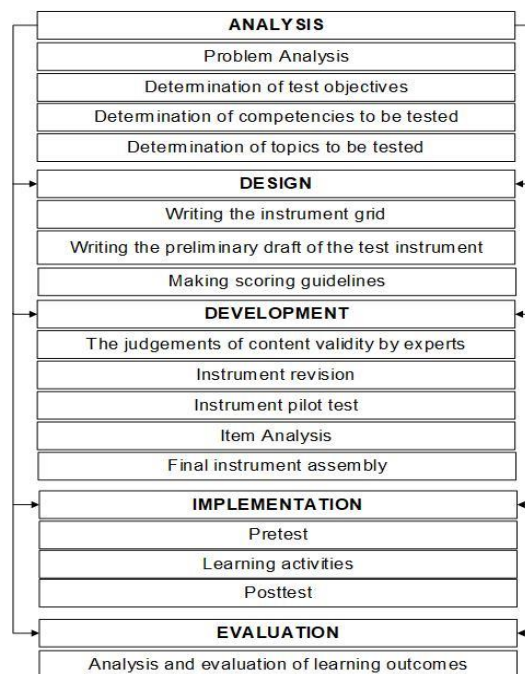


Fig. 1. Assessment instrument development procedure.

2.2. Participants

The participants involved in the pilot test were 339 senior high school students majoring in science. The students comprised 28% male ($N = 95$) and 72% female ($N = 244$). The students involved in this study were students who had studied the topic of sound waves. The students were from 2 schools in Kebumen, Central Java, Indonesia.

During the implementation stage, the participants were 72 students from 2 different classes from one school in Central Java, Indonesia. The classes and schools used in this study were randomly selected. The data analyzed in this study are from students who participated in the whole research series from the pre-test and learning activity to post-test. The number of participants who followed all procedures at the implementation stage was 44, consisting of 12 male and 32 female students.

2.3. Data collections

Data collection in this study was carried out at the Development and Implementation stages. Data collection techniques used in this study include distributing questionnaires and tests. Questionnaire distribution was carried out to collect content validity assessment data. The assessment questionnaire with five ratings was distributed to six expert judgments to assess the instrument's content validity. After the content validity assessment, the test was carried out at the pilot test stage to collect data on student responses to the instruments developed.

Data collection using the test method was also carried out at the Implementation stage. However, the test technique is different from the pilot test stage. Tests at the implementation stage were carried out using pretest and posttest techniques. Between pretests and posttests, a learning activity was carried out for students. Pretests and posttests were conducted to capture data on students' graph representation ability before and after learning. The learning activity applied to students is learning sound wave topic with the discovery learning model. This model was chosen because it involves mental processes related to scientific inquiry, such as observing, measuring, predicting, and concluding (Sund & Trowbridge, 1971). The inquiry process expressed in the learning steps of the discovery learning model involves the utilization of various representations to facilitate drawing conclusions. This involvement can teach students various representation skills, including graph representation.

2.4. Data analysis

The collected data were then analyzed using various analytical techniques. The content validity of the items was analyzed by calculating Aiken's V index. The data used in this calculation was data from the questionnaire. Item analysis with the Rasch model was conducted to analyze student response data. This analysis was conducted with the help of jMetrik software. The psychometric parameters obtained through item analysis include item fit parameters with the Rasch model, item difficulty, item reliability, test information function, standard error of test estimation, and item information function. Data at the implementation stage were analyzed using descriptive statistics to determine the profile of students' graph representation before and after the learning process. Paired sample t-test was conducted to analyze the effect difference before and after the learning process. The effect size coefficient was calculated using Cohen's d-index to describe the improvement of students' graph representation ability due to learning with the discovery learning model.

3. Result and discussion

3.1. Development result

The development carried out in this study succeeded in producing a test instrument consisting of two packets of instruments, packet A and packet B. The researchers wrote the developed instrument in Indonesian language. The instrument developed in this study is different from previously developed test instruments such as those by Pramudia and Agustin (2018), Armanto et al. (2021), and Bunawan et al. (2015) because this instrument was explicitly developed for sound wave topic, made in the form of multiple choice in two sets of instruments, and analyzed using classical and modern test theory to provide better accuracy. At the beginning of the test design stage, we first set the test's purpose to

measure the graph representation ability of high school students. The learning topic to be tested was the topic of sound waves. This topic was chosen because graph representations can be used to explain the concept of sound waves. Another consideration in this selection is related to the important position of sound waves in physics learning.

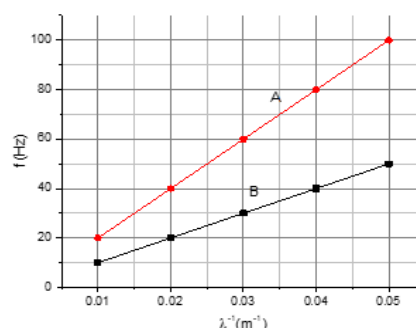
Instrument development is carried out after the test objectives and topic are determined. The initial instrument developed comprised eight items in packet A and eight in packet B. Among these items, 1 item in both packets served as an anchor item. The items distribution matrix and examples of items can be seen in Table 1 and Fig. 2, respectively.

Table 1

Items distribution matrix and indicator of graph representation

Aspect	Sub-Aspect	Indicator of Graph Representation	Item No.
Graph representation ability	Understanding	Understanding the meaning of graphs	1A,1B
	Describing	Describing graphs	2A,2B
	Selecting	Selecting the right graph	3A,3B
	Intepreting	Interpreting the meaning of graphs	4A*,4B* (anchor item)
	Connecting	Connecting quantities based on graphs	5A,5B
	Indentifying	Identifying key information from the graph	6A,6B
	Summarizing	Summarize information based on graphs	7A, 7B
	Making	Making a graph	8A, 8B

Look at the following graph.



The graph illustrates the relationship between the wavelength and frequency of two sound waves. The correct interpretation of the graph is...

- Sound wave A propagates twice as fast as sound wave B.
- Sound wave A propagates two times slower than sound wave B.
- The slope of the graph represents the value of one per sound wave propagation speed.
- The greater the frequency of the sound wave, the greater the wavelength.
- The wavelength of sound A is always two times greater than the wavelength of sound B at the same frequency.

Fig. 2. example of an item that translated into English.

The instruments developed in this study were tested for quality through several parameters. The assessment parameters for item quality used include item validity, instrument reliability, and item difficulty. Item content validity was assessed based on expert judgment and analyzed using the Aiken method. Content validity was used

because it is the most commonly used type of validity in item quality analysis. Item reliability was assessed using classical methods (item reliability index) and modern methods based on the SEM curve and Test Information Function. Item difficulty was assessed based on the results of item analysis with the Rasch model. The use of modern test theory to estimate item reliability and difficulty was chosen because modern test theory has advantages over classical test theory. After all, instruments analyzed using modern test theory are considered more accurate in measuring latent constructs (Harvey, 2016). Even so, classical test theory is still used in the reliability test. This is because in modern test theory, the instrument is considered reliable for measuring students' abilities in a particular range but cannot be used to assess reliability qualitatively, in contrast to classical test theory (item reliability index), which provides a quantification of instrument reliability which can be further categorized qualitatively.

The results of the validity analysis using the V Aiken method are presented in Fig. 3. Validity testing by experts in this study used a questionnaire with five ratings. The criterion for the minimum value of Aiken's V index for five ratings with six raters is $V = 0.88$ ($p = 0.05$) (Aiken, 1985). When we look at Fig. 3, it can be seen that all items have a V Aiken index of more than 0.88. These values indicate that all items developed have met the content validity criteria so that they can be continued at the next stage of development.

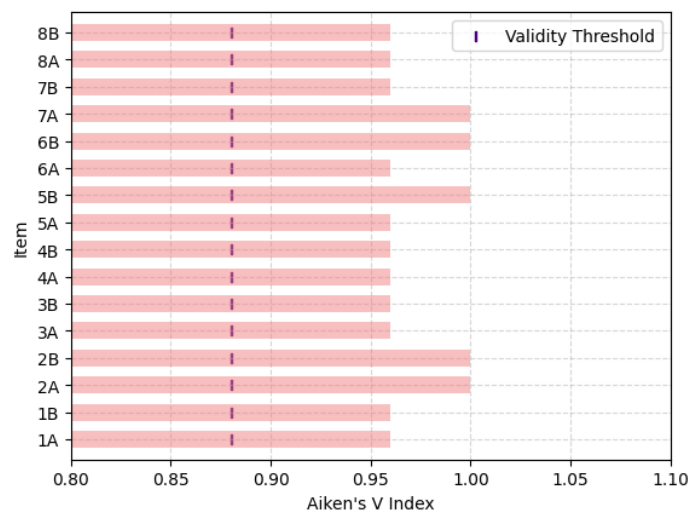


Fig. 3. Distribution of Aiken's V index of items

The item analysis results for item fit with the Rasch model are presented in Fig. 4. The dashed lines represent the minimum and maximum limits of the infit MNSQ values, indicating the item's fit with the Rasch model. This value is based on the model fit range criteria of 0.7 and 1.3 (Bond & Fox, 2013; Liu, 2020). Based on Fig. 4, the asterisk symbols depicting the infit MNSQ position of the items are all within the boundaries of the red line. This pattern indicates that the items that have been developed all fit the Rasch model.

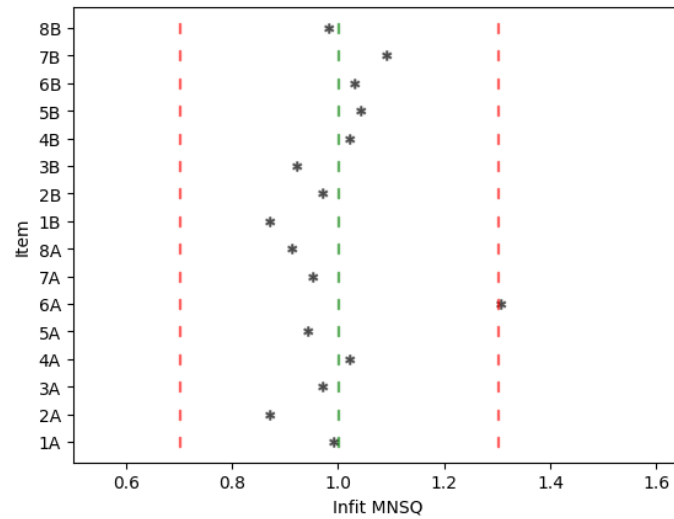


Fig. 4. Item map depicting the distribution of infit MNSQ values

The results of the item difficulty analysis are presented in Fig. 5. Based on Fig. 5, it can be seen that almost all items have a good level of item difficulty because they have an item difficulty index in the range of -2 to 2 (Hambleton et al., 1992). However, items 1A, 2B, and 6A are outside this range, so they are classified as items with a poor level of difficulty.

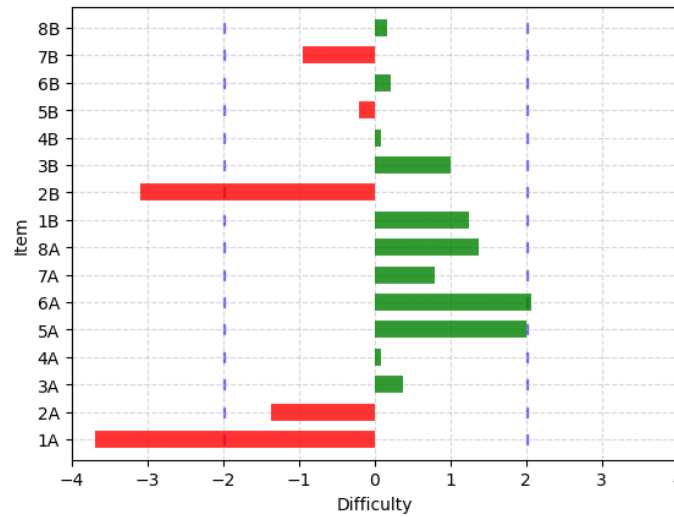


Fig. 5. Item difficulty of the assessment instrument

Fig. 6 presents the item characteristic curves for the curve peaks at the lowest ability or θ values (Item 1A), medium θ values (Item 4A), and high θ values (Item 6A). All three curves in the figure form a normal curve with a high peak. The curve shape indicates that the corresponding items are highly informative for measuring students' ability for $\theta = -3.8$ (item 1A), $\theta = 0.1$ (item 4A), and $\theta = 2$ (item 6A), respectively.

The item information curves for the other items have curve peaks of -3.8 to 2. All item information curves of the developed items form a normal curve with a peak at 0.25. Items that are informative when used to measure students' abilities are expected to measure students' abilities accurately.

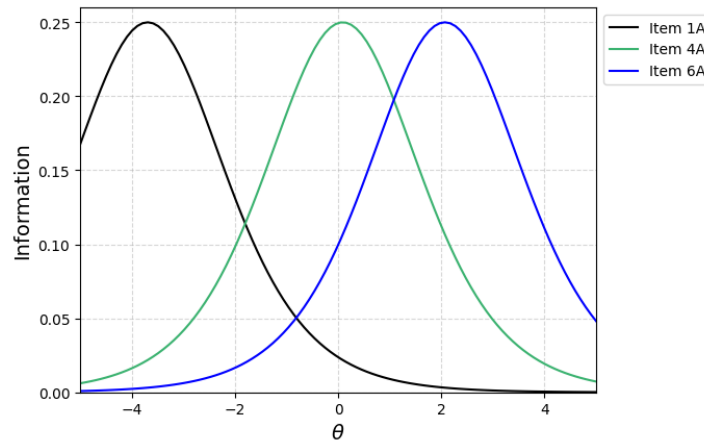


Fig. 6. Item information curves for item 1A, items 4A, and item 6A

The JMetrik software analysis results produce instrument reliability information based on classical and modern test theory assumptions. The classical analysis results are shown through the estimated reliability coefficient value. The instrument developed has an estimated reliability coefficient of 0.98. This value is above the minimum value of the reliability coefficient by Kaplan and Saccuzo (2018), which is in the range of 0.70 - 0.80, which indicates that the item is reliable for use in the test. The test information and standard error curves show the reliability analysis results using modern theory. Fig. 7 presents the test information curve (TIC) and test standard error curve (TSE). Based on Fig. 7, it can be seen that the TIC and TSE curves intersect at θ values of -3 and 3.2. The intersection of these two curves indicates that the test that has been developed is reliable for measuring graph representation ability for students with abilities -3 to 3.2 on the logit scale. TIC, which tends to form a normal curve with a high peak at $\theta = 0.5$, indicates that the test has the best performance to measure students with ability $\theta = 0.5$.

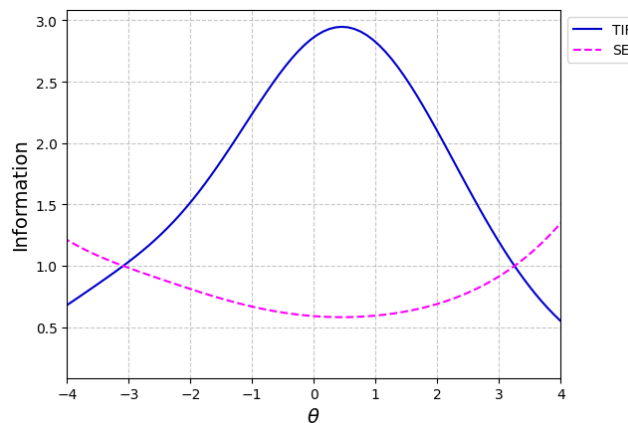


Fig. 7. Test information curve (TIF) and test standard error (TSE)

The content validity analysis and item analysis results can be used to assess the feasibility of test items for measurement. The analysis results show that almost all items fulfill content validity, are reliable enough to measure the abilities of diverse students, fit the Rasch model, and have a good level of item difficulty. Items that fulfill all of these can be classified as good items according to Istiyono's criteria (2020). In addition to the items classified as good, some items fulfill content validity and are reliable in measuring diverse students' abilities but have poor levels of item difficulty. These items are items 1A, 2B, and 6A. These three items can be classified as fairly good based on the criteria from Istiyono (2020) and can still be used in the test. These fairly good items must be improved for better psychometric parameters.

Many factors can cause the existence of items with poor psychometric characteristics in this study. One of the factors that can affect the quality of item parameters in item analysis is the characteristics of the respondents during the pilot test. Fig. 8 presents the distribution of respondents' abilities based on Rasch model analysis. When examined in Fig. 8, the normal distribution fitting (dashed red line) shows that students have an average ability of -0.95 . This average ability value indicates that students have abilities that tend to be at a medium-low level. Furthermore, the high-frequency histogram bars tend to be clustered at ability less than 0, which indicates that most students have low ability. This condition may cause students to guess. The number of students who guess can impact the poor results of item analysis (Hula et al., 2012). Therefore, improvements to the instruments that have been developed can be made by conducting test trials on more significant respondents and more diverse students. Test trials on a more significant number of respondents and more diverse student abilities are expected to produce good item parameters. In addition, adding respondents also provides other benefits, it can provide more stable item parameter estimation results (O'Neill et al., 2020).

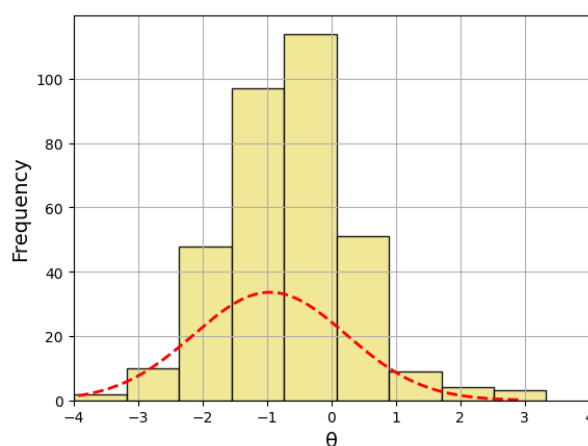


Fig. 8. Histogram of the distribution of respondents' abilities based on the results of Rasch analysis

3.2. Student's graph representation ability on implementation of measurement

Students' graph representation ability based on pre and post-test assessments is represented in the θ value. The distribution of students' graph representation ability (θ) before and after learning the sound wave topic is presented through histograms in Fig. 9

and Fig.10. The dashed red line is data modeling with the normal distribution approach. Based on Fig. 9 and 10, it can be seen that the distribution of students' abilities before and after treatment is mostly at $\theta < 0$. The average ability of students with normal distribution modeling shows that the average ability of graph representation before treatment is -1.22 and after treatment is -1.21. Although there is no significant difference in the mean before and after treatment, there is an increase in the number of students for ability > 0 from the logit scale.

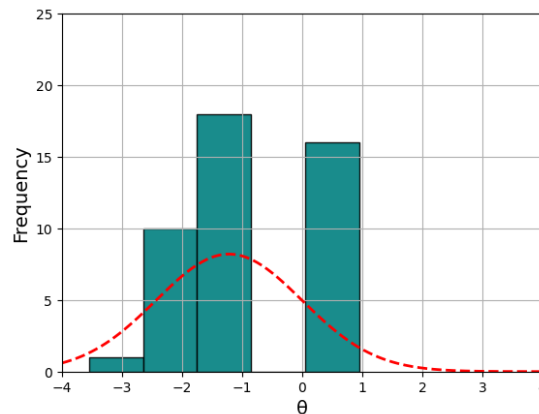


Fig. 9. Histogram of graph representation ability before learning

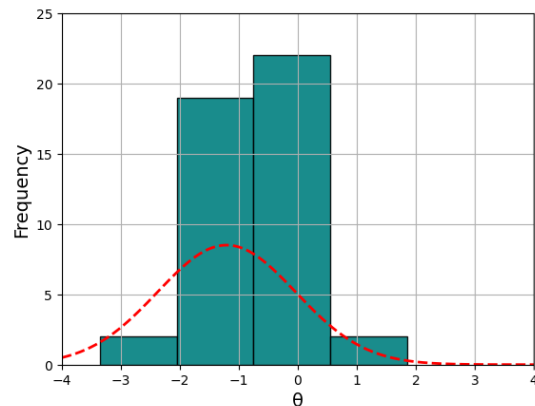


Fig. 10. Histogram of graph representation ability after learning

The measurement results during the pretest and posttest, consistent with the value of $\theta < 0$, indicate that the students' graph representation ability is still low both before and after learning with the discovery learning model. These measurement results follow the findings of Kusumawati et al. (2019) and Pebriana et al. (2022), which showed that students' representation skills were still low. The effect of learning sound wave topic with the discovery learning model on students' abilities, as shown in the histograms in Fig. 9 and 10, was confirmed through t -tests for paired samples and the Cohen's d -index calculation. The results of the t -test for paired samples ($p = 0.05$) and the calculation of Cohen's d -index are presented in Table 2.

Table 2

Results of paired samples t-test and Cohen's d-index

	Average pre-test	Average post-test	Mean difference	t	Sig. (2- tailed)	Cohen's <i>d</i>
Graph representation ability (θ)	-1.2178	-1.2067	0.011	0.045	0.964	0.0091

The results in Table 2 show that the significance value in the t-test for paired samples is > 0.05 . This result means no significant difference in student's ability before and after learning. This result is confirmed through the calculation of Cohen's d-index to see the effect of the discovery learning model on improving graph representation ability. The calculation value of Cohen's d-index obtained is below the low category threshold value for effect size with Cohen's d-index of 0.2 (Ellis, 2010). This result means that the discovery learning model had a negligible effect on students' graph representation. This result differs from previous research that shows that the discovery learning model has a good impact on mathematical and visual representation, including graph representation (Ertikanto et al., 2018; Juandi & Priatna, 2018). If we look deeply, the discovery learning model is closely related to science inquiry activities and active learning. Previous research shows that inquiry-based learning (Ryplova, 2016) and active learning (Weigel & Angra, 2023) can improve students' graph representation skills. The findings on active learning and inquiry learning show a deviation between this study's findings and the previous theory.

When looking at the implementation of learning, it was observed that the learning had implemented all the syntax of the discovery learning model. However, learning skips the steps of apperception, motivation, and reflection of learning. Student motivation, apperception, and reflection have been shown to influence student learning outcomes (Musthofa & Sujadi, 2020; Orhan Özen, 2017; Zhai et al., 2023). The effect of these learning steps on learning outcomes makes it necessary to pay attention to their implementation to optimize the effect of the discovery learning model on graph representation.

The low graph representation ability of students and the lack of effectiveness of the discovery learning model in improving graph representation ability can be caused by several factors. One of the factors that can influence is problem misinterpretation (Klein et al., 2019). In addition to these factors, semiotic errors can affect students' performance in representing a graph. This semiotic error arises because students see the graph as a picture, so diagrammatic reasoning does not work to interpret the relationship between variables depicted by the graph (Hull & Atkins, 2017). In addition, other forms of representation that are more familiar may deter students from using graph representations in problem-solving (Treagust et al., 2017). These factors can cause students to have low graph representation performance. The effect of learning on graph representation ability can be seen from the characteristics of the discovery learning model. Discovery learning involves constructivist learning theory. This learning theory states that students' knowledge is built on prior knowledge (Akpan & Kennedy, 2020; Pritchard, 2017; Schunk, 2016). Based on this argument, the low learning effectiveness of the discovery learning model can be caused by low mastery of previous concepts or students who still need to be more in contact with graph representations.

The effect of discovery learning on students' graph representation ability can be further examined based on each sub-aspect of graph representation ability. Fig. 11 presents data on the percentage of correct answers for pretest and post-test questions.

Based on the graph, it can be observed that the highest percentage of correct answers is 62% on the pretest question for the subaspect of understanding the graph. This percentage of correct answers indicates that students have correct answers in the medium and low categories in each subaspect of graph representation ability. These results confirm the low graph representation ability represented in the θ score. Fig. 11 also shows an increase in the percentage of correct answers observed in 3 sub-aspects of graph representation ability. Stagnation in the percentage of correct answers was observed in the connecting and inferring sub-aspects. A decrease in correct answers was observed in understanding, interpreting, and identifying.

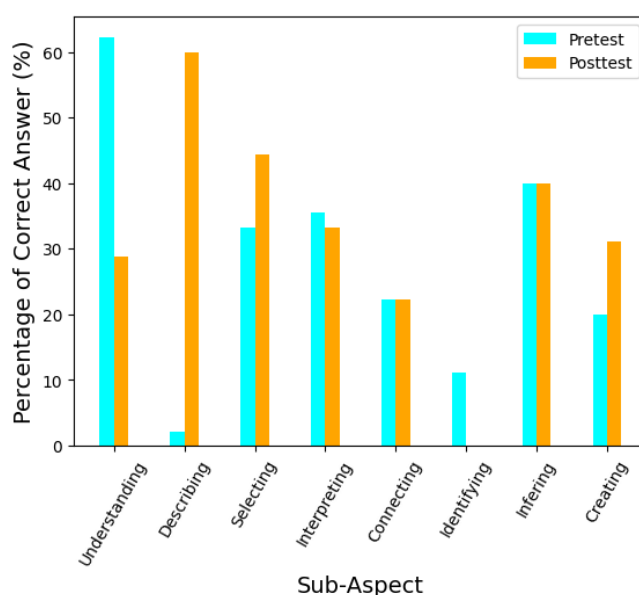


Fig. 11. Percentage of correct answers from students for each sub-aspect of graph representation ability

The increase in the percentage of correct answers for graph representation ability sub-aspect indicates an increase in representation ability in the corresponding sub-aspect. This result means learning sound waves with the discovery learning model can improve the graph representation ability. Although some sub-aspects have increased, in this study, there was a decrease in the percentage of correct answers in several sub-aspects of graph representation ability, representing a decrease in students' ability. A decrease in student ability should not naturally occur in the learning process.

Several factors can influence this decrease in the percentage of correct answers. We can see an interesting relationship when we compare Fig. 5 and Fig. 11. Many of the pre-test items in the sub-aspects that experienced a decrease in the percentage of correct answers were observed to have lower item difficulty levels than the post-test items. This result shows that item difficulty can affect the percentage of correct answers of students. In addition to item difficulty, other factors affecting the percentage of correct answers include students' guessing behavior. Furthermore, several studies have shown that media, student worksheets, and representation-based learning designs can improve students' representation skills (Nurlisna et al., 2020; Raras & Kuswanto, 2019; Siswanto et al., 2018). This result means that improving students' ability in each sub-aspect of graph

representation ability may be further encouraged by media, student worksheets, or learning designs that emphasize these sub-aspects.

4. Conclusions

Based on the description in the results and discussion section, it can be concluded that a test instrument to measure graph representation ability has been successfully developed for high school students on sound wave topics. The instrument's construction consists of 16 multiple-choice items, divided into eight items in packet A and packet B. Of the eight items for each packet, there is one anchor item. The items measure graph representation ability, which consists of 8 sub-aspects. The instrument that has been developed is feasible to use because it meets the criteria of content validity, is reliable to measure students' abilities in the range of -3.8 to 3, fits the Rasch measurement model, can provide good information on students' abilities, and most of the items have a good level of item difficulty. The measurement implementation results show that students' graph representation ability before and after learning is low. This result is confirmed by the low effect size value and the percentage of correct answers that tend to be at the medium and low levels.

The results of this study are expected to open new perspectives to improve the quality of physics learning. This research is not free from limitations. The limitation of this study is the need for researchers to find the newest and representative data to describe students' graph representation ability. This limitation makes it difficult for researchers to get respondents who can represent students with low, medium, and high graph representation abilities on the test trial. Another limitation of this study is the implementation of measurements only carried out on learning sound waves with the discovery learning model alone, without any experiments or comparisons with other models. Further research and development can be done by (1) conducting test trials on larger and more diverse respondents, (2) analyzing validity, reliability, and item analysis with different method approaches, and (3) implementing measurements for the learning process with different models and methods to find the most effective learning design in improving graph representation ability on sound waves topic.

These findings show that students' graph representation ability still needs to improve and using the discovery learning model is not so effective in boosting students' graph representation ability. The finding of low graph representation ability strengthens previous findings, which show that students' representation ability is still low in both graph representation and other forms of representation. The findings related to the effectiveness of this discovery learning model open new insights related to learning models or methods that are effective in boosting students' representation skills. However, further research needs to be done to see if other factors can affect the effectiveness of the discovery learning model.

Author Statement

The authors declare that there is no conflict of interest.

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