The use of a four-tier wave diagnostic instrument to measure the scientific literacy among students in SMA Negeri 2 Karanganyar

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Abstract. This study aims to investigate the scientific literacy among 12th grade science students in SMA Negeri 2 Karanganyar. The instrument used is a four-tier wave diagnostic instrument. This instrument was originally used to diagnose students’ conceptions about nature and propagation of waves. This study using quantitative descriptive method. The diagnostic results based on dominant students’ answers show the lack of knowledge percentage of 14.3%-77.1%, alternative conceptions percentage 0%-60%, scientific conceptions percentage 0%-65.7%. Lack of knowledge indicated when there is doubt about at least one tier of the student’s answer. The results of the research shows that the students’ dominant scientific literacy is in the nominal literacy category with the percentage of 22.9% - 91.4%, the functional literacy with the percentage 2.86% - 28.6%, and the conceptual/procedural literacy category with the percentage 0% - 65.7%. Description level of nominal literacy in context of the current study is student have alternative conceptions and lack of knowledge. Student recognize the scientific terms, but is not capable to justify this term.

1. Introduction

1.1. Identification Students' Alternative Conceptions

Students often answer questions about physics using intuition or naive ideas based on experience from the world around them. The students’ intuition or ideas are often wrong if viewed in a scientific perspective [1]. Researchers use several terms to describe students' mistakes in understanding scientific facts. Terms such as alternative conceptions, misconceptions, preconceptions, child's scientific intuitions, children's sciences, general knowledge concepts, and spontaneous knowledge are used by researchers to describe the errors of students in relating scientific facts [2]. The present study will use the term alternative conception. Alternative conceptions can be interpreted also as an initial conception that is different from scientifically accepted concepts. Investigations of students' alternative conceptions can provide information about the diversity they have in content knowledge, explanatory knowledge, and the power of understanding or incomprehension about a particular concept [3]. Investigations about understanding scientific facts should be made before starting a particular subject matter. The results of study are use to select appropriate teaching activities for students [4].
It’s important to identify students’ alternative conception correctly using a valid and reliable instrument. Diagnostic tests of alternative conceptions are assessment tools focusing on alternative conceptions that have been held or are being possessed by students and not handled resulting in learning difficulties. From the results of questionnaires given to physics teachers in SMA Negeri 2 Karanganyar obtained information that teachers consider the need to identify alternative conceptions of students. Unfortunately, teachers never give diagnostic tests to diagnose students’ alternative conceptions.

One of diagnostic tests is a four-tier wave diagnostic test to diagnose alternative conceptions on nature and propagation of waves. Each item of four tier wave diagnostic test consists answer and reason tiers with the additional tiers of confidence rating specification for selected options at the answer and reason tier separately. Including a confidence rating at answer and reason tiers separately make the determination of conception categories more precise. The use of four tier wave diagnostic test is capable of diagnosing the nature and strength of alternative conceptions with error-free and less detectable knowledge in an easier way, especially for nature and propagation of waves [5]. Five categories are based on the students' responses on each tier of four tier wave diagnostic test. The five categories consist of scientific conceptions, false positives, false negative, alternative conceptions and lack of knowledge. The division of the four tier test categorization will make the proportion of less knowledge not lessened and the proportion of alternative conceptions not exaggerated.

1.2. Identification Students’ Scientific Literacy Level

The main goals of science education curriculum are to provide an opportunity for students to be able to use scientific understanding in public debates, resulting in a balance of information and decisions about socioscientific issues that affect their lives [6]. The term used to indicate coverage and affirming the goals of science education is the scientific literacy. Paul De Hart Hurd [7] in an article entitled “Science Literacy It's Meaning for American Schools,” describes scientific literacy as an understanding of science and its application to social experience.

The achievement of scientific literacy becomes the main goal of learning. The two most comprehensive survey programs aimed at measuring science literacy are: The Program for International Student Assessment (PISA) and Trends in Mathematics and Science Studies (TIMMS). The ability of scientific literacy of Indonesian students can be seen based on the average score of PISA (Program for International Student Assessment). In the achievement, Indonesia is still at a low level with a score below the average score. In 2000, the subject of science placed Indonesia at number 38 out of 41 participating countries. In 2003, Indonesia was ranked 38 out of 40 participants. In 2006, the number of participants increased, Indonesia ranked 50th out of 57 countries, and in 2009 Indonesia ranked 60th out of 65 participating countries. In 2012 Indonesia ranked 64 out of 65 participants, and the latest in 2015 Indonesia ranked 62 out of 70 participants.

Bybee [8] suggests a comprehensive theoretical scale that is more appropriate for the measurement of scientific literacy at the 8] suggests a comprehensive theoretical scale that is more appropriate for the measurement of scientific literacy at the school level because it is easily transferred into learning objectives. The scale created suggests scientific literacy levels as a nominal, functional, conceptual or procedural, and multidimensional level of literacy. This level of scientific literacy was originally developed with reference to science programs and teaching in schools, but the level of scientific literacy can also be identified when measuring student achievement in science learning. For example, Sumarni, et al., [9] uses an evaluation instrument of achievement of generic science skills to measure students' scientific literacy in the integrated chemistry learning of ethnosciences and Ranikmae [10] found that instruments for measuring problem-solving and decision-making ability can also be used to measure the attainment of the scientific literacy aspect.

Assessment of students’ scientific literacy is not used to determine the final students’ literacy level but to know the indication of the existence of the seeds of literacy in the minds of students. Measurement of science literacy of students only aims to measure the effectiveness of science learning in providing attitudes, values, basic skills, knowledge, and understanding of science.
One of the challenges in science education is to create a link between theoretical framework and taxonomy with the practical assessment of learning [11]. The present study will use a conception diagnostic test instrument to measure students' scientific literacy levels according to Bybee's theoretical framework on nature and propagation of waves. Knowledge of the concepts and ideas of science or called content knowledge is one of the aspects of scientific knowledge. By using one instrument that is the four-tier wave diagnostic test, can be obtained the diagnosis of alternative conception and also information students’ competence of specific scientific literacy.

The objectives of this study are using four-tier wave diagnostic test instrument to identify the students’ alternative conceptions profile and scientific literacy levels on nature and propagation of waves. The results obtained can be used as an information and reference materials about of students alternative conceptions and scientific literacy levels, as a discourse to determine learning strategies that are able to remedy/reduce alternative conceptions, provide input to determine and develop conceptualized learning approach.

### Table 1. Determining Students’ Conceptions Categories.

| Tier 1  | Tier 2  | Tier 3  | Tier 4  | Categories |
|---------|---------|---------|---------|------------|
| (Answer)| (Rating)|(Rating) |         |            |
| 1a High | 1       | Higha   |         | SCc        |
| 1 High  | 1       | Lowi    |         | LKg        |
| 1 Lowg  | 1       | High    |         | LK         |
| 1 Low   | 1       | Low     |         | LK         |
| 1 High  | 0b      | High    |         | FPd rarely AC |
| 1 High  | 0       | Low     |         | LK         |
| 1 Low   | 0       | High    |         | LK         |
| 1 Low   | 0       | Low     |         | LK         |
| 0 High  | 1       | Highb   |         | FNc        |
| 0 High  | 1       | Lowi    |         | LK         |
| 0 Low   | 1       | High    |         | LK         |
| 0 Low   | 1       | Low     |         | LK         |
| 0 High  | 0       | Highb   |         | ACf rarely Mistakes |
| 0 High  | 0       | Lowi    |         | LK         |
| 0 Low   | 0       | High    |         | LK         |
| 0 Low   | 0       | Low     |         | LK         |

*aTrue response score ‘1’
*bFalse response score ‘0’
*cSC = Scientific Conceptions
*dFP = False Positive
*eFN = False Negative
*fAC = Alternative Conceptions
*gLK = Lack of Knowledge

### 2. Research Methods

The study was conducted in SMA Negeri 2 Karanganyar. This study uses a four-tier wave diagnostic test with a total of 12 items of questions. The sample of this research are 35 students of grade 12th class of science 1 in SMA Negeri 2 Karanganyar, Central Java Indonesia. Students are asked to do the test independently by ensuring that this test is only to diagnose their conception not to measure their learning achievement.
Students response by selecting A, B, C, D or E for the answer and reason tiers, and option 1, 2, 3, 4, 5 or 6 for each confidence ratings. In the four-tier wave diagnostic test, each correct response was scored '1' and the wrong response was scored '0'. The confidence rating has a range of 1 to 6. Number 1 for 'guess only', 2 for 'very unsure', 3 for 'unsure', 4 for 'confident', 5 for 'very confident ', and 6 for 'be completely sure'. The guidance of Table 1 uses to determine students' conceptions.

| Categories               | Score |
|--------------------------|-------|
| Scientific Conceptions   | 5     |
| False Positive           | 4     |
| False Negative           | 3     |
| Alternative Conceptions  | 2     |
| Lack of Knowledge        | 1     |

The diagnostic results of the students’ conceptions then inserted into the scientific literacy levels with the following comparisons.

| Conceptions Categories | Scientific Literacy Levels |
|------------------------|----------------------------|
| Lack of Knowledge      | Nominal                    |
| Alternative Conceptions|                            |
| False Negative         | Functional                 |
| False Positive         |                            |
| Scientific Conceptions | Conceptual or procedural    |

| Scientific Literacy Level Measured | Specific Competency |
|------------------------------------|---------------------|
| Nominal                            | student have alternative conceptions and lack of knowledge. Student recognizes the scientific terms but is not capable to justify this term |
| Functional                         | Students are still experiencing both false positive and negative. Students are able to use scientific vocabulary, as well as remember and write down basic information. But students are not able to determine the exact relationship of the information because of the limitations of understanding. |
| Conceptual or procedural            | Students have a scientific conception. Students understand the principles and theories in science. Students understand the relationship of concepts from various disciplines. Students learn about the process of inquiry, how to determine the choice based on the correct information from the text, graphics or tables. |
Statistical analysis using the QUEST program is performed after the student's scoring process is completed. Four-tier wave diagnostic test results were analyzed using classical test theory elements. The ‘program QUEST will be measured descriptive statistics, reliability coefficients (Cronbach α), the degree of difficulty, and discrimination.

2.1. Test Statistics
Table 5 summarizes the mean, reliability, degree of difficulty, and discrimination of four-tier wave diagnostic test results.

| N Students | N items | Mean ± St. Dev. | Reliability | Mean Degree of Difficulty | Mean Discrimination index |
|------------|---------|-----------------|-------------|--------------------------|--------------------------|
| 35         | 12      | 13.54±5.60      | 0.47        | 0.12                     | 0.17                     |

Reliability is obtained based on Internal Consistency value using Cronbach alpha (α) statistic. The α value for the four-tier wave diagnostic test is 0.47. A value below 0.7 indicates a weak correlation between items so it raises the question of whether the data is considered reliable or not. The value of α is an inappropriate indicator for conception test questions. Low α values indicate when student construct the knowledge they have gaps and errors, and negligence in learning based on the prior experience [12].

The degree of difficulty is a statement about how easy or difficult a test item is for the students concerned. Problem items with difficulty levels below 0.3 are categorized as difficult and above 0.8 are categorized as easy. The difficulty of obtaining a score of 5 (scientific conception) on a four-tier wave diagnostic test was in the range of 0-0.65 with an average of 0.12. From this data it can be seen that students found it difficult to provide response answers and reason according to the correct concepts on properties and propagation of mechanical waves.

The discrimination index (D) on the four-tier wave diagnostic test results is in the range of 0.17 to 0.45 with an average of 0.17. Based on the result, it can be concluded that the instrument is capable enough to distinguish high testee ability and low testee ability.

3. Results and Discussions
The four-tier wave diagnostic test in previous research by Caleon and Subramaniam has successfully diagnosed the nature and strength of alternative conceptions of 598 students from 9th and 10th grade in Singapore. The use of the four-tier wave diagnostic test on wave material has been able to identify 19 alternative conceptions, with 9 of which are original alternative conceptions (due to lack of understanding and false reason). The use of four-tier wave diagnostic tests can be used as the window of cognitive process information, to measure and detect variations in content knowledge, explanatory knowledge, and the power of understanding or misunderstanding certain concepts.

The same instrument, the four-tier wave diagnostic test, is used to identify the students’ conceptions in Indonesia. Problems given to students in Indonesia are rewritten using Bahasa. The students' conceptions can be studied based on the response to each item of the four-tier wave diagnostic test. The four-tier wave diagnostic test indicators are understand the general characteristics of waves and waveform representations, understand about frequency, source, and medium, and understand the velocity of waves with mediums having constant properties.

In Figure 1, we can see that the dominant response of students indicates a lack of knowledge, followed by alternative conceptions, scientific conceptions, and a small portion of both negative and positive false. The highest percentage of the less knowledge category is found in 8 problem numbers. Less knowledge category has a percentage of 14.3%-77.1%. Lack of knowledge is shown when students provided low confidence ratings (<4) for each selected response. The response that shows lack knowledge is the result of guessing because students did not have the confidence to choose the answer. The number of questions with the dominance of lack knowledge response are 2, 3, 4, 5, 6, 7, 8, and 10.
Alternative conceptions are shown when students gave a high confidence rating (> 4) but their answers are wrong. The category of alternative conception has a percentage of 0%-60%. The question numbers with the dominance of alternative conceptions are 1 and 11. The dominance of alternative conceptions is indicated when students gave respond to question number 1 about the interpretation of wave properties shown in the time-displacement graph (y-t). In accordance with the findings of Maurines [13], that students tend to ignore the labels on the axes of the graph and assume that the graph is a representation of waves traveling on the medium. The dominant response for question number 1 given by 25% of students assumes that the maximum displacement between two possible particle points in the time-displacement graph (y-t) is the wavelength. The dominance of alternative conceptions is also shown by students when responding to the question number 11. Questions number 11 contains the determination of the frequency of waves propagating at the connection of two ropes with different masses. Students were not able to understand the relationship between wave sources and frequency. The dominant responses to number 11 are given by 57% of students assuming a heavier rope provides greater resistance to vibration thereby reducing the frequency of waves propagating on the rope. Students are unable to provide the correct response that the fact is that waves travel through two different mediums so that the wavelengths remain the same as the waves are generated by one common source and the two mediums are connected. The teacher must know the alternative conceptions and difficulties that the students experience and fix them for the purpose of effective learning [14].
The highest percentage for the category of scientific conception is found in questions 9 and 12. The category of scientific conception has a percentage of 0%-65.7%. Scientific conception is shown when students are able to choose the right choice and give a high confidence rating (> 4). The dominance of scientific conception is demonstrated when students respond to the number 9 of the effect on the magnitude of the wave as the energy carried by the waves decreases. The dominance of scientific conception is also shown when students respond to the number 12 predicted changes in wave velocity as it travels from a light-medium to a heavier medium.

The diagnostic results of students' conceptions are inserted into scientific literacy levels according to the comparison in Table 3. Distribution of students’ scientific literacy levels is shown in Figure 2.

In Figure 2, can be seen the results of four-tier wave diagnostic test in students of grade XII IPA 1 in SMA Negeri 2 Karanganyar. Students' scientific literacy is dominant at the level of nominal literacy percentage 22.9% - 91.4%, functional literacy level 2.86% -28.6%, and level of conceptual or procedural literacy 0% -65.7% . These results mean student have alternative conceptions and lack of knowledge. The student recognizes the scientific terms but is not capable to justify this term. Students have the ability of science literacy on the category able to give opinions agree and disagree with an idea but unable to explain the reasons behind it [15]. The results of this study are supported by the results of some research on the identification of students' scientific literacy level in Indonesia and found that the majority of students are at the level of nominal literacy and the percentage of literacy’s achievement is below 50% [16-17].
4. Conclusion
Based on the results of the four-tier wave diagnostic test, showed that students of grade XII IPA 1 in SMAN 2 Karanganyar majority have less knowledge and level of nominal literacy on materials nature and properties of waves. The results of this study are also consistent with Caleon and Subramaniam's statements in 2010 that the use of four-tier wave diagnostic test can be used as a window of cognitive process information experienced by students, providing it can be used to measure and detect variations in content knowledge, explanatory knowledge, and the strength understanding or misunderstanding of certain concepts [3]. The category of conception of students can be associated with the level of science literacy. According to the PISA 2015 terminology, knowledge of facts, concepts, and explanatory theories become one of the knowledge that construct science literacy.

References

[1] Wood A K, Galloway R K and Hardy J 2016 Am. Phys. Soc. 12 023101(1)
[2] Ozkan G and Selcuk G S 2015 J. Baltic Sci. Educ. 14 753
[3] Caleon I S and Subramaniam R 2010 Res. Sci. Educ. 40 313
[4] Ozkan G and Selcuk G S 2015b Univers. J. Educ. Res. 3 981
[5] Gurel D K, Eryilmaz A and McDermott L C 2015 Eur. J. Math. Sci. Technol. Educ. 11 989
[6] OECD 2013 PISA 2015 Draft Science Frame Work
[7] Hurd P D 1958 Educ. Leadersh. 16 13
[8] Bybee R W 1997 Scientific Lit. Int. Symp. 37
[9] Shwartz Y, Ben-Zvi R and Hofstein A 2006 Chem. Educ. Res. Practice 7 203
[10] Sumarni W, Sudarmin, Wiyanto and Supartono 2016 Int. J. Evaluation Res. Educ. 5 221
[11] Soobard R and Rannikmäe M 2011 Sci. Educ. Int. 26 263
[12] Luxford C J and Bretz S L 2014 J. Chem. Educ. 91 312
[13] Maurines L 1992 Int. J. Sci. Educ. 14 279
[14] Maries A and Singh C 2016 Phys. Rev. ST Phys. Educ. Res. 12 010131(1)
[15] Odja A H and Payu C S 2014 Pros. Semin. Nas. Kimia Univ. Neg. Surabaya
[16] Fakhriyah F, Masfuah S, Rosya M, Rusilowati A and Rahayu E S 2017 J. Pendidik. IPA Indonesia 6 81
[17] Rusilowati A, Kurniawati L, Nugroho S E and Widyatmoko A 2016 Int. J. Environ. Sci. Educ. 11 5718