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Analysis of Eleventh-Grade Students' Scientific Literacy Skills on Wave Topics

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ABSTRACT

This study departs from a fundamental question regarding the level of scientific literacy skills of eleventh-grade students on the topic of sound waves and the factors that influence them. The researcher positions scientific literacy as an essential competency in 21st-century physics learning that not only encompasses conceptual understanding, but also the ability to think critically and apply knowledge in real-world contexts. This study employed a descriptive quantitative approach using a validated scientific literacy test instrument administered to 30 students. Data were analyzed using descriptive statistics to determine the category levels of scientific literacy. The results indicate that students' scientific literacy skills fall within the sufficiently high category, with a mean score of 67.22. Most students were able to understand basic scientific concepts; however, they were not yet able to integrate and apply these concepts optimally in complex situations. These findings suggest that students' higher-order thinking skills still need to be enhanced through more innovative and contextual learning strategies.

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INTRODUCTION

Education is fundamentally aimed at optimally developing the potential of students in terms of knowledge, skills, and attitudes. In physics learning, the ideal condition expected is that students are not only able to understand concepts theoretically, but are also able to relate these concepts to natural phenomena and apply them in everyday life. Thus, physics learning

should be able to foster scientific, critical, and evidence-based thinking as a foundation for dealing with real-world problems.

Entering the era of 21st-century education, the demands on student competencies have become increasingly complex. Students are expected to possess critical thinking, creative, communicative, and collaborative skills as part of 21st-century competencies. In this context, physics learning is no longer focused solely on memorizing concepts, but on students' ability to understand, analyze, and solve science-based problems. Therefore, a competency is needed that can integrate knowledge, skills, and scientific attitudes, namely scientific literacy.

Scientific literacy is an essential competency in physics learning that plays a role in shaping students' ability to understand scientific concepts, explain natural phenomena, and use scientific evidence in decision-making. In the context of 21st-century education, scientific literacy has become an important indicator in assessing students' readiness to face global challenges. However, various research results indicate that students' scientific literacy skills still fall within the low category, particularly in the aspects of interpreting data and relating concepts to everyday life phenomena (Mazidah & Suwarna, 2024; Adhari et al., 2025). In addition, other studies show that low scientific literacy is influenced by the lack of student engagement in learning and the minimal use of real-world contexts in the learning process (Patigu et al., 2024). Other studies also reveal that learning that is not problem-based causes students to have difficulty in applying physics concepts in everyday life (Wulandari et al., 2024). This situation indicates that physics learning has not been fully able to develop scientific literacy competencies optimally.

These problems are reinforced by the results of a preliminary study conducted at MAS Al-Mufassir among eleventh-grade students. Based on the analysis of the results of problem-based worksheets (LBM) and scientific literacy instruments, the average scientific literacy score of students was found to be 67.22, which falls within the Sufficiently High category (level 4). This indicates that most students are only able to understand basic concepts, but have not been able to relate and apply these concepts deeply in the context of real life. The scientific literacy level shows that 46.67% of students are in the Low category (level 2), 26.67% are in the Very Low category (level 1), and only 6.67% have reached the Very High category (level 6). More specifically, students experience difficulties in explaining scientific phenomena, particularly in the process of sound wave propagation, the relationship between frequency and pitch, and the application of sound concepts in everyday life. In addition, students also show limitations in interpreting data and drawing conclusions based on the scientific information provided. These findings indicate that students' scientific literacy skills on the topic of sound waves still need serious attention, especially in the aspects of critical thinking and problem-solving.

The topic of sound waves has an abstract character because it involves concepts of longitudinal waves, frequency, amplitude, and the propagation of energy through a medium. These characteristics demand good conceptual understanding and scientific representation abilities. However, in learning practice, students tend to experience difficulties in visualizing these concepts and relating them to real phenomena, which consequently impacts on the low

scientific literacy skills. This situation further clarifies the gap between the ideal demands of physics learning and the reality in the field.

Based on this review, the novelty in this study lies in the analysis of students' scientific literacy skills that is specifically focused on the topic of sound waves by utilizing empirical data from the preliminary study and referring to comprehensive scientific literacy indicators. This study does not only identify the level of students' scientific literacy skills, but also analyzes weaknesses in each scientific literacy indicator so as to provide a more in-depth picture of the student competency profile.

The research problem in this study is: how is the profile of scientific literacy skills of eleventh-grade students on the topic of sound waves? The research hypothesis is that students' scientific literacy skills are still in the low category on most scientific literacy indicators. This study aims to analyze the scientific literacy skills of eleventh-grade students on the topic of sound waves and to identify weaknesses in each scientific literacy indicator. The results of this study are expected to provide comprehensive information as a basis for designing more effective physics learning oriented toward improving scientific literacy.

The importance of scientific literacy in the current era cannot be overstated. PISA (Programme for International Student Assessment) has consistently placed scientific literacy as one of the core domains of measurement since the year 2000, emphasizing that it encompasses not just knowledge, but the capacity to engage with science-related issues in a meaningful way. Internationally, countries with high PISA scores in science show a strong correlation between effective science education practices and student outcomes. Indonesia, however, continues to face challenges in this domain, highlighting the urgency of research such as the present study.

Sound waves, as a topic in physics, provide a rich context for assessing scientific literacy because they bridge abstract physical concepts with everyday life experiences. The hum of a guitar string, the echo in a canyon, the functioning of a stethoscope — all of these are manifestations of wave physics. When students fail to connect classroom learning with such real-world applications, it signifies a gap in scientific literacy that needs to be addressed through targeted pedagogical interventions.

METHOD

This study employed a quantitative approach with a descriptive research design aimed at analyzing the scientific literacy skills of eleventh-grade students on the topic of sound waves. The descriptive quantitative approach was used to describe phenomena systematically, objectively, and based on numerical data without providing treatment to the research subjects (Creswell & Creswell, 2023). Through this approach, the researcher was able to obtain an accurate picture of the level of students' scientific literacy skills.

The research was conducted at MAS Al-Mufassir in the even semester of the 2025/2026 academic year with a research sample of 30 eleventh-grade students selected using the purposive sampling technique. This technique was used by considering the suitability of the

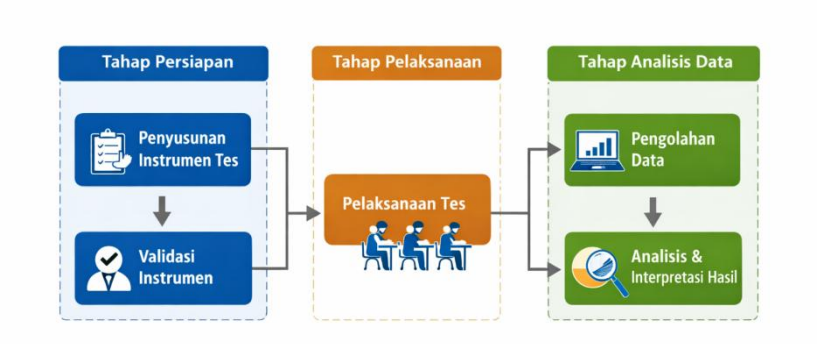
subject characteristics with the research objectives, so that the data obtained is more relevant for analysis.

The research design used was descriptive quantitative, namely to describe the level of students' scientific literacy skills based on the results of the administered test. This design allows the researcher to obtain a factual picture of the condition of students' scientific literacy on the topic of sound waves (Fraenkel et al., 2022).

The research procedures were carried out through several systematic stages, namely:

1. Preparation of scientific literacy test instruments based on scientific literacy indicators;
2. Validation of instruments by experts to ensure content validity;
3. Administration of the test to students;
4. Processing of test data results; and
5. Data analysis and interpretation.

These stages were structured systematically to ensure the quality of the data obtained so that the research results can be scientifically accounted for (Aldilla & Usmeldi, 2024). The overall research flow is presented in Figure 1.



Gambar 1. Research flow of analysis of students' scientific literacy abilities

The research instrument used was an essay test consisting of 10 items referring to scientific literacy indicators, namely: (1) explaining scientific phenomena, (2) interpreting data and scientific evidence, (3) applying science concepts in everyday life, and (4) analyzing science-based problems. The preparation of this instrument refers to the scientific literacy framework that emphasizes scientific thinking skills and problem-solving (Adhari et al., 2025; Patigu et al., 2024). The instrument used had been validated by experts to ensure content validity and conformity with the measured indicators.

Tabel 1. Likert scale questionnaire

Score Range	Category
4	Very Good
3	Good
2	Fair
1	Poor

Data collection was carried out through written tests, in which students were asked to complete essay questions within a specified time. The test method was chosen because it is effective for directly measuring students' cognitive and scientific literacy skills (Fraenkel et al., 2022). Students' answers were then assessed using a scoring rubric that had been prepared to obtain objective and measurable scores.

Data analysis was performed using descriptive statistical techniques. The scores obtained by students were calculated and converted into percentage form using the Likert scale formula:

$$\text{Score} = \frac{Obtained\ Score}{Maximum\ Score}\ x100\%$$

Furthermore, the obtained scores were categorized into scientific literacy levels, namely: ≤40 (Very Low), 41–55 (Low), 56–65 (Medium), 66–75 (Quite High), 76–85 (High), and 86–100 (Very High). This categorization aims to facilitate the interpretation of students' scientific literacy abilities.

This categorization aims to facilitate the interpretation of students' scientific literacy skill levels. In addition, the mean score was calculated to determine the overall level of scientific literacy skills. The results of data analysis were presented in the form of a frequency distribution table and then interpreted to describe the profile of students' scientific literacy skills on the topic of sound waves.

The validity of the research instrument was evaluated through expert judgment involving two physics education specialists and one science education expert. The Content Validity Ratio (CVR) was calculated for each item, and only items achieving a CVR above the threshold for 30 students were retained. Reliability was assessed using the Cronbach's Alpha coefficient, with a value above 0.70 considered acceptable for the purposes of this study.

To ensure the quality of the scoring process, inter-rater reliability was established by having two independent raters score a 20% subsample of the student responses. Cohen's Kappa was computed to assess the degree of agreement between the two raters. The resulting value indicated substantial agreement, confirming that the scoring rubric was sufficiently clear and consistently applicable.

RESULTS AND DISCUSSION

Results

Based on the results of scientific literacy tests administered to 30 eleventh-grade students, a mean score of 67.22 was obtained, which falls within the Sufficiently High category. This result indicates that students have been able to understand basic scientific concepts, but have not been able to integrate, analyze, and apply these concepts in more complex contexts. The distribution of students' scientific literacy levels is presented in Table 2.

The data shows that the majority of students are at the functional level, while the multidimensional category remains very low. This indicates that higher-order scientific literacy skills have not yet developed optimally.

Tabel 2. Distribution of students' scientific literacy levels

Category	Score Range	Number of Students	Percentage (%)
Very Low	≤ 40	8	26.67
Low	41 – 55	14	46.67
Moderate	56 – 65	0	0.00
Sufficiently High	66 – 75	6	20.00
High	76 – 85	0	0.00
Very High	86 – 100	2	6.67

A per-indicator analysis reveals that students performed best on the indicator of explaining scientific phenomena (mean = 72.3), followed by applying science concepts in everyday life (mean = 68.1), interpreting data and scientific evidence (mean = 65.4), and analyzing science-based problems (mean = 62.8). This distribution suggests that students are more comfortable with tasks requiring recall and basic application, while analytical and integrative tasks remain challenging.

Discussion

Finding 1: Dominance of Scientific Literacy at the Functional Level

The main finding of this study shows that students' scientific literacy skills are predominantly in the Sufficiently High category (46.67%). More deeply, this condition indicates that most students are already at the functional level of scientific literacy, meaning they are able to understand basic concepts, recall scientific information, and solve simple routine problems. However, this ability has not yet developed to a higher stage, such as the ability for critical analysis, evaluation of scientific evidence, and data-based decision-making.

At this functional level, students tend to be able to work on direct questions, but experience difficulties when faced with contextual questions that demand more complex reasoning. This shows that the thinking processes that have developed are still at the lower-order thinking skills (LOTS) level, especially in the aspects of understanding and applying, and have not yet reached the analyzing and evaluating stages in the cognitive taxonomy.

Pedagogically, the dominance in this category indicates that the physics learning that takes place still tends to be oriented toward one-way knowledge transfer and procedural problem practice. As a result, students are not accustomed to exploring concepts in depth or connecting concepts with real phenomena. This is consistent with the findings of Suryani et al. (2023) which state that the dominance of scientific literacy at the intermediate level is caused by the lack of learning activities based on analysis and complex problem-solving.

Furthermore, at the sufficiently high level, students are only able to identify explicit information in texts or questions, but have not been able to interpret implicit meanings or integrate several concepts simultaneously. This condition shows that the knowledge structure they possess is still partial and not yet systematically organized, which impacts on the low ability to transfer concepts into the context of everyday life.

These findings are consistent with those reported in the international literature. Research by Bybee (2021) identifies a similar pattern across diverse educational contexts, where students often plateau at the functional level of scientific literacy due to curriculum designs that prioritize content coverage over deep inquiry. The pedagogical challenge, therefore, lies not in whether students can recall information, but in whether they can mobilize that information to reason about novel situations.

The relationship between teaching methodology and scientific literacy outcomes has been well-documented. Studies employing inquiry-based instruction (Simanjuntak et al., 2023) and problem-based learning (Rahman et al., 2025; Wulandari et al., 2024) consistently demonstrate improved performance on scientific literacy assessments, particularly in the higher cognitive domains. The implication for practice is clear: instructional design must intentionally create opportunities for students to engage with ambiguous, open-ended, and real-world problems.

Finding 2: Low Higher-Order Scientific Literacy (Multidimensional)

The research results show that only 6.67% of students achieve the Very High category. This finding indicates that scientific literacy skills at the multidimensional level are still very limited. More specifically, this level reflects students' ability to integrate scientific concepts, critically analyze data, evaluate evidence, and provide solutions to science-based problems in a logical and systematic manner.

The low achievement at this level shows that students' higher-order thinking skills (HOTS) have not developed optimally. This is caused by the lack of exposure to learning activities that demand complex thinking processes. In everyday learning, students are more often faced with algorithmic questions compared to phenomenon-based or scientific investigation questions.

Furthermore, the development of HOTS requires familiarization with scientific activities such as graph interpretation, analysis of experimental data, hypothesis testing, and drawing evidence-based conclusions. The absence of these activities in learning means that students do not have sufficient cognitive experience to develop higher-order scientific literacy skills.

Another factor that contributes is the abstract nature of sound wave material. Concepts such as longitudinal waves, energy propagation, frequency, and resonance cannot be directly observed, thus requiring visual representation or simulation to facilitate understanding. When such representations are not optimal, students experience difficulty in building correct mental models, which in turn impacts on weak analytical and interpretive abilities.

Thus, it can be concluded that the low level of higher-order scientific literacy is not only caused by students' cognitive abilities, but also by the limitations of learning experiences that support the systematic development of HOTS.

Research on conceptual change theory suggests that misconceptions about wave propagation are prevalent among secondary school students globally. In the Indonesian context, these misconceptions are compounded by limited access to laboratory equipment and digital simulation tools, which restricts students' opportunities to engage with the material at a

phenomenological level. The use of technology-enhanced learning environments, including physics simulation software, could serve as a bridge between abstract theory and observable phenomena, potentially improving multidimensional scientific literacy outcomes (Sinaga et al., 2025; Rahman et al., 2025).

The development of HOTS is further complicated by assessment practices. When classroom assessments predominantly measure recall and procedural knowledge, students are not incentivized to engage in deeper cognitive processing. Aligning assessment with higher cognitive levels, as recommended by Bloom's Revised Taxonomy, is a necessary condition for fostering the kind of thinking that underpins multidimensional scientific literacy.

Finding 3: Variation in Students' Scientific Literacy Skills

The research results indicate that there is a fairly significant variation in scientific literacy skills among students, ranging from the very low to the very high category. This variation reflects the heterogeneity in cognitive abilities, prior knowledge backgrounds, and students' learning experiences.

Theoretically, this condition can be explained through the concept of prior knowledge, namely that prior knowledge greatly influences students' ability to understand new concepts. Students who have a strong initial understanding tend to be quicker in relating new concepts to the cognitive structures they already possess, thus being able to achieve higher levels of scientific literacy. Conversely, students with low prior knowledge experience difficulties in the process of assimilation and accommodation of concepts.

In addition, differences in learning motivation also become an important factor in explaining this variation. Students who have high motivation tend to be more active in the learning process, more frequently ask questions, and are more capable of exploring concepts independently. This directly impacts on the improvement of scientific literacy skills.

This study also shows that scientific literacy is closely related to problem-solving skills. Students who have good problem-solving skills tend to be able to understand context-based questions, identify important information, and develop systematic solution strategies. In addition, scientific literacy also has a strong relationship with critical thinking skills, so that variations in critical thinking skills also influence the distribution of students' scientific literacy results.

The variability observed is not unique to this study's context. A systematic review by Holbrook and Rannikmäe (2009) found substantial within-class variation in scientific literacy across multiple countries, attributing this primarily to differences in motivational orientation, self-efficacy beliefs, and metacognitive awareness. These findings suggest that interventions aimed at improving scientific literacy should not adopt a one-size-fits-all approach, but should instead be differentiated to address the diverse needs within any given classroom.

Socioeconomic factors also play a role. Research consistently shows that students from lower socioeconomic backgrounds tend to score lower on measures of scientific literacy, partly due to reduced access to enriching out-of-school experiences (such as visits to science museums, nature, or technology environments) and partly due to lower levels of parental academic engagement. While the present study did not directly measure socioeconomic

variables, future research in similar contexts would benefit from incorporating such variables to provide a more complete explanatory model.

Relationship with the Research Hypothesis

The research hypothesis stated that students' scientific literacy skills are still in the low category on most scientific literacy indicators. The findings partially support this hypothesis. While the overall mean score of 67.22 places students in the Sufficiently High category, disaggregated data reveal that the majority of individual students (73.34%) scored in the Low or Very Low categories. This discrepancy highlights the importance of examining distributional data rather than relying solely on mean scores, which can mask significant heterogeneity within the sample.

The hypothesis was therefore confirmed in the sense that a majority of students have not achieved the level of scientific literacy expected for 21st-century learners, even if the aggregate mean suggests otherwise. This nuanced interpretation underscores the need for targeted interventions that address the specific indicators where weaknesses are most pronounced.

Implications of Research Findings

The results of this study have important implications for physics learning, particularly in the development of scientific literacy. The low level of scientific literacy shows that learning not only needs to emphasize mastery of concepts, but must also develop higher-order thinking skills in a systematic manner.

Therefore, innovations in learning are needed that can encourage students' active involvement in scientific processes, such as problem-based learning, scientific inquiry, and contextual approaches. These learning models allow students to experience the scientific process firsthand, from observing, formulating problems, collecting data, to drawing conclusions.

In addition, the use of interactive learning media that can visualize abstract concepts such as sound waves is very important. Media such as digital simulations, wave animations, and simple experiments can help students build stronger conceptual understanding.

Thus, improving scientific literacy needs to be carried out continuously through a combination of improvements in learning strategies, improvement in the quality of cognitive activities, and the use of learning media appropriate to the characteristics of physics material.

From a policy perspective, the findings of this study suggest that pre-service and in-service teacher training programs should place greater emphasis on equipping physics teachers with the pedagogical content knowledge necessary to teach for scientific literacy, not merely for content coverage. Teachers need to be proficient in designing open-ended investigations, facilitating evidence-based discussions, and using formative assessment data to differentiate instruction. Professional development initiatives aligned with these goals could significantly improve the quality of physics education and, by extension, scientific literacy outcomes in Indonesian schools.

The role of school leadership and institutional culture should also not be overlooked. Schools that foster a culture of inquiry, where questioning is valued and curiosity is rewarded, tend to produce students who are more scientifically literate. Creating such a culture requires deliberate effort at the institutional level, including the provision of time, resources, and professional development opportunities for science teachers.

CONCLUSION

Based on the results of the research and discussion, it can be concluded that the scientific literacy skills of eleventh-grade students on the topic of sound waves fall within the sufficiently high category, with a mean score of 67.22. This finding indicates that students are generally able to understand basic scientific concepts, but are not yet able to optimally integrate, analyze, and apply these concepts in more complex contexts. Scientifically, this finding indicates that the learning process that takes place has not fully supported the development of higher-order thinking skills, so that students' scientific literacy skills are still limited to the stage of understanding and simple application. The low proportion of students who reach the multidimensional category shows that the abilities of evaluation, synthesis, and evidence-based decision-making still need to be improved.

The indicator-level analysis reveals that students perform relatively better on tasks requiring the explanation of scientific phenomena and basic concept application, while analytical and interpretive tasks — particularly those involving data evaluation and cross-contextual synthesis — remain the areas of greatest weakness. These patterns are consistent with broader findings in the literature regarding the challenges of developing higher-order scientific literacy in secondary school physics.

This study contributes to the growing body of knowledge on scientific literacy in the Indonesian educational context, specifically by providing an empirically grounded profile of eleventh-grade students' competencies on the topic of sound waves. The findings provide actionable insights for teachers, curriculum developers, and policymakers seeking to enhance the quality of physics education and promote the development of scientifically literate citizens.

Future research should consider longitudinal designs to track how scientific literacy develops over time, as well as experimental designs to evaluate the effectiveness of specific interventions such as problem-based learning, digital simulation tools, and inquiry-based instruction on scientific literacy outcomes in the context of sound waves and beyond.

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