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Scientific Literacy as a Differentiated Learning Strategy to Improve Students' Science Literacy Competence

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ABSTRACT
This study aimed to: (1) assess the level of students' science literacy competence on the topic of the human movement system; (2) investigate the effect of science literacy strategies on students' science literacy competence in the same topic; and (3) evaluate the effectiveness of science literacy as a differentiated learning strategy to enhance students' literacy competence. A pre-experimental design with a control group pretest-posttest was employed, involving two 11th-grade science classes at MAN 1 South Konawe as the experimental and control groups. Research instruments included a science literacy-based written test on the human movement system and an observation sheet to monitor instructional implementation. Data were analyzed using descriptive and inferential statistics, including normality and homogeneity tests, independent t-tests, and N-Gain analysis to evaluate the effectiveness of the literacy-based strategy. Results indicated that students' average pretest scores were categorized as basic prior to the intervention. Following the implementation of the science literacy strategy, the experimental class demonstrated significant improvement, reaching a competent category, with posttest scores exceeding those of the control group. N-Gain analysis confirmed that the science literacy strategy was more effective in enhancing students' science literacy competence compared to conventional strategies. These findings suggest that the science literacy approach is a viable alternative for promoting conceptual understanding and critical thinking skills, particularly in biology education focused on the human movement system. Therefore, its implementation in madrasa biology learning is recommended to improve the quality of science literacy-based education.

Keywords: *science literacy, student competence, human movement system, learning effectiveness*

INTRODUCTION

Science literacy was first introduced by Paul DeHart Hurd in 1958 in his article entitled "Science Literacy: Its Meaning for American Schools", and the term has since been used to describe the understanding of science and its applications in society. Science literacy is defined as an individual's ability to understand, evaluate, and use scientific information across a variety of contexts (Hurd, 1958). In addition, science literacy encompasses an understanding of scientific concepts, analytical skills, the ability to make decisions based on scientific knowledge, the capacity to relate scientific concepts to real-world situations, and the ability to communicate findings effectively to the public (Yuyu, 2017).

In today's society, which is increasingly driven by science and technology, science literacy has become essential. International assessments such as the Programme for International Student Assessment (PISA) measure 15-year-old students' scientific literacy skills. In 2022, PISA results indicated an improvement in Indonesian students' scientific literacy, with the country rising six positions compared to 2018. However, the cumulative scores showed a slight decrease from the previous year (Anonim, 2023). This highlights ongoing challenges, such as the quality of educators, the tendency to conduct monotonous learning, and the limited implementation of science literacy concepts across schools, particularly in madrasahs—educational institutions under the Ministry of Religious Affairs. Teachers, as frontline facilitators of learning, require adequate understanding of science literacy to enhance their pedagogical competence and foster students' scientific literacy. These challenges underscore the need for continuous efforts to improve education quality in Indonesia.

Science literacy is particularly relevant in subjects related to natural phenomena and scientific approaches, such as biology. In biology, scientific literacy plays a central role in shaping students' understanding of concepts and their practical applications in daily life. Despite its importance, many students in Indonesia still face difficulties in understanding and applying scientific information. Often, schools cite limited learning facilities as a reason for declining educational quality. In reality, the surrounding environment can serve as an effective natural laboratory for teaching biological concepts, allowing teachers to utilize available resources to enhance scientific literacy.

In biology, science literacy is classified into five proficiency levels: Requiring Assistance, Basic, Proficient, Skilled, and Requiring Space for Creation. These levels are determined by students' abilities to analyze and solve problems related to natural phenomena, which are part of high-order thinking skills (Kemenag, 2022). Learning activities based on science literacy involve analyzing students' needs according to their proficiency levels, aligning with the principles of differentiated learning. Differentiated learning aims to provide students with tailored learning opportunities based on their abilities and learning styles, promoting meaningful and effective learning (Pitaloka & Arsanti, 2022; Marlina, 2019). This approach begins with diagnostic assessments to map students' learning needs, followed by targeted interventions that match students' proficiency levels, enabling independent learning and maximization of their potential.

The Ministry of Religious Affairs has conducted assessments of madrasah students' science literacy competencies through the AKSI (Asesmen Kompetensi Siswa Indonesia) program to improve education quality. Selected madrasahs, such as MAN 1 South Konawe in Southeast Sulawesi, serve as model schools for these assessments. The results provide comprehensive data to guide education policy and identify students' learning needs, supporting the design of targeted learning strategies. Previous research at MAN 1 South Konawe indicated that the 11th-grade students' science literacy competencies in 2023 were at the Basic level, meaning students could explain the application of scientific knowledge but were not yet proficient in analyzing, interpreting, and communicating data. Consequently, the government recommended that madrasahs improve learning processes oriented toward enhancing scientific literacy as part of differentiated learning (AKMI Kemenag Report, 2023).

The human movement system was chosen as the focus for this study due to its relevance to daily life and its capacity to engage students in complex biological concepts, such as bone structure and function, joint relationships, and skeletal health. This topic allows students to participate in contextual and phenomenon-based learning activities, such as analyzing body posture, evaluating habits affecting bone health, and interpreting data on bone disorders. Implementing a science literacy strategy in this topic can develop high-order thinking skills, including analysis, interpretation, and scientific communication. Furthermore, the variation in students' understanding of the topic allows the application of differentiated learning based on diagnostic, formative, and summative assessments, providing an effective model to enhance science literacy competencies.

Previous studies have highlighted the positive correlation between differentiated learning and science literacy. Fauzia & Ramadan (2023) emphasized that differentiated learning tailored to students' characteristics aligns with the latest curriculum and enhances literacy. Similarly, Tilamsari et al. (2023) demonstrated that process differentiation based on diagnostic assessments improved students' learning outcomes. However, these studies did not fully examine the effectiveness of biological science literacy across all types of assessments (diagnostic, formative, and summative). Therefore, this study aims to investigate the effectiveness of science literacy as a differentiated learning strategy to improve students' scientific literacy competencies, particularly in the context of the human movement system.

METHODOLOGY

This study employed a quantitative approach with a pre-experimental design, aiming to examine the effectiveness of science literacy strategies on students' science literacy competence in the human movement system topic. The research was conducted at MAN 1 South Konawe, Southeast Sulawesi Province, from May to July 2024. The population consisted of all 11th-grade science students, totaling 40 individuals across two classes: XIF1 (10 male and 10 female students) and XIF2 (6 male and 14 female students). Total sampling was applied, considering that all students exhibited diverse abilities suitable for differentiated instruction. Random assignment was then used to determine the experimental and control groups, with XIF1 designated as the control class and XIF2 as the experimental class.

The independent variable in this study was the science literacy strategy, which incorporated five proficiency levels: Need Support, Basic, Competent, Proficient, and Creative Space. The dependent variable was students' science literacy competence in the human movement system topic. A control group pretest-posttest design was employed to compare outcomes before and after the intervention in both the experimental and control groups. The study design is illustrated as follows:

$O_1 \longrightarrow X_A \longrightarrow O_3$
$O_2 \longrightarrow X_B \longrightarrow O_4$

Description:
O_1 : Results of pretest/diagnostic test of control class students (XIF_1)
O_2 : Results of the pretest/diagnostic test of experimental class students (XIF_2)
O_3 : Posttest results of control class students (XIF_1)
O_4 : Posttest results of experimental class students (XIF_2)
X_A : Control treatment (conventional strategy)
X_B : Experimental treatment (scientific literacy strategy)

(Priadana & Sunarsi, 2021).

Data were collected using two main instruments: tests and observation sheets. The test was the primary source of data to assess students' science literacy competence before and after the intervention. It consisted of a written test based on science literacy indicators covering five subtopics of the human movement system, as presented in Table 1.

Table 1. Indicators of Science Literacy Test on the Human Movement System Topic

No	Subject	Question Indicator
1	Axial Frame	Students can identify parts of the axial skeleton and their functions in the human body.

No	Subject	Question Indicator
2	Appendicular Skeleton	Students can differentiate between the axial and appendicular skeletons based on their structure and function.
3	Joints	Students can classify the types of joints based on their shape and movement.
4	Muscle	Students can explain the working mechanism of muscles in human body movement.
5	Disorders/Abnormalities/Diseases of the Human Movement System	Students can analyze the causes, symptoms, and ways to prevent disorders or diseases of the human musculoskeletal system.

In addition to the test, classroom observations were conducted to support data on the implementation of the science literacy strategy, both by teachers and students. The biology teacher at MAN 1 South Konawe conducted the teacher observations, while student observations were carried out by research team members. The observation instrument referred to science literacy competence indicators and student proficiency levels, as outlined in Table 2.

Table 2. Observation Indicators for Science Literacy-Based Learning Strategies by Proficiency Level

Competency Achievement (CK – *Capaian Kompetensi*)	Proficiency Level	Competence		
		Explaining Phenomena Scientifically	Developing and Evaluating Designs for Scientific Inquiry and Interpreting Data	Researching, Evaluating, and Using Scientific Information for Decision Making
CK 5	Requiring Assistance	Making and proving accurate scientific predictions and solutions	Evaluating an appropriate experimental design to answer a research question	Constructing arguments to support scientific conclusions from a set of data
CK 6	Basic	Identifying and building models	Analyzing data based on data representation	Criticizing standard weaknesses in science-related arguments
CK 7	Proficient	Evaluating models	Interpreting data presented in various representations	Finding the strength of an argument related to science
CK 8	Skilled	Recognizing and developing clear hypotheses about phenomena in the world	Drawing appropriate conclusions based on data representation	Making decisions using scientific arguments related to solving contemporary issues
CK 9	Requiring Space for Creation	Explaining the potential implications of scientific knowledge for society	Evaluating the relative merits of data	Justify decisions with scientific arguments that contribute to solving contemporary issues or sustainable development.

(Kemenag, 2022).

Data were analyzed using both descriptive and inferential statistical methods. Descriptive statistics were employed to calculate the mean pretest and posttest scores, providing an overview of students' initial and final competencies. Inferential statistics were applied to evaluate the influence and effectiveness of the science literacy strategy. This included normality tests and homogeneity tests to verify data assumptions, independent t-tests to compare the means between groups, and N-Gain analysis to assess the magnitude of improvement in students' science literacy competence.

RESULT AND DISCUSSION

Interpretation of Students' Scientific Literacy Competency Levels on the Topic of Human Movement System

This study describes students' science literacy competency in the topic of the human movement system by referring to the aspects of scientific literacy adapted from the Indonesian Madrasah Competency Assessment (AKMI – Asesmen Kompetensi Madrasah Indonesia) conducted by the Indonesian Ministry of Religious Affairs. The analysis focused on categorizing and evaluating students' science literacy competency, as well as identifying differences in competency levels between the experimental and control classes. The pretest scores for the experimental class are presented in Table 3, which illustrate the initial competency levels of students prior to the implementation of the science literacy strategy. These scores serve as a baseline for assessing the effectiveness of the intervention in improving students' science literacy competencies.

Table 3. Pretest Scores of Students' Science Literacy Competence

Class	Number of Students	Average Score	Category
Experimental	6	13.33	Need Support
	13	33.85	Basic
	1	50	Competent
Average		28.50	Basic
Control	10	17	Need Support
	7	35.71	Basic
	3	50	Competent
Average		28.50	Basic

Based on the pretest results, the majority of students in the experimental class exhibited low levels of science literacy, with most falling into the Basic category. In contrast, a larger proportion of students in the control class were categorized as Need Support, indicating very limited understanding of scientific literacy concepts related to the human movement system and requiring targeted instructional support. These findings are consistent with previous research. Santos et al. (2023) reported that secondary-level students' scientific literacy skills remain relatively low, particularly for concepts requiring in-depth understanding and critical thinking. Similarly, the Programme for International Student Assessment (PISA) shows that Indonesian students' scientific literacy is below the international average, highlighting the need for more effective learning strategies (OECD, 2023).

One factor contributing to the low pretest scores is the limited use of student-centered learning models that promote exploration and active participation. Constructivist theory posits that learning is more effective when students are encouraged to construct their own understanding through social interactions and guidance from teachers or peers (Vygotsky, 1978). In this context, inquiry-based learning or problem-based learning (PBL) models can serve as effective strategies to enhance students' comprehension of the human movement system.

Given the low pretest results, the implementation of more innovative learning strategies was necessary. Differentiated instruction was particularly important for students in the Need Support and Basic categories, as they required tailored guidance and support. Following the pretest (diagnostic test) and the identification of students' scientific literacy competencies, a science literacy-based learning strategy was applied in the experimental class. This strategy addressed three proficiency levels: Requiring Assistance, Basic, and Proficient. Learning activities were conducted in a differentiated manner, with the teacher dividing students into three groups according to their respective proficiency levels. The human movement system material was delivered across five meetings, covering the following sub-topics: the axial skeleton, the appendicular skeleton, the joints, muscles, and disorders/abnormalities/diseases related to the human movement system. In each meeting, the teacher implemented three differentiated approaches based on students' scientific literacy levels, ensuring that the learning process was tailored to the needs and conditions of each group. The implementation of the science literacy-based strategy for students at the Requiring Assistance level during the five meetings is summarized in Table 4.

Table 4. Observation Sheet for the Implementation of Science Literacy-Based Learning Strategies at the Proficiency Level of Requiring Assistance on the Human Movement System Material

No.	Observation Indicators	Meeting					Score	%
		1	2	3	4	5		
Competency 1: Explaining Phenomena Scientifically								
1	Students are able to make scientific predictions about the working mechanisms of the human movement system.	2	2	2	3	3	12	80.00
2	Students are able to prove scientific predictions through simple experiments.	2	2	2	2	3	11	73.33
3	Students can connect the results of experiments to the concept of the human movement system.	1	2	2	2	3	10	66.67
Amount		5	6	6	7	9	33	
%		55.56	66.67	66.67	77.78	100		73.33
Competency 2: Developing and Evaluating Scientific Investigation Designs								
4	Students are able to formulate research questions related to the human movement system.	2	2	2	3	3	12	80.00
5	Students are able to design simple experiments to answer research questions.	1	2	2	2	3	10	66.67
6	Students can evaluate the accuracy and relevance of the experimental design they conducted.	1	2	2	2	3	10	66.67
Amount		4	6	6	7	9	32	
%		44.44	66.67	66.67	77.78	100		71.11
Competency 3: Building Scientific Arguments Based on Data								
7	Students are able to interpret experimental data correctly.	2	2	2	3	3	12	80.00
8	Students can relate experimental results to relevant theories.	1	1	2	2	3	9	60.00
9	Students are able to construct scientific arguments that support conclusions from experimental results.	1	1	2	2	3	9	60.00
Amount		4	4	6	7	9	30	
%		44.44	44.44	66.67	77.78	100		66.67

Observations of the implementation of the science literacy-based learning strategy at the Requiring Assistance proficiency level revealed variations in student achievement across three main competencies: (1) explaining phenomena scientifically, (2) compiling and evaluating scientific investigation designs, and (3) constructing scientific arguments based on data. The following section presents the analysis of students' progress across the five meetings and the strategies employed by the teacher to optimize learning.

In the first meeting, which focused on the axial skeleton, students scored 55.56% in explaining phenomena scientifically, 44.44% in designing scientific investigations, and 44.44% in building scientific arguments. These low scores indicated difficulty in understanding the role of the axial skeleton in supporting the body, formulating research questions, designing experiments, and linking observations to theory. To address these challenges, the teacher applied exploratory demonstrations and discussion-based approaches, including digital simulations and simple experiments analyzing posture and load distribution. During the second meeting on the appendicular skeleton, students' scores improved to 66.67% in explaining phenomena and designing investigations, while argumentation remained at 44.44%. Guidance included simple joint movement experiments, lever principle analysis, and formulating focused research questions.

In the third meeting, covering joint types and functions, students' scores for explaining phenomena and designing investigations remained at 66.67%, while argumentation improved to 66.67%. Demonstrations of joint models, measurement of joint movement angles, and comparative group discussions facilitated understanding of joint mechanisms. The fourth meeting addressed muscles and contraction mechanisms. Scores increased to 77.78% across all three competencies. Learning activities included handgrip experiments, monitoring muscle activity during physical tasks, and discussions on exercise and nutrition to strengthen conceptual understanding. In the fifth meeting, focusing on disorders and diseases affecting the human movement system, students achieved 100% across all competencies. Case study-based learning analyzed real teacher data on motor system disorders, fostering understanding of theoretical concepts and practical applications.

Overall, the first competency, explaining phenomena scientifically, showed a steady increase from 55.56% to 100% across five meetings. The second competency, designing and evaluating scientific investigations, similarly improved from 44.44% to 100%. The third competency, constructing scientific arguments, progressed more gradually, reaching 100% at the final meeting. These results indicate that repeated practice, guided demonstrations, experiments, reflective discussions, and case studies effectively enhanced students' science literacy skills.

The implementation of science literacy-based learning for students at the Basic proficiency level across five meetings is presented in Table 5.

Table 5. Observation Sheet for the Implementation of Science Literacy-Based Learning Strategies at Basic Proficiency Level on the Human Movement System Material

No.	Observation Indicators	Meeting					Score	%
		1	2	3	4	5		
Competency 1: Explaining Phenomena Scientifically								
1	Students are able to identify the structure and function of the human motor system.	2	2	2	3	3	12	80.00
2	Students are able to build simple models of the human movement system.	2	2	2	2	3	11	73.33
3	Students can explain the relationship between the structure and function of the motor system based on a model.	2	2	2	3	3	12	80.00
Amount		6	6	6	8	9	35	
%		66.67	66.67	66.67	88.89	100		77.78
Competency 2: Developing and Evaluating Scientific Investigation Designs								
4	Students are able to collect and represent data about the human movement system.	2	2	2	3	3	12	80.00
5	Students are able to analyze data that has been collected in the form of tables, graphs, or diagrams.	2	2	2	2	3	11	73.33
6	Students can draw conclusions based on the data analysis carried out.	2	2	2	2	3	11	73.33
Amount		6	6	6	7	9	34	
%		66.67	66.67	66.67	77.78	100		75.56

No.	Observation Indicators	Meeting					Score	%
		1	2	3	4	5		
Competency 3: Building Scientific Arguments Based on Data								
7	Students are able to criticize weak assumptions in arguments related to the motion system.	2	2	3	3	3	13	86.67
8	Students can distinguish between cause and correlation in the data they studied.	2	2	2	3	3	12	80.00
9	Students are able to evaluate whether conclusions drawn are too generalized from limited data.	2	2	2	2	3	9	60.00
Amount		6	6	7	8	9	34	
%		66.67	66.67	77.78	88.89	100		75.56

The interpretation of the data is presented based on each meeting to compare students' achievements at the Basic proficiency level (Table 6) with those at the Requiring Assistance level (Table 5). Furthermore, the variations in teacher support strategies across these two proficiency levels are also discussed. During the first meeting, the learning topic focused on the structure and function of the axial skeleton, which includes the skull, vertebral column, and ribs. Students at the Basic proficiency level demonstrated a relatively good understanding of this concept, achieving 66.67% in explaining scientific phenomena. They were able to identify the structure and function of the human movement system and explain the relationship between both aspects using models (80.00%). However, they still encountered challenges in constructing simple movement system models (73.33%). In the competency domain of designing and evaluating scientific investigations, these students were fairly capable of collecting and representing data (80.00%), although difficulties were observed in data analysis and drawing conclusions from the collected evidence (73.33%). Regarding the competency of constructing scientific arguments based on data, students exhibited a strong ability to identify weak assumptions in arguments (86.67%), but continued to face challenges in distinguishing between causation and correlation within the investigated data (80.00%).

In contrast, students categorized under the Requiring Assistance proficiency level showed greater difficulties in several competencies. Their achievement in explaining scientific phenomena was lower (55.56%), as was their performance in designing and evaluating scientific investigations (44.44%). This indicates a limited understanding of the relationship between the structure and function of the axial skeleton. Furthermore, in the aspect of constructing scientific arguments, students at this level demonstrated weaker performance (60.00%) compared to those at the Basic level (86.67%) in identifying weak assumptions in argumentation. Overall, these findings suggest that students at the Basic proficiency level possess a more coherent conceptual understanding and reasoning ability in connecting structure-function relationships and in evaluating evidence-based arguments. Meanwhile, students at the Requiring Assistance level still rely heavily on teacher guidance to develop analytical and reasoning skills, particularly in interpreting data and constructing valid scientific explanations.

Teacher mentoring at the Basic proficiency level continued to be implemented with the same goal—enhancing students' scientific literacy competencies. However, the intensity of teacher guidance at this level was lower compared to that provided to students in the Requiring Assistance category. At the Basic level, teachers employed reflective and inquiry-based questioning strategies, such as "How does the shape of the spine affect posture?", to encourage deeper conceptual understanding. Students were also engaged in data analysis activities, for example, by examining human posture data and presenting their findings in the form of graphs or tables.

During the second meeting, the learning focus shifted to the function of the appendicular skeleton in supporting body movement, particularly the bones of the upper and lower limbs.

Students at the Basic proficiency level demonstrated adequate analytical skills in examining the structure of the appendicular skeleton and were able to construct simple models of the human movement system (73.33%). They showed competence in data collection and representation related to human motion (80.00%) and in analyzing the data they gathered (73.33%). In the aspect of developing scientific arguments, students were able to differentiate between cause-and-effect relationships and correlations in the context of movement system data (80.00%), although they continued to face challenges in evaluating generalized conclusions from limited data (60.00%).

In contrast, students at the Requiring Assistance proficiency level continued to display lower performance across all assessed competencies. Their achievement in explaining scientific phenomena and in designing and evaluating scientific investigations both reached only 66.67%. Their greatest difficulty was observed in designing simple experimental procedures to explore the mechanisms of the appendicular skeleton, indicating the need for more structured guidance. To support learning at the Basic proficiency level, teachers provided data analysis and comparative assignments, such as examining the relationship between bone length and movement strength across different individuals. Additionally, case-based learning was applied by comparing the skeletal structures of humans and various animals to help students understand the adaptation and functional diversity of the appendicular skeleton. This approach not only strengthened students' understanding of biological structures and functions but also fostered their ability to integrate scientific reasoning with real-world contexts.

During the third meeting, the learning material focused on the types of joints and their functions in enabling body movement. Students at the Basic proficiency level demonstrated improved understanding in constructing simple models of the human movement system (73.33%) and in analyzing the relationship between joint structure and function (66.67%). In the competency of designing and evaluating scientific investigations, students were able to analyze collected data presented in tables and graphs (73.33%), although they still encountered challenges in drawing accurate scientific conclusions. In building scientific arguments, students were relatively proficient in distinguishing between cause-and-effect and correlational relationships in the data (80.00%), yet they continued to struggle with evaluating overgeneralized conclusions based on limited data (60.00%).

When compared to the Requiring Assistance level, the students in this group achieved lower results in both explaining scientific phenomena (66.67%) and designing and evaluating scientific investigations (66.67%). This indicates that their understanding of the relationship between joint structures and movement remained limited. Teacher guidance for Basic-level students at this stage focused on analytical and comparative tasks, such as examining differences in range of motion among individuals of varying ages and physical conditions. Additionally, students were guided to analyze joint injury patterns in athletes and relate them to biomechanical principles, fostering deeper conceptual understanding through real-world connections.

In the fourth meeting, learning centered on the types of muscles, the mechanism of muscle contraction, and the role of muscles in movement. Students at the Basic proficiency level demonstrated significant improvement in explaining scientific phenomena, with achievement scores reaching 88.89%. They were able to identify muscle types and their respective functions, and effectively analyze the relationship between muscle contraction and body movement. In designing and evaluating scientific investigations, students successfully collected and represented muscle activity data (77.78%) and analyzed the data through tables and graphs (73.33%). However, they still faced difficulties in drawing accurate scientific conclusions (73.33%), suggesting a need for continued guidance in constructing arguments based on experimental evidence.

In the competency of building scientific arguments, students showed the ability to differentiate causal and correlational relationships between muscle contraction and movement (80.00%), though some still struggled with identifying overgeneralized conclusions (60.00%).

Compared to their peers at the Requiring Assistance level, Basic-level students displayed deeper analytical understanding, while those at the Requiring Assistance level achieved similar scores (77.78%) but with more superficial comprehension. The most significant gap remained in scientific argumentation, where Requiring Assistance students reached only 66.67%, compared to 75.56% for Basic-level students. This finding suggests that students needing assistance still had difficulty interpreting experimental data and linking it with theoretical concepts.

Teacher mentoring for Basic-level students emphasized data-driven inquiry, involving assignments that required analyzing muscle contraction data under various conditions—such as rest, exercise, and repetitive activities. Students also examined differences in muscle endurance between athletes and non-athletes, presenting their findings in graphical form. The discussions extended to the relationship between energy metabolism, muscle fatigue, and the influence of nutrition and physical training on muscle strength. This activity encouraged students to apply scientific reasoning to physiological phenomena encountered in everyday life.

In the fifth meeting, students explored disorders and diseases affecting the human motor system, including osteoporosis, arthritis, and muscular dystrophy. The Basic proficiency students demonstrated excellent comprehension, achieving 100% in all aspects of scientific literacy. They were able to explain how motor system disorders influence mobility and connect medical data to previously learned scientific concepts. In designing and evaluating investigations, they accurately collected, represented, and analyzed data on motor system disorders (100%) and drew valid scientific conclusions. In constructing scientific arguments, they effectively identified causal relationships among risk factors (80.00%) and critically evaluated whether conclusions were overgeneralized (60.00%).

Students at the Requiring Assistance level also exhibited notable improvement in this session, achieving 100% across all competencies. This indicates that concrete and contextual topics, such as musculoskeletal disorders, are easier for students to grasp than abstract content like skeletal or muscular structures. However, despite equal achievement percentages, Basic-level students demonstrated deeper analytical and interpretive abilities, especially in data analysis and argument construction. They could relate osteoporosis risk factors to lifestyle variables and utilize epidemiological data to support their arguments.

Teacher guidance for Basic-level students involved data-based projects, such as analyzing health data on the motor system of teachers at MAN 1 Konawe Selatan through statistical studies on osteoporosis prevalence across age groups. Students also participated in data-driven discussions on risk factors and prevention of movement system disorders, comparing various medical research findings to examine the relationship between lifestyle and musculoskeletal health. Case studies emphasized urban–rural lifestyle differences and their implications for osteoporosis or arthritis risks, enhancing students' contextual understanding.

A comparison between Table 6 (Basic proficiency) and Table 5 (Requiring Assistance) clearly indicates that students at the Basic level demonstrated higher performance in analytical thinking, experimental design, and scientific argumentation. Conversely, Requiring Assistance students continued to face challenges in experiment design and scientific reasoning, though they showed notable progress in understanding more tangible and real-world materials, such as motor system disorders. Teacher guidance played a crucial role in these outcomes. At the Requiring Assistance level, instruction was more directive, involving explicit demonstrations and step-by-step procedural guidance. In contrast, at the Basic proficiency level, instruction was facilitative, emphasizing independent exploration, inquiry-based data analysis, and discussion guided by scientific reasoning. This differentiation of instructional strategies according to students' proficiency levels effectively fostered optimal growth in scientific literacy, enabling students to not only comprehend the human movement system conceptually but also apply it to authentic life contexts.

Overall, in the first competency, *explaining scientific phenomena*, Basic-level students showed a steady progression—from 66.67% in the first meeting to 100% in the fifth. This improvement demonstrates the impact of interactive and activity-based learning in strengthening conceptual understanding of human movement mechanisms. As noted by Hake (1998), activity-based instruction significantly enhances science learning outcomes compared to traditional lecture approaches.

A similar trend was observed in the second competency, *designing and evaluating scientific investigations*. Students' performance increased from 66.67% at the first meeting to 100% at the fifth. The initial difficulties in formulating research questions and designing experiments suggest the need for teacher scaffolding in understanding the scientific method. This aligns with Piaget's constructivist theory, which emphasizes that students must engage in active exploration to develop deeper conceptual understanding (Carpendale et al., 2020). Moreover, Aquino et al. (2025) found that inquiry-based learning effectively enhances students' critical thinking and experimental design skills, supporting the findings of this study.

For the third competency, *constructing scientific arguments based on data*, the development occurred more gradually. The Basic-level students' score rose from 66.67% in the first meeting to 77.78% in the third, and finally to 100% in the fifth meeting. This indicates that students require continuous practice in interpreting experimental data and linking it with scientific theory. Erduran et al. (2005) emphasized that scientific argumentation skills develop through repeated practice and guided discussion, which enable students to construct evidence-based reasoning effectively.

Overall, the improvement in students' scientific literacy was strongly influenced by the teacher's mentoring strategies, which included demonstrations and simple experiments, using visual aids to make abstract concepts concrete; reflective discussions, encouraging Basic-level students to relate observations to theoretical concepts through small-group dialogues; and case studies and problem-based learning (PBL), which trained students to investigate real-world issues, particularly those related to disorders of the human movement system, thereby fostering critical thinking and problem-solving skills.

The implementation of these scientific literacy-based instructional strategies across the five meetings is summarized in Table 6.

Table 6. Observation Sheet for the Implementation of Science Literacy-Based Learning Strategies at Proficient Level Students on the Human Movement System Material

No.	Observation Indicators	Meeting					Score	%
		1	2	3	4	5		
Competency 1: Explaining Phenomena Scientifically								
1	Students are able to evaluate models of the human movement system.	2	2	3	3	3	13	80.00
2	Students can identify the advantages and disadvantages of the simulation model they used.	2	2	2	3	3	12	73.33
3	Students are able to provide suggestions for improvements to the simulation model they used.	2	2	2	3	3	12	66.67
Amount		6	6	7	9	9	37	
%		66.67	66.67	77.78	100	100		82.22
Competency 2: Developing and Evaluating Scientific Investigation Designs								
4	Students are able to interpret data presented in various forms (graphs, tables, diagrams).	2	3	3	3	3	14	93.33
5	Students are able to explain patterns or trends from the data they obtained.	2	2	2	3	3	12	80.00

No.	Observation Indicators	Meeting					Score	%
		1	**2**	**3**	**4**	**5**		
6	Students are able to draw conclusions based on various data representations.	2	3	3	3	3	14	93.33
Amount		6	8	8	9	9	40	
%		66.67	88.89	88.89	100	100		88.89
Competency 3: Building Scientific Arguments Based on Data								
7	Students are able to find strength in science-based arguments.	2	3	3	3	3	14	93.33
8	Students can compare arguments with a strong versus weak scientific basis.	2	2	2	3	3	12	80.00
9	Students are able to construct valid arguments based on the data they analyzed.	2	2	2	2	3	9	60.00
Amount		6	6	7	8	9	35	
%		66.67	66.67	77.78	88.89	100		77.78

Based on the data in Table 7 (the students with a Proficient level), it is clear that the students in this category have a higher understanding of explaining scientific phenomena, compiling and evaluating scientific investigation designs, and building scientific arguments based on data compared to students in Table 6 (the students with a Basic proficiency level) and Table 5 (the students with a Requiring Assistance level). The interpretation of data in Table 7 will be discussed based on each meeting to see how students develop at the Proficient level and how it differs from the Basic and Requiring Assistance levels. In addition, the differences in the teacher assistance strategies applied at each proficiency level will also be discussed.

In the first meeting, students learned the structure and function of the axial skeleton, which includes the skull, spine, sternum, and ribs. The students with a Proficient level of proficiency had a very good understanding of evaluating a model of the human movement system (80.00%). They were able to identify the advantages and disadvantages of the simulation model they used (73.33%). However, the students still had a little difficulty in providing suggestions for improvements to the simulation model (66.67%), which shows that although they were able to evaluate a model, students still needed reinforcement in compiling innovations based on scientific evidence.

In the competence of compiling and evaluating scientific investigation designs, the Proficient level students were able to interpret data in various forms (graphs, tables, and diagrams) with very high achievement (93.33%) and explain patterns or trends from the data they obtained (80.00%). In the competence of building scientific arguments based on data, they were able to find strengths in science-based arguments (93.33%) and compare arguments with a strong versus weak scientific basis (80.00%). However, the students still had difficulty in compiling valid arguments based on data that had been analyzed (60.00%).

Compared to the students with Basic and Requiring Assistance levels, the Proficient students have an advantage in evaluating models and interpreting data in various forms. In contrast, the Basic students were only able to identify the structure and function of the motor system, and the Requiring Assistance students had difficulty connecting experimental results with scientific theory. Another major difference is data analysis skills, where the Proficient students have achieved 93.33% in interpreting data, the Basic students have only 66.67%, and the Requiring Assistance students 55.56%.

The teacher's guidance at the Proficient level includes the teacher taking on a more facilitator role by asking students to critically evaluate the axial skeleton model. In addition, the discussion was more focused on the advantages and disadvantages of the human movement system model used in scientific research.

In the second meeting, students learned the function of the appendicular skeleton in supporting body movement, including the bones of the upper and lower limbs. The students with a proficiency level of Proficient had high abilities in evaluating the appendicular skeleton model, with an achievement of 77.78% in explaining scientific phenomena. The students were able to identify the advantages and disadvantages of the appendicular skeleton simulation model (73.33%) and propose improvements to the model based on the analysis they conducted (66.67%).

In the competency of compiling and evaluating scientific investigation designs, the Proficient students showed a very good understanding of interpreting data in various forms, such as graphs, tables, and diagrams (88.89%), and were able to explain patterns or trends from the data they obtained (80.00%). In the competency of building scientific arguments based on data, the students were quite good at finding strengths in science-based arguments (93.33%). However, they still had difficulty in compiling valid arguments based on data that had been analyzed (60%).

The students with the Basic proficiency level and those Requiring Assistance still had difficulty in analyzing the relationship between the structure and function of the appendicular skeleton. The Basic students were better able to build simple models of the movement system, but the Proficient students were able to assess the validity of the model and propose improvements. In addition, the Proficient students excelled more in interpreting data (88.89%), while Basic students were only 66.67%, and Requiring Assistance students were only 44.44%.

The teacher's assistance for the Proficient level students is that the teacher was more facilitative by asking students to critically evaluate the appendicular skeleton model. Then, the discussion was more focused on the advantages and disadvantages of the appendicular skeleton simulation model used in scientific research.

In the third meeting, students learned about the types of joints and their roles in enabling body movement. The students with a Proficient level had a high understanding of explaining the patterns and trends of data obtained about joints (80.00%). They were also very good at interpreting joint biomechanics data from various forms of representation (88.89%). In the competence of building scientific arguments based on data, the students found strength in science-based argumentation (93.33%). Still, they had difficulty in constructing valid arguments based on data that had been analyzed (60%).

In contrast, students at the Requires Assistance level continued to experience difficulties in explaining the relationship between joint structures and movement mechanisms. Meanwhile, students at the Basic proficiency level were able to organize and interpret data but still struggled to formulate scientifically sound conclusions. On the other hand, students categorized as Proficient demonstrated the ability to connect experimental results with biomechanical theories. The teacher's support at this level was primarily facilitative, involving the provision of biomechanical data on joints for students to analyze. Furthermore, Proficient students were encouraged to critique the accuracy of the joint models used in scientific simulations.

In the fourth meeting, the learning activities focused on types of muscles and the mechanisms of muscle contraction related to body movement. Students at the Proficient level showed a very strong understanding of explaining scientific phenomena regarding muscles, achieving 100% mastery. They were able to evaluate muscle system models and identify both strengths and weaknesses in the muscle simulation models used during learning. However, despite their strong analytical thinking, some students still faced minor challenges in providing suggestions for improving the muscle simulation models (66.67%). This finding suggests that although Proficient students are capable of critical analysis, they still require reinforcement in proposing innovative modifications based on empirical data.

Regarding the competency of compiling and evaluating scientific investigation designs, Proficient students demonstrated a high level of achievement in interpreting various data representations, including graphs, tables, and diagrams (93.33%). They were also able to explain patterns or trends emerging from the data (80.00%) and to draw coherent conclusions from multiple data forms (93.33%). In the competency related to constructing scientific arguments based on data, the students showed strong abilities in identifying the strengths of science-based arguments (93.33%), although some still struggled to construct valid arguments grounded in analyzed evidence (60.00%).

In contrast, students at the Basic and Requires Assistance levels encountered greater challenges in understanding the relationship between muscle contraction mechanisms and the human movement system. Basic students were capable of collecting and representing data on muscle contractions in tables and graphs (73.33%), but they had not yet fully grasped the underlying trends or patterns within the data. Meanwhile, Requires Assistance students continued to struggle with connecting experimental outcomes to scientific concepts, achieving 77.78% in explaining scientific phenomena and 66.67% in designing and evaluating scientific investigations.

Teacher mentoring for Proficient students was characterized by a facilitative approach that encouraged critical reflection on the validity of the muscle contraction simulation models. Discussions were directed toward analyzing the advantages and limitations of the models used in scientific research. Additionally, students were challenged to analyze the relationship between the frequency of muscle exercise and muscle endurance using authentic scientific data. In the fifth meeting, the learning focused on various disorders and diseases affecting the human motor system, such as osteoporosis, arthritis, and muscular dystrophy. Students at the Proficient level achieved a very high level of mastery in all dimensions of scientific literacy (100%). They were able to explain the effects of motor system disorders on human mobility and effectively link epidemiological data with the scientific concepts learned throughout the course.

For the competency of compiling and evaluating scientific investigation designs, Proficient students demonstrated excellent performance in collecting, representing, and analyzing data on motor system disorders (100%), as well as in drawing scientifically accurate conclusions. In constructing scientific arguments, they were able to identify causal relationships among risk factors for motor system disorders (80%) and critically assess whether certain research conclusions were overly generalized from limited datasets (60.00%).

At this stage, students with a Requiring Assistance proficiency level also demonstrated notable improvement, achieving 100% mastery across all aspects of scientific literacy. This finding indicates that topics related to musculoskeletal disorders are more concrete and easier for students to comprehend compared to more abstract materials such as bone structure or muscle contraction. However, students at the Proficient level exhibited a deeper level of understanding, particularly in data analysis and the construction of scientific arguments. The Proficient students were able to relate osteoporosis risk factors to lifestyle patterns and support their reasoning with relevant epidemiological data.

The teacher's mentoring strategy for the Proficient group involved the use of case studies derived from scientific research examining the relationship between lifestyle and musculoskeletal health. The teacher facilitated discussions grounded in evidence-based medicine, supported by current epidemiological data. Furthermore, the Proficient students were tasked with analyzing the relationship between lifestyle factors and the risk of musculoskeletal disorders using global statistical data.

A comparative analysis of data from Table 5 (Requiring Assistance level), Table 6 (Basic level), and Table 7 (Proficient level) reveals a clear progression in students' scientific literacy skills as their proficiency levels increased. Students at the Requiring Assistance level still found it challenging to connect experimental results with scientific theories, particularly in verifying predictions through experimentation and drawing valid conclusions from data. They also tended to follow experimental procedures mechanically, without fully understanding the relationships between scientific concepts and observed phenomena.

Meanwhile, students at the Basic level demonstrated a better grasp of identifying the structure and function of the movement system. They were able to collect and represent scientific data in the form of tables or graphs but still required guidance in analyzing data patterns and formulating valid conclusions. In contrast, students at the Proficient level exhibited higher-order thinking skills, such as evaluating scientific models, identifying the strengths and weaknesses of simulation models, and proposing improvements based on analytical reasoning. This indicates that Proficient students not only comprehend the concepts but are also capable of critically examining and refining them further.

Differences in students' understanding levels were also evident in their ability to design and evaluate scientific investigations. Students at the Requiring Assistance level continued to struggle with designing valid experiments and assessing the reliability of their results. They required intensive guidance in determining experimental variables as well as organizing and interpreting the collected data. Conversely, Basic level students began to demonstrate competence in collecting and representing data effectively, though they still faced difficulties in connecting observed data patterns with broader scientific interpretations. Students at the Proficient level, however, showed significant advancement; they were able to interpret various data representations—such as graphs and tables—explain observable trends, and draw well-supported conclusions based on multiple forms of data.

In terms of constructing scientific arguments from data, Requiring Assistance students were still limited in developing robust arguments. Their explanations often focused solely on experimental results without connecting them to underlying theories. Basic students were better able to distinguish between arguments with strong and weak scientific foundations, though they still struggled to construct valid arguments grounded in analyzed data. Proficient students demonstrated more critical thinking, identifying strengths in scientific arguments and comparing evidence-based claims more effectively. Nonetheless, they still required additional support in developing more complex arguments that integrated broader datasets and interdisciplinary perspectives.

These variations in students' comprehension levels influenced the mentoring strategies implemented by the teacher. For the Requiring Assistance group, the teacher provided more direct demonstrations and explicit guidance, as students at this level needed structured support to link theoretical knowledge with practical application. This stage was characterized by a more instructive approach, emphasizing detailed guidance in experiment design and data analysis. At the Basic level, the teacher began to apply a more facilitative approach, giving students opportunities to explore concepts independently. Although students became more active in organizing data and attempting to draw conclusions, they still required scaffolding to understand emerging data patterns and relationships. For the Proficient group, the teacher acted as a facilitator who introduced higher-level academic challenges, such as research-based case studies and model evaluation tasks. Mentoring at this level emphasized critical evaluation of scientific models and research outcomes, fostering deeper understanding of scientific inquiry and methodology.

Overall, the progression of students' scientific literacy skills followed a consistent developmental pattern. Students at the Requiring Assistance level benefited from explicit instruction and concrete demonstrations to grasp fundamental concepts. Basic level students showed growing independence in exploring and representing scientific data, though they still needed guidance to formulate stronger scientific conclusions. Proficient students, on the other hand, achieved a higher level of mastery, being able to interpret, evaluate, and synthesize data to construct evidence-based arguments and critique scientific models. Tailoring teacher assistance to students' respective proficiency levels allowed for optimal development of scientific literacy—

enabling students not only to comprehend the human movement system conceptually but also to apply it meaningfully in scientific investigations and real-world contextsOverall, in the first competency, "explaining phenomena scientifically," the initial score obtained by the Proficient students was quite low, which was 66.67% at the first meeting, but increased gradually to reach 100% at the fifth meeting. It shows that students' understanding of the mechanisms of the human movement system has improved after being given guidance and more interactive learning methods, such as demonstrations and simple experiments. A study by (Council, 2000) stated that problem-solving and experience-based learning can significantly improve students' conceptual understanding compared to conventional methods.

In the second competency, "compiling and evaluating scientific investigation designs," the observation results showed almost the same pattern. The initial score of the Proficient students only reached 66.67% at the first meeting but increased to 100% at the fifth meeting. The initial difficulties students have in formulating research questions and designing experiments indicate that they need guidance in understanding scientific methods. The experiential learning theory of (Kolb, 1984) supports these results, which states that direct experience in conducting experiments can help students internalize scientific concepts better. This increase is also in line with research conducted by (Kuhn & Dean, 2005), which shows that scientific thinking skills can develop through the process of independent exploration and evaluation.

In the third competency, "building scientific arguments based on data," the students experienced slower development compared to the other two competencies. The initial score was only 66.67% at the first meeting, and although it increased, it only reached 77.78% at the third meeting before finally increasing significantly to 100% at the fifth meeting. It indicates that students need more practice interpreting experimental data and connecting it to scientific theory. Research by (Duschl & Osborne, 2002) shows that scientific argumentation skills require systematic practice and more intensive guidance to help students understand the structure of evidence-based arguments.

The improvement in students' scientific literacy skills achievement is inseparable from the mentoring strategy implemented by the teacher. First, the teacher applies PBL, where the Proficient students are given real problems about disorders/abnormalities that humans often experience. It requires students to think critically and find scientific-based solutions. Second, the teacher takes a collaborative approach, where students work in groups to design and evaluate their own experiments related to the solutions they provide in overcoming disorders/abnormalities in the human movement system.

The posttest scores for the students' scientific literacy competency test on the human movement system material in the experimental class can be seen in Table 7.

Table 7. Posttest Scores of the Science Literacy Competency

Class	Number of Students	Average Score	Category
Experimental	2	15	Need Support
	6	38.33	Basic
	8	57.5	Competent
	3	73.33	Proficient
	1	90	Creative Space
Average		51.50	Competent
Control	2	20	Need Support
	10	34	Basic
	5	54	Competent
	3	73.33	Proficient
Average		43.50	Competent

Based on the posttest results of students' science literacy competence on the topic of the human movement system in the experimental class after the implementation of the science literacy-based learning strategy, there was a noticeable improvement in student competence compared to the pretest results. The average posttest score reached 51.50, which falls into the "Competent" category—showing a significant increase from the pretest average, which was categorized as "Basic." This indicates that the science literacy-based learning strategy applied in the experimental class had a positive impact on enhancing students' understanding and science literacy competence.

These results are in line with research by (Merrydian et al., 2025), which, through a systematic literature review, found that a learning environment that supports scientific literacy allows students to develop a holistic understanding of science and technology, including how science can be used to protect the environment and address global threats. In addition, research by (Litina & Rubene, 2024)shows that digital school culture, including integrating digital technology into educational practices significantly impacts students' scientific literacy. The use of digital technology in science learning can increase student engagement and their understanding of scientific concepts.

The teacher implemented several follow-up mentoring actions to further enhance students' learning outcomes. First, innovative learning media were utilized, integrating digital technology and visual aids into science instruction. This integration effectively increased students' engagement and facilitated a better understanding of the human movement system topic. Second, the incorporation of the STEM (Science, Technology, Engineering, and Mathematics) approach helped students connect scientific concepts to real-world applications in technology and engineering. This not only improved the relevance of the learning material but also strengthened students' ability to apply scientific knowledge in practical contexts.

These findings suggest that science literacy-based learning strategies are effective in improving students' conceptual understanding, particularly among those who initially demonstrated lower levels of proficiency. However, additional and more targeted interventions remain necessary for students in the Requiring Assistance category to help them reach the expected competency level. Differentiated support—through remedial instruction, scaffolded inquiry, or more interactive digital simulations—could further enhance these students' learning progress.

Regarding the posttest results of the control class, students also showed improvement in their scientific literacy competence on the human movement system topic compared to the pretest results. The average posttest score in the control class increased to 43.50, categorized as Competent, from a pretest average of 28.50, which was categorized as Basic. Although this reflects a positive trend, the improvement was less substantial than that observed in the experimental class, both in terms of mean scores and the distribution of students across higher proficiency levels. This finding reinforces that literacy-oriented instructional strategies—especially those supported by digital tools and STEM integration—yield more meaningful learning gains compared to conventional approaches.

These results are in line with research by (Nugraha et al., 2020) which found that an inquiry-based learning approach can improve students' scientific literacy, yet its effectiveness depends on students' active involvement and instructional support from teachers. In addition, a study by (Wang & Degol, 2013) showed that the use of technology-based learning strategies can provide more significant results than conventional methods in improving students' understanding of scientific concepts.

These results indicate that the learning strategies applied in the control class still increase understanding but are not as effective as the science literacy-based learning strategies applied in the experimental class. The majority of students in the control class are still in the Basic category, so a more innovative learning approach is needed so that they can achieve a higher level of understanding.

Interpretation of the Influence of Science Literacy Learning Strategies on Students' Science Literacy Competencies in the Human Movement System Material

The results of the present study indicate the significance of the application of science literacy-based learning strategies to students' science literacy competencies in the human movement system material. This is evidenced by the comparison of pretest and posttest results between the experimental and control classes, which were analyzed inferentially as shown in Table 8.

Table 8. Results of the T-Test of Students' Science Literacy Competency Scores on the Human Movement System Material

Treatment Class	Partial T Value	T Value (Sig.2 Direction)	T Value (Sig.α)
Experimental	0.00	0.00	0.05
Control	0.00		

According to the partial testing criteria, the value of Sig. count (0.00) of the experimental and control classes is smaller than the Sig. value (0.05). This result indicates that there is a significant difference between the value of students' scientific literacy competency before and after being given treatment in both classes. However, simultaneously the Sig. count (0.00) value is smaller than the Sig. value (0.05). This result indicates that there is a significant difference between students' scientific literacy competency in the experimental and control classes. The science literacy-based learning strategy applied to the experimental class has significantly increased the students' scientific literacy competency in the human movement system material compared to the control class, which did not receive the treatment.

This finding is in line with research showing that learning approaches that integrate scientific literacy can improve students' understanding and competence in science. For example, a study by Yusmaliana et al. (2024) highlighted the importance of integrating environmental education and creative imagination in Islamic education to foster environmental affection in students (Yusmaliana et al., 2024). Although the context is different, the principle of integrating various aspects of education to improve students' competence is relevant to the findings of this study. In addition, other studies (e.g. Wiyarsi et al., 2021) have confirmed that learning strategies that focus on scientific literacy effectively improve students' analytical and critical abilities in understanding scientific concepts. This approach allows students to connect theory with practice, thereby improving their overall understanding.

The results of this t-test provide empirical evidence that the implementation of science literacy-based learning strategies has a significant effect on improving students' science literacy competencies. Implementing such strategies in the classroom can be an important step in improving the quality of science education and preparing students to face real-world challenges that require a strong scientific understanding.

Interpretation of the Effectiveness of Science Literacy Learning Strategies on Students' Science Literacy Competencies in the Human Movement System Material

The effectiveness of science literacy learning strategies on students' science literacy competencies in the human movement system material can be analyzed using the N-Gain test by calculating the comparison of pretest and posttest values between the experimental class and the control class, which can be seen in Table 9.

Table 9. Results of the N-Gain Test of the Research

Treatment Class	N-Gain	Conversion %
Experiment	0.31	30.94

Based on the calculation results, the N-Gain value was found to be 0.31, corresponding to an increase of 30.94%. According to the standard interpretation criteria for N-Gain scores, this value falls within the moderate category ($0.3 \leq g < 0.7$). These findings indicate that the science literacy-based learning strategy effectively enhances students' scientific literacy competencies in the human movement system topic. The moderate level of improvement suggests that while the implemented strategy successfully deepened students' conceptual understanding, it has not yet achieved the optimal level of effectiveness. Nevertheless, this outcome implies strong potential for improvement through the reinforcement of literacy-oriented instructional components—such as the inclusion of more exploratory activities, problem-based discussions, and diverse learning resources that encourage critical inquiry and reflection.

This finding aligns with previous research by Wiyarsi et al. (2021), which demonstrated that the application of socio-scientific issue-based learning in literacy contexts can significantly improve students' scientific thinking habits and literacy-related competencies. Similarly, Strat et al. (2024) found that inquiry-based literacy approaches in science learning foster students' conceptual understanding and critical thinking skills. Although the observed gains in both studies were also within the moderate range, these results consistently highlight the positive impact of literacy-oriented instructional strategies in deepening scientific comprehension. Therefore, optimizing the implementation of science literacy-based learning—by improving design, contextualization, and classroom engagement—can further enhance its effectiveness in elevating students' literacy competencies to a higher level.

Based on the results and data interpretation presented above, it can be concluded that the differentiated implementation of science literacy-based instructional strategies holds significant pedagogical and policy implications for teachers, madrasahs, and education stakeholders. For teachers, this strategy can serve as a reference framework in designing instruction that aligns with students' learning profiles, consistent with the principles of the Merdeka Curriculum and differentiated learning. For madrasahs, the findings provide a foundation for integrating science literacy approaches into teacher professional development programs and school-level curricula. Moreover, at the policy level, these findings underscore the importance of positioning scientific literacy as a central competency within national education policies, particularly in relation to AKMI (Asesmen Kompetensi Madrasah Indonesia) and PISA (Programme for International Student Assessment) initiatives.

Despite its promising results, this study acknowledges several limitations. First, the use of a pre-experimental design restricted the researchers' ability to control external variables that may have influenced the outcomes. Second, the relatively small sample size, limited to two classes at MAN 1 South Konawe, constrains the generalizability of the findings to broader populations. Third, the short intervention period, consisting of only five sessions, did not allow for a comprehensive assessment of the long-term effects of the literacy-based learning strategy on students' scientific competencies. Therefore, these findings should be interpreted with caution and considered as an initial contribution that warrants further investigation.

For future research, it is recommended to employ more rigorous designs—such as quasi-experimental or true experimental methods—to enhance internal validity and control for extraneous factors. Expanding the research to include a larger and more diverse sample of madrasahs across multiple regions would also improve representativeness and allow for nationwide generalization. Furthermore, the development of science literacy-based instructional materials for other biological concepts is essential to broaden the implementation of this approach in classroom practices. Finally, longitudinal studies are needed to examine the sustained impact of science literacy-based strategies on students' critical thinking skills, scientific reasoning, and attitudes toward science, thereby contributing meaningfully to the advancement of literacy-oriented science education in Indonesia.

CONCLUSION

Based on the findings and discussion, it can be concluded that the implementation of a science literacy-based learning strategy has a significant positive effect on improving students' scientific literacy competencies in the topic of the human movement system. This improvement is evidenced by the increase in the average score of students in the experimental class—from 28.50 (categorized as Basic) to 51.50 (categorized as Competent). The results of the hypothesis test showed a significance value of 0.00, which is lower than $\alpha = 0.05$, indicating that the applied strategy was statistically effective in enhancing students' scientific literacy competence. Furthermore, the effectiveness level of 30.94%, as reflected by the N-Gain value of 0.31, falls within the moderate category ($0.3 \leq g < 0.7$). This demonstrates that the science literacy-based approach contributes meaningfully to students' conceptual understanding and analytical ability, although there remains potential for further optimization. The findings also suggest that the integration of a science literacy framework within a differentiated learning model is pedagogically appropriate, as it allows instruction to be tailored to students' varying proficiency levels and learning needs.

In addition, this strategy is in line with the principles of the Merdeka Curriculum implemented at MAN 1 South Konawe, emphasizing learner-centered and differentiated instruction. Therefore, the application of science literacy-based learning not only enhances students' academic performance but also supports the realization of contextualized and inclusive madrasah education. Overall, this approach provides an effective pedagogical pathway for developing students' literacy-oriented scientific competence, which is essential for preparing them to engage critically and meaningfully with scientific issues in real-life contexts.

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