

Scientific Literacy Assessment for Future Elementary Teachers: Instrument Development and Validation

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Abstract Scientific literacy is an essential competency that pre-service elementary school (SD) teachers must master in order to foster their future students' scientific literacy, yet assessment instruments designed specifically for this population remain scarce. This study aimed to develop a scientific literacy-oriented assessment instrument for pre-service SD teachers and to establish its content validity. Using the 4D model, the define, design, and develop stages were carried out, while developmental testing and dissemination were planned as subsequent stages. The instrument integrates three scientific competencies adapted from the PISA framework explaining phenomena scientifically; designing and evaluating scientific inquiry and interpreting data and evidence; and using scientific information for evidence-based decision-making into seven elementary science topics: the respiratory, digestive, and circulatory systems, electricity, the water cycle, the solar system, and biotechnology. The resulting instrument consists of eight contextual stimuli and 20 items (6 multiple-choice and 14 open-ended items). Five Science Education lecturers evaluated the content, construction, and language of each item, and content validity was analyzed using Aiken's *V*. All items obtained *V* values between 0.82 and 0.92 (overall mean = 0.86), placing them in the high validity category, with comparable means for the three competencies. The items with the lowest values were higher-order items requiring inquiry evaluation or decision-making, indicating where refinement should be prioritized. The instrument is therefore content-valid and ready for field testing to examine its reliability, difficulty, and discrimination with pre-service SD teachers.

Keywords 4D model; Aiken's *V*; assessment instrument; pre-service elementary teachers; scientific literacy

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I. Introduction

Scientific literacy is one of the key 21st-century competencies that enables individuals to engage reflectively with scientific issues as citizens (OECD, 2019). This ability is not only related to the mastery of science content, but also to critical and innovative thinking skills in facing complex global issues in the digital era (Sanjiartha et al., 2024; Budianti et al., 2024). Various international studies affirm that scientific literacy remains a primary goal of science education across all levels, from early childhood education to higher education, and its concept continues to evolve alongside changes in social context and curricula (Broderick, 2025; Yuliana et al., 2025).

Although scientific literacy has become a globally recognized educational goal, the scientific literacy achievement of Indonesian students in international assessments still lags far behind. The 2022 Programme for International Student Assessment (PISA) results showed that the average science score of Indonesian students was only 383, 102 points below the OECD countries' average of 485 (OECD, 2023). This achievement gap indicates that the scientific literacy mastery of Indonesia's younger generation has not yet met the expected international standards, making the strengthening of scientific literacy-oriented science learning at all levels of education an urgent need that must be addressed immediately.

Elementary education is an important foundation for fostering scientific literacy from an early age, because science learning at this level plays a major role in building students' ability to explain phenomena, reason scientifically, and think critically about the information they receive (Fadlurrahman et al., 2026). The implementation of the Merdeka Curriculum through the Natural and Social Sciences (IPAS) subject also affirms

the importance of integrating scientific and social literacy from elementary school onward (Zakarina et al., 2024). Nevertheless, the success of strengthening SD students' scientific literacy depends heavily on teacher readiness, including pre-service SD teachers, in understanding and applying the principles of scientific literacy in learning (Muliani et al., 2021). Studies exploring teachers' perceptions of scientific literacy likewise show that the way teachers understand scientific literacy shapes how it is implemented in science learning (Limiansih et al., 2024; Suwarma et al., 2020; Tae et al., 2023).

This lack of readiness is further compounded by the scarcity of evaluation instruments that are explicitly oriented toward scientific literacy in Science Education courses at universities offering the Elementary School Teacher Education (PGSD) program (Fatimah et al., 2024). A systematic review of scientific literacy instruments also revealed that their development is still dominated by the primary and secondary education levels, while instruments for the higher-education teacher-training context remain limited in number (Istyadji & Sauqina, 2023). This condition indicates a gap between the need to strengthen the scientific literacy of pre-service SD teachers and the availability of valid measurement tools to comprehensively map that ability.

Based on the description above, this study offers novelty in three respects. First, it specifically targets pre-service SD teachers in the PGSD Study Program, a population for whom scientific literacy instruments remain limited. Second, it integrates the content, competency, and context dimensions of scientific literacy into seven essential elementary science topics identified in the define stage. Third, it uses contextual stimuli drawn from local, national, and global issues and combines selected-response and open-ended formats. This study is also a continuation of the research team's roadmap, which previously focused on developing contextual science teaching materials for SD students. The objective of this study was to develop a scientific literacy-oriented assessment instrument for pre-service SD teachers and to establish its content validity through expert judgment, as the basis for subsequent field testing of its reliability and item characteristics with more than 50 students.

II. Literature Review

A. Scientific Literacy of Pre-Service Elementary School Teachers

Teachers, including pre-service elementary school (SD) teachers, have a strategic role in fostering students' scientific literacy from an early age (Muliani et al., 2021). Unfortunately, a number of studies show that the scientific literacy level of pre-service teachers in Indonesia is still low. Muhimmatin and Prasetyo (2024) reported that the initial scientific literacy of pre-service biology teacher students was in the low category (30.24%), while Naila and Khasna (2021) and Marlina (2019) found that the critical and creative thinking abilities of PGSD students tended to be underdeveloped in science learning. A comparative study by El Islami and Nuangchalerm (2020) on Indonesian and Thai pre-service science teacher students further confirmed that the scientific literacy of novice pre-service teachers in both countries still needs improvement, particularly in the process and context aspects of science.

B. Scientific Literacy Assessment Instruments

One cause of the low scientific literacy of pre-service teachers is the scarcity of evaluation instruments explicitly oriented toward scientific literacy. Fatimah et al. (2024) revealed that the evaluation commonly used by lecturers in SD Science Education courses still consists of essay tests that only measure levels from knowledge to application, while the analysis level which is closely related to scientific literacy is rarely tested. This condition is consistent with the findings of Istyadji and Sauqina (2023) in a systematic review of scientific literacy instruments, which concluded that the development of scientific literacy instruments is still dominated by the primary and secondary education levels, while instruments for the higher-education context particularly teacher-training study programs remain limited in number.

Several studies on the development of scientific literacy instruments have been conducted at the primary and secondary education levels, such as scientific-literacy-based formative assessment on the topic of global warming (Lestari & Setyarsih, 2020) and a scientific literacy instrument on the sub-topic of the human circulatory system (Azizah & Budijastuti, 2022), and higher-order thinking assessment in elementary school has also been developed (Hanifah, 2019). At the higher-education level, studies by Utaminingsih et al. (2024) and Zhang et al. (2023) produced valid and reliable scientific literacy instruments, although their scope was still limited to certain science competency aspects and a limited number of respondents (Berlian et al., 2022). Instrument-development studies using the 4D R&D model have also been widely applied in other science fields, such as the development of a STEM-based e-book with augmented reality (Ramdani et al., 2026) and a physics module assisted by a virtual laboratory (Maiyanti et al., 2025), both of which demonstrate that the 4D model can produce valid and practical scientific literacy-oriented learning products.

III. Methods

A. Research Design

This study employed a research and development (R&D) design using the 4D model, consisting of the define, design, develop, and disseminate stages (Thiagarajan et al., 1974). This model was chosen because its stages are systematic and suitable for producing a measurement instrument whose validity is established before it is tried out more widely, as has also been applied in other studies developing scientific literacy-based instruments and teaching materials (Suparya et al., 2024; Ramdani et al., 2026).

This article reports the define, design, and develop stages up to expert appraisal. The developmental testing (limited and wide-scale trials), instrument finalization, and dissemination are planned as the continuation of this study. The activities and status of each stage are summarized in Figure 1.

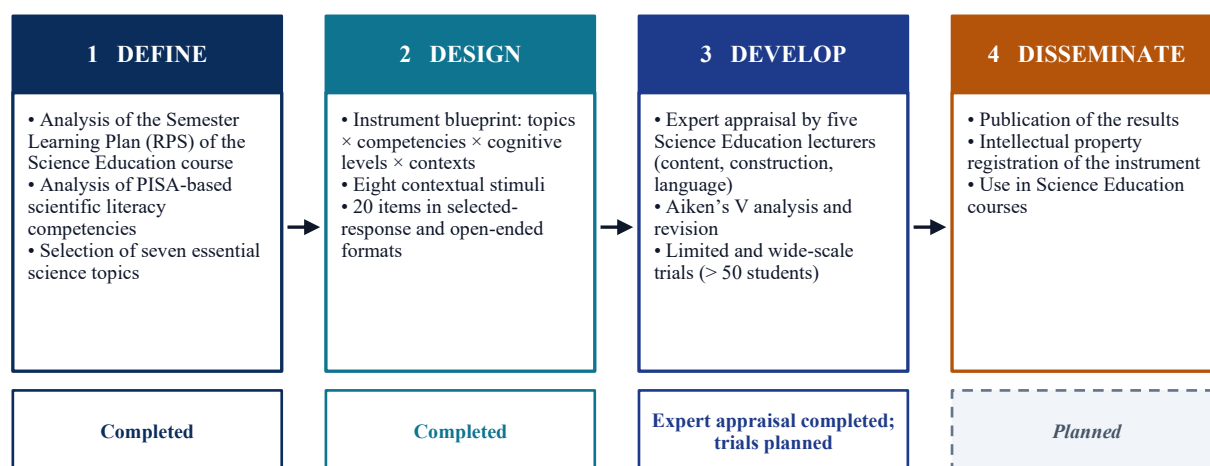


Figure 1. Stages of the 4D model and their status in this study The stages and their outputs are represented in sequential blocks flowing from Define to Disseminate; arrows connecting the blocks indicate the direction of the R&D workflow, and status markers (Completed / Planned) indicate the current progress of each stage.

B. Define Stage

This stage identified the basic needs for instrument development through an analysis of the Semester Learning Plan (RPS) of the Science Education course and of PISA-based scientific literacy competencies. The curriculum, student characteristics, and scientific literacy competency demands were examined to determine the scope of essential topics, namely the respiratory system, the digestive system, the circulatory system, electricity, the water cycle, the solar system, and biotechnology.

C. Design Stage

Based on the results of the define stage, an instrument blueprint was developed that maps the relationships among science topics, scientific literacy competencies, cognitive levels (low, medium, and high), defined following the revised Bloom's taxonomy (Anderson & Krathwohl, 2001) as remembering/understanding (low), applying/analyzing (medium), and evaluating/creating (high), and application contexts (local, national, and global). The items were built around contextual stimuli (texts, data, tables, or illustrations) representing everyday phenomena, in accordance with the PISA scientific literacy assessment format, and were presented in regular multiple-choice, complex multiple-choice, data-interpretation, and open-ended essay formats.

D. Develop Stage

This stage aimed to produce a content-valid instrument through expert appraisal. Following common recommendations for content-validity studies (Aiken, 1985; Retnawati, 2016), a panel of five Science Education lecturers evaluated the content, construction, and language of each item using a validation sheet with a four-point scale. The validators were selected purposively based on the following criteria: (a) holding at least a Master's degree in Science Education or a related field, (b) having a minimum of five years of teaching experience in Science Education at the university level, and (c) prior involvement in the development or evaluation of science-related learning instruments (4 = very good, 3 = good, 2 = poor, 1 = very poor). Content validity was calculated using Aiken's V (Aiken, 1985): $V = \sum s / [n(c - 1)]$, where $s = r - l_0$, r is the score given by a validator, l_0 is the lowest possible score (1), c is the number of rating categories (4), and n is the number of validators (5). The item-level V was obtained by averaging the coefficients across the aspects assessed, and the overall V was the mean of the 20 item-level coefficients. The V values were interpreted as high ($0.80 < V \leq$

1.00), moderate ($0.40 < V \leq 0.80$), or low ($V \leq 0.40$) (Retnawati, 2016). The validators' qualitative comments were used to revise the items.

E. Disseminate Stage

The dissemination stage will consist of publishing the research results, registering the intellectual property rights of the developed instrument, and making the instrument available for use in Science Education courses in PGSD programs.

IV. Results and Discussion

A. Research Results

1. Define Stage: Topics and Competencies

The analysis in the define stage identified seven essential topics of the SD Science Education course that pre-service teachers need to master, namely the respiratory system, the digestive system, the circulatory system, electricity, the water cycle, the solar system, and biotechnology. The competency analysis established three scientific literacy competencies adapted from the PISA framework as the reference for item development: (1) explaining phenomena scientifically (hereafter Competency 1); (2) designing and evaluating scientific inquiry and interpreting data and evidence critically (Competency 2); and (3) researching, evaluating, and using scientific information for evidence-based decision-making (Competency 3). This finding is consistent with Fatimah et al. (2024), who emphasized the lack of analysis-oriented evaluation in SD Science courses, and with Zhang et al. (2023), who stressed the importance of the PISA framework as a basis for developing valid scientific literacy instruments across education levels.

2. Design Stage: Instrument Blueprint and Items

In the design stage, an instrument blueprint was produced that maps the relationships among topics, scientific literacy competencies, cognitive levels, and application contexts. A summary of this blueprint is presented in Table 1.

Table 1. Summary of the Instrument Blueprint

Science Topic	Competencies Measured	Items	Cognitive Level	Context
Respiratory system	C1, C2, C3	1a–1c	Low–High	Air pollution (local)
Digestive system	C1, C2	2a–2c	Low–High	Disease control (local)
Circulatory system	C1, C2, C3	3a–3c	Low–High	Healthy lifestyle (global)
Electricity	C1, C2, C3	4a–4c	Low–High	Electricity and renewable energy (national)
Water cycle	C1, C2	5a–5b	Low–High	Climate change (global)
Solar system	C1, C2, C3	6a–6b, 7a–7b	Low–High	Space exploration (global)
Biotechnology	C1, C2	8a–8b	Medium–High	Traditional food biotechnology (national)
Total		20 items		

The instrument was designed in the form of eight contextual stimulus discourses such as the issue of air pollution in Jakarta, digestive disorders (heartburn/GERD), hypertension at a young age, electricity transmission, climate change and the water cycle, a total lunar eclipse, the planet Mercury, and traditional food biotechnology each accompanied by several sub-items (format a, b, c), resulting in 20 scientific literacy items. The selection of contexts close to everyday life is in line with the ethnoscience and context-based learning approaches, which have been shown to be effective in improving the scientific literacy of both students and pre-service teachers (Yuliana et al., 2021; Suparya et al., 2024).

The detailed design of each item is presented in Table 2. The eight contextual stimuli were elaborated into 20 items (codes a, b, and c) representing the three competencies. The item formats were varied according to the cognitive demands of each competency and included regular multiple-choice items, complex multiple-choice items (selecting all correct statements), a table-based data-interpretation item, and open-ended essay items — all of which are commonly used in PISA-based scientific literacy assessments (OECD, 2019) requiring written scientific reasoning and argumentation.

Table 2. Design of the Items by Stimulus Context, Item Format, and Competency

No	Stimulus Context	Science Topic	Item	Item Format	Competency
1	Rising air pollution in Jakarta	Respiratory system	1a	Essay	C1
			1b	Essay (inquiry design)	C2
			1c	Essay (policy recommendation)	C3
2	Heartburn and GERD in Indonesia	Digestive system	2a	Multiple choice	C1
			2b	Essay	C1
			2c	Structured essay	C2
3	Hypertension at a young age	Circulatory system	3a	Multiple choice	C1
			3b	Short essay	C2
			3c	Essay	C3
4	Electricity transmission	Electricity	4a	Complex multiple choice	C1
			4b	Essay	C2
			4c	Essay	C3
5	The water cycle and climate change	Water cycle	5a	Short essay	C1
			5b	Essay (design evaluation)	C2
6	Total lunar eclipse (blood moon)	Solar system	6a	Complex multiple choice	C1
			6b	Table data interpretation	C2
7	Planet Mercury	Solar system	7a	Complex multiple choice	C1
			7b	Essay (scientific solution)	C3
8	Traditional food biotechnology	Biotechnology	8a	Complex multiple choice	C2
			8b	Essay	C1

Of the 20 items, 6 (30%) are selected-response items (regular and complex multiple choice), whereas 14 (70%) are open-ended items requiring written scientific argumentation or data interpretation. In terms of competencies, 9 items (45%) measure Competency 1, 7 items (35%) measure Competency 2, and 4 items (20%) measure Competency 3 (Table 3). This proportion places greater emphasis on explaining scientific phenomena while still accommodating the higher-order competencies of designing inquiries, interpreting data, and making evidence-based decisions, in line with the characteristics of contextual scientific literacy assessment recommended by Istyadji and Sauqina (2023) and Zhang et al. (2023).

As an illustration of the resulting item design, the stimulus and sub-items in the air-pollution context (items 1a–1c), which sequentially measure the three competencies, are presented below.

Discourse: “Air Pollution in Jakarta Is Rising; Children and the Elderly Are Most Vulnerable to Respiratory Problems” containing data from the World Health Organization and Indonesia’s Ministry of Health on air-pollution levels in Jakarta, expert statements on the impact of PM2.5 particles on the respiratory system, and mitigation efforts undertaken by the government.

1a. Based on the discourse, why are children and the elderly more vulnerable to respiratory problems caused by air pollution than other age groups? (Indicator 1)

1b. The government wants to evaluate the effectiveness of using N95 masks in reducing cases of respiratory problems. Design a simple scientific investigation including the independent variable, dependent variable, control group, and measurement method to test this hypothesis. (Indicator 2)

1c. As a pre-service SD teacher, propose two concrete science-based actions that schools can take to protect students from the impact of air pollution, along with the reasons for their effectiveness. (Indicator 3)

A similar item-development pattern a contextual discourse followed by tiered sub-items covering the indicators of explaining phenomena, designing/evaluating inquiry, and decision-making was applied consistently to the other seven discourse contexts, as summarized in Table 2.

3. Develop Stage: Expert Appraisal

Five Science Education lecturers assessed the content, construction, and language of each item. The content validity analysis using Aiken’s V yielded an overall mean of 0.86, which falls into the high category. The results for each item are presented in Table 3, and the distribution of the coefficients is visualized in Figure 2. When

examined by aspect, the mean Aiken's V coefficients were comparable across the three evaluation aspects: content ($M = 0.87$), construction ($M = 0.85$), and language ($M = 0.86$). This aspect-level consistency indicates that the items were judged as valid across the substantive, structural, and linguistic dimensions of the instrument. In addition, an inter-rater agreement analysis was conducted to complement the Aiken's V estimates. Fleiss' kappa across the five validators was $\kappa = 0.71$, which falls in the substantial-agreement category (Landis & Koch, 1977), indicating that the validators applied the rating criteria consistently across items.

Table 3. Content Validity of the Items Based on Aiken's V

Item	Comp.	Aiken's V	Category	Item	Comp.	Aiken's V	Category
1a	C1	0.85	High	4b	C2	0.82	High
1b	C2	0.89	High	4c	C3	0.86	High
1c	C3	0.90	High	5a	C1	0.87	High
2a	C1	0.92	High	5b	C2	0.87	High
2b	C1	0.88	High	6a	C1	0.86	High
2c	C2	0.89	High	6b	C2	0.82	High
3a	C1	0.88	High	7a	C1	0.83	High
3b	C2	0.86	High	7b	C3	0.82	High
3c	C3	0.87	High	8a	C2	0.85	High
4a	C1	0.85	High	8b	C1	0.84	High

Note: Comp. = competency (C1, C2, C3 as defined in Table 1); overall mean $V = 0.86$.

All 20 items obtained Aiken's V values between 0.82 and 0.92, all of which fall into the high category. The highest value was obtained for item 2a ($V = 0.92$), which measures Competency 1 in the context of digestive disorders, whereas the lowest values were obtained for items 4b, 6b, and 7b ($V = 0.82$), which require inquiry evaluation, data interpretation, or decision-making in the contexts of electricity transmission, the lunar eclipse, and the planet Mercury. When aggregated by competency (Table 4), the mean coefficients were almost identical across the three competencies, indicating that the higher-order items were judged to be as appropriate as the items measuring the explanation of phenomena, although their lowest values were slightly lower.

Table 4. Content Validity by Scientific Literacy Competency

Competency	Number of Items	Aiken's V Range	Mean V	Category
C1: Explaining phenomena scientifically	9 (45%)	0.83–0.92	0.864	High
C2: Designing and evaluating inquiry; interpreting data and evidence	7 (35%)	0.82–0.89	0.857	High
C3: Using scientific information for decision-making	4 (20%)	0.82–0.90	0.863	High
Overall	20 (100%)	0.82–0.92	0.861	High

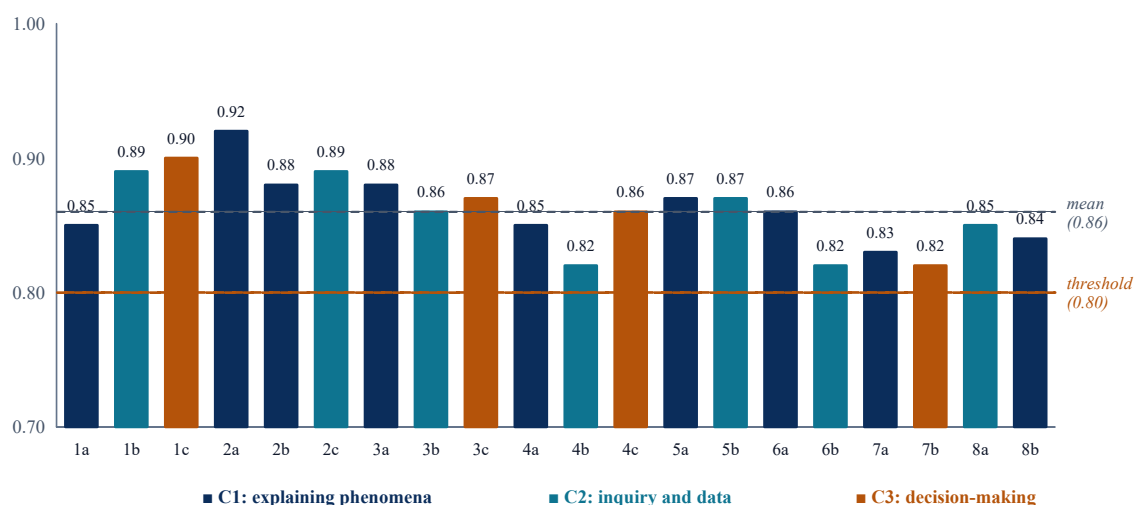


Figure 2. Aiken's V coefficients of the 20 items by competency

B. Discussion

The results show that a scientific literacy instrument designed around contextual stimuli and systematically validated can achieve a high level of content validity, in line with Utaminingsih et al. (2024) and Zhang et al. (2023), who also reported scientific literacy instruments with high validity. The slightly lower coefficients of items 4b, 6b, and 7b are understandable because items that ask students to evaluate an inquiry design, interpret tabulated data, or propose evidence-based solutions demand more complex stimuli and scoring criteria than items that ask for explanations. These items should therefore be prioritized in revision, particularly the clarity of their instructions and scoring rubrics. In addition, previous instrument trials for pre-service teachers have involved limited numbers of respondents (Berlian et al., 2022), whereas the subsequent trial of this instrument is designed to involve more than 50 students so that more stable estimates of reliability and item characteristics can be obtained.

This result is also relevant to the comparative studies by El Islami and Nuangchalerm (2020) and Tsoumanis et al. (2023), who found that the scientific literacy of pre-service teachers and teacher-education students is generally still low to moderate. With a content-valid instrument now available, lecturers teaching Science Education courses have a more comprehensive measurement tool to map students' scientific literacy profiles, as suggested by Torrijos-Muelas et al. (2024), who emphasized the importance of strengthening self-regulated learning and scientific reading literacy among pre-service elementary and early-childhood education teachers.

The distribution of items across competencies also deserves attention. With 45% of the items measuring the explanation of phenomena and only 20% measuring evidence-based decision-making, the instrument currently emphasizes the foundational competency. This emphasis is reasonable for a diagnostic instrument for pre-service teachers, whose initial scientific literacy has been reported to be low (Muhimmatin & Prasetyo, 2024), but future versions could increase the proportion of decision-making items so that the three competencies are represented more evenly.

From a learning-design perspective, integrating scientific literacy indicators into the seven essential SD science topics also opens opportunities for applying active learning strategies such as project-based learning (Agustina et al., 2022; Kristiantari et al., 2022) as well as inquiry-based and augmented-reality-based learning (Ramdani et al., 2026; Maiyanti et al., 2025), which have been shown to improve the scientific literacy of university students and elementary school pupils. Thus, the instrument developed in this study not only functions as a measurement tool but also has the potential to serve as a reference for designing more scientific-literacy-oriented Science Education learning strategies in the PGSD Study Program.

This study has several limitations. It is limited to the content validity stage, and the content validity evidence is based on the judgments of five experts from a single institution. Field trials have not yet been conducted to determine the reliability, discrimination index, and difficulty level of the items, or the inter-rater reliability of the essay scoring. Therefore, these results need to be followed by limited and wide-scale trials, as planned in the develop and disseminate stages.

V. Conclusion

This study produced a scientific literacy-oriented assessment instrument for pre-service SD teachers through the define, design, and develop stages of the 4D model. The instrument consists of eight contextual stimuli and 20 items that integrate three scientific literacy competencies adapted from the PISA framework into seven essential elementary science topics. Expert appraisal using Aiken's V yielded values between 0.82 and 0.92 (overall mean = 0.86), all in the high category, with comparable means across the three competencies. The instrument is therefore content-valid and suitable for field testing to examine its reliability and item characteristics. It is expected to serve as a reference for Science Education lecturers in mapping the scientific literacy profiles of pre-service SD teachers and as a basis for developing scientific literacy-oriented teaching materials and learning strategies in teacher education.

Future research is recommended to conduct limited and wide-scale trials to determine the reliability, discrimination index, and difficulty level of the items, as well as to expand the sample coverage across several universities offering the PGSD program to strengthen the generalizability of the results.

Conflict of Interest

The authors declare no conflict of interest in this study.

Author Contributions

F.P.A. conceptualized the study, coordinated the research, and drafted the manuscript. H., N.M.Y.S., M.P.S., and S.R. contributed to instrument development, data collection, data analysis, and interpretation of the findings. All authors reviewed and approved the final version of the manuscript.

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