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Learning Models for Enhancing Science Literacy in Elementary Schools: Evidence from Indonesia

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ABSTRACT

Scientific literacy serves as a critical foundation for cultivating critical thinking from an early age; however, instructional approaches that contextually accommodate diverse student characteristics remain limited, particularly at the elementary level. Therefore, this study aims to analyze the urgency of an innovative instructional model that strengthens science literacy among elementary school students. Employing a Design-Based Research (DBR) approach, this study is limited to the initial phase of problem identification and analysis. The research subjects comprised 16 elementary school teachers and 111 students across five districts in Surakarta, Indonesia. Data were collected through in-depth interviews, questionnaires, and an extensive literature review. The data analysis process involved data reduction, data display, and conclusion drawing. Source and methodological triangulation were applied to ensure data validity. The findings indicate that the integration of ethnoscience into science learning through a differentiation approach to significantly improve science literacy among elementary school students is needed.

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Introduction

Science has become an integral and inseparable component of education in Indonesia. Within formal schooling, science is delivered through the subject of Natural Sciences [1]. Broadly, science is understood as a body of knowledge and understanding related to environmental phenomena, grounded in the systematic collection and interpretation of empirical data [2]. The Organisation for Economic Co-operation and Development (OECD), through its Programme for International Student Assessment (PISA), emphasizes that scientific competency involves not only the comprehension of scientific concepts, but also active engagement with scientific issues and the application of scientific knowledge in decision-making processes within real-life contexts [3]. However, findings from the 2022 PISA assessment indicate that Indonesian students ranked 68th out of 81 participating countries, with a mean score of 383, which is substantially below the OECD average [4]. This highlights persistent gaps in students' science literacy and underscores the need for developing more effective instructional models in science learning.

Science literacy serves as a critical benchmark for assessing students' ability to understand scientific content and processes [5], often required in decision-making for everyday life, is often applied by nonscientists [6]. Through the development of science literacy, science learning can be more impactful in preparing learners for participation in a knowledge-based society in the 21st century [7]. For instance, implementing science literacy, which is focused on learning experiences, can significantly influence students' abilities to think critically and understand scientific concepts [8]. One of the central aims of K–12 science education is not only to build students' understanding of scientific concepts, but also to help them understand how science works and it is important that science education should nurture students as lifelong learners by fostering a mastery-oriented approach to learning science, strengthening their confidence in learning science independently, and cultivating positive attitudes toward continuous learning throughout life [9].

On the other hand, in many classrooms, teachers still use a conventional lecture-based method, which fails to actively engage students in constructing their knowledge. These approaches often ignore students' diverse sociocultural backgrounds and individual learning styles, leading to instruction that is monotonous and disconnected from learners' contextual reality [10–11]. The consequence of inadequate science literacy is not merely academic; it also results in students' diminished awareness and responsiveness to environmental changes and natural phenomena, such as natural disasters [12]. These findings correlate with observations in several elementary schools across the Surakarta region, where teacher-centered pedagogies continue to dominate. Teachers have not yet systematically considered student diversity, whether in terms of sociocultural context or learning preferences. Furthermore, students'

science literacy has not been assessed, so it is difficult to determine the actual level of science competence among learners.

Recent studies have explored differentiated learning approaches to improve science literacy among students. The differentiated learning model has a positive impact on the development of students' science literacy, with a substantive increase in their ability to apply scientific concepts in various situations [13], and also can improve science learning outcomes [14]. Differentiated learning enables teachers to fulfill students' individual learning needs, interests, and learning profiles [15] to achieve content, processes, and learning outcomes [16]. This approach is a powerful and effective tool that can improve both academic performance and students' educational experience [17]. It can be integrated with Project-Based Learning and Problem-Based Learning models, and has shown effectiveness in improving science literacy competencies [18–19]. Indeed, significant improvements in students' science literacy scores across different grade levels can be achieved through these approaches [20]. Furthermore, [21] developed a differentiated science module integrated with social-emotional competence that can improve students' science literacy and learning independence. These findings suggest that differentiated learning strategies, particularly when integrated with project or problem-based approaches, offer promising solutions for enhancing science literacy among students.

For further contextualized science learning, ethnoscience as an additional pedagogical strategy can be employed. This approach has demonstrated significant potential in improving science literacy in 21st-century science learning [22]. Furthermore, science teachers should continuously explore the local environment to discover relevant indigenous materials, practices, and concepts that can be integrated into the teaching and learning of science [23], and it supports sustainable development [24]. Additionally, [25] found that science worksheets infused with ethnoscience elements improved students' scientific literacy and engagement. Its implementation makes possible the identification of learning materials that are embedded in everyday life and rooted in local cultural systems, encompassing methods, content, and processes developed within those cultural systems [26]. This approach enables students to get scientific principles through culturally familiar aspects, thereby improving scientific thinking and contextual understanding [27]. For primary students, developing scientific literacy by integrating an ethnoscience themed picture book able to increase, improve, or have positive effects [28]. This highlights the urgent need for its continued development and wider use in the classroom [27–29]. Although differentiated instruction and ethnoscience have been widely studied in the context of improving science learning and science literacy, their combined application has yet to be explored specifically in elementary science education. Moreover, there

is a lack of in-depth investigation into the practical implementation of this integrated model, particularly its potential to improve science literacy at the primary level.

Therefore, this study aims to analyze the urgency of an innovative instructional model that strengthens science literacy among elementary school students. This research contributes to the existing literature in the following ways: (1) by highlighting the specific needs of students and teachers for a science differentiated learning model integrated with ethnoscience to enhance science literacy in elementary education; and (2) by providing a qualitative perspective on the essential characteristics of an effective integrated model, offering valuable insights for future educational innovations.

Material and Methods

This study employed a Design-Based Research (DBR) framework, which consists of four phases: (1) preliminary research; (2) development or prototyping phase; (3) assessment; (4) reflection, revision, and dissemination [30]. This present article reports findings exclusicely from the preliminary research phase, which consists of needs and context analysis, review of literature, and development of a conceptual or theoretical framework for the study [30]. The detailed steps undertaken in this phase of the study are illustrated in Fig. 1.



Fig. 1. Research Phases

The study was conducted in elementary schools in Surakarta, Central Java, Indonesia. Participants consisted of 16 elementary school teachers (Grade 3 and Grade 4) and 111 students, selected from five sub-district in Surakarta. Grade 3 and Grade 4 were chosen because at these levels, students are in the early development of science literacy. They begin to move beyond concrete thinking and start to engage in scientific reasoning. From a pedagogical point, these grades are sufficiently mature to respond to varied learning approaches, while the teachers play a role in integrating science instruction.

Data were collected over a four-week period during the second semester of 2024/2025 academic year using three complementary techniques: literature review, questionnaires, and in-depth interviews. The literature review focused on analyzing key documents related to the national curriculum, science literacy, differentiated instruction, and ethnoscience approaches in elementary science learning. This review served to identify theoretical constructs, gaps in existing instructional practices, and design principles relevant to the development of an instructional model. The questionnaires were administered to students to explore their learning interests, perceived difficulties in science learning, and expectations regarding an

ideal science learning experience. Parallel questionnaires were distributed to teachers to capture their perceptions of current instructional practices and their pedagogical needs for enhancing students' science literacy. The questionnaire instruments underwent construct validation through expert judgment before data collection. The in-depth interviews were conducted with the teachers, focused on science instruction practices, challenges in classroom implementation, and requirements for designing an innovative and contextually relevant learning model. The interviews allowed for deeper exploration of issues identified through the questionnaire data.

Data were analyzed using a qualitative approach based on the Miles and Huberman model, which includes data reduction, data display, and conclusion drawing. In order to become familiar with the data, questionnaire answers and interview transcripts were read several times during the data reduction phase. Units of meaning related to ethnoscience, differentiated instruction, and science literacy were found and coded. To make it easier to identify patterns and compare data from different sources, codes were categorized and themed using matrices and thematic charts during the data display stage. Ultimately, conclusions were reached by verifying and interpreting emerging themes iteratively.

To ensure the rigor and trustworthiness of the findings, triangulation strategies were employed. Methodological triangulation was conducted by comparing data obtained from questionnaires and interviews, while data source triangulation was achieved by cross-checking perspectives from students and teachers. Consistency across data sources strengthened the credibility of the findings. In addition, analytical decisions were documented throughout the analysis process to enhance dependability, and interpretations were grounded explicitly in participants' responses to ensure confirmability.

This research was conducted in accordance with the Declaration of Helsinki. Ethical clearance letter was granted by the Health Research Ethics Committee, Faculty of Medicine of Universitas Muhammadiyah Surakarta, approval No. 5879/B.2/KEPK-FKUMS/IX/2025.

Results and Discussion

The objective of this study is to analyze and describe the learning needs of teachers and students in designing a science learning model to enhance science literacy among elementary school students in Surakarta. The study incorporates curriculum analysis and a comprehensive needs assessment from both students and teachers. The findings are organized into three core areas: curriculum analysis, student needs, and teacher needs.

A. Curriculum Analysis

A curriculum analysis was conducted to ensure that the developed instructional model is aligned with current curriculum requirements and addresses actual educational needs. Science is a compulsory subject in the national curriculum [31]. Science learning at the elementary

school level emphasizes deep learning to foster scientific knowledge, its application in everyday life, and students' contributions to society, while also strengthening problem-solving skills [1]. Therefore, students must develop scientific literacy to understand issues related to the environment, technology, health, and socio-economic systems through scientific reasoning [22]. In Indonesia, science literacy is expected to be integrated effectively into the science curriculum, fostering students' abilities to interpret the world scientifically and socially [32]. Not only in Indonesia, but also the World Economic Forum [33] state that science literacy is recognized as one of the 16 essential skills for 21st-century learning, as outlined by the World Economic Forum. Therefore, curriculum alignment is vital to ensuring that science literacy is developed meaningfully.

In Merdeka Curriculum, science instruction begins at Phase B (Grade 3), with an emphasis on facilitating student needs through differentiated instruction [34]. Differentiated learning is considered an effective approach to addressing the diverse learning profiles of elementary students in science education [35–36]. Moreover, flexible grouping according to instructions is a characteristic of the differentiated approach, which accommodates various learning styles, from auditory to kinesthetic to visual [37]. The differentiated approach has proven positive results in student learning outcomes in science subjects [37]. Moreover, research by Roslina et al. [38] shows that learning that can map student needs) and provide activities that emphasise differentiation (content, process, and product) has been proven to improve science literacy. This is certainly in line with the perspective of the Merdeka Curriculum, which supports student-centred learning, intending to support students to learn independently and inclusively [39]. Furthermore, Hariyanto et al. [40] reported that it can improve students' science literacy and has been adapted to student diversity. In addition, through differentiated learning, students can improve their science performance and engagement in learning [38], [41]. Additionally, differentiated instruction also enhances learners' academic achievement in basic science better than the traditional methods [42–43]. Thus, by using this approach, learning gains advantages in the areas of academics, inclusivity, and student engagement in the classroom.

The Merdeka Curriculum framework is in line with the integration of differentiated approaches and ethnoscience, which can encourage the development of scientific literacy and cultural preservation [44]. The ethnoscience approach module provides students with the opportunity to gain a more meaningful and relevant learning experience [45], which not only develops academic fields but also cultural awareness and critical thinking [46]. Although ethnoscience has advantages, there are limitations in its implementation, namely limitations in teacher capacity and the need for adaptation in the existing curriculum [46]. Thus, learning

that incorporates elements of ethnoscience, particularly in science learning, science literacy, and cultural identity, can be strengthened at the same time [47].

The science curriculum can effectively improve science literacy by implementing a structured learning model. Several models that have been tested and widely used by teachers are the Problem-Based Learning (PBL) model and the Project-Based Learning (PjBL) model. Previous research by Ermawati et al. [20] using classroom action studies showed a significant increase in science literacy among Grade X.2 students at SMAN Rambipuji between the first and second cycles after implementing PBL. The PBL model provides a good incentive for students by contextualising and presenting real-world problem analysis through scientific investigation [48]. Similarly, it was found that PjBL also demonstrated its effectiveness in improving science literacy in Grade 4 at SDN Ciracas 07, with statistically significant improvements in science literacy in hypothesis testing [49]. These findings underscore the importance of selecting appropriate instructional models to support science literacy. Thus, based on curriculum analysis, the instruction that is appropriate to enhance science literacy is differentiated learning using PBL and PjBL model and integrated with ethnoscience.

B. Students' Need Analysis

To investigate the needs of a learning design model to enhance students' science literacy, the following section presents preliminary data concerning students' current learning experiences and their specific needs in science instruction.

1. Current Conditions of Science Learning

Based on the interview and questionnaire results, most respondents reported that their current science learning experiences were delivered using various ways. The methods, like doing experiments and exercises, are the most frequently employed by teachers. In the other hand, science is still taught by explanation, students read textbooks, and learn in the classroom. These findings are illustrated in Fig. 2.

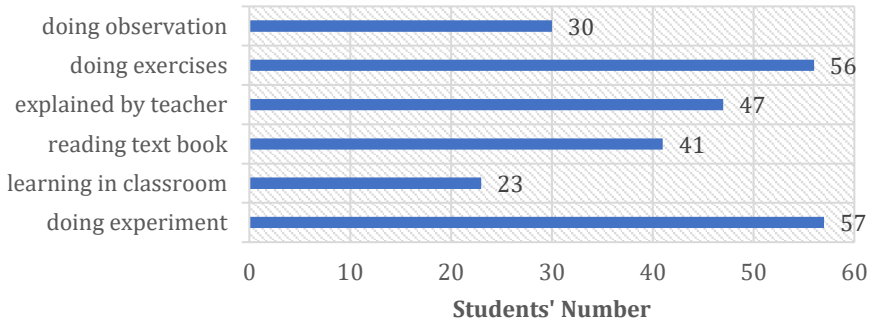


Fig. 2. Science Learning in Schools

Despite the science instruction, students exhibited a generally positive response, with 44% reporting that they were "happy," 55% "very happy," and only 1% "less happy" with

the learning activities. However, scientific practices such as observing, concluding, and presenting have not yet become habitual in the classroom. This is evidenced by a significant proportion of students who responded with "occasionally" when asked about their involvement in scientific inquiry activities, as illustrated in Fig. 3.

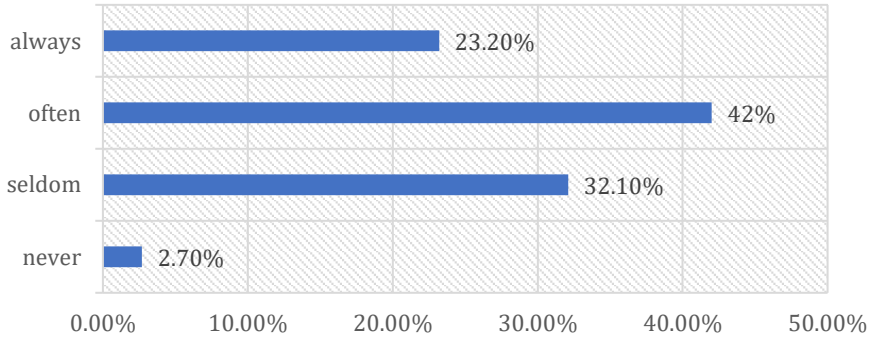


Fig. 3. Frequency of Instruction Integrating Scientific Inquiry

Students also reported several challenges in science learning, including difficulty understanding the material, limited access to learning resources, and insufficient instructional time, as summarized in Fig. 4.

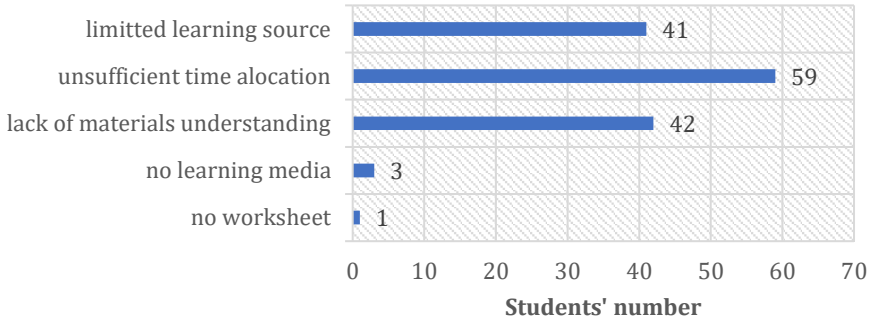


Fig. 4. Students' Challenges in Science Learning

Actually, inquiry-based approaches, which involve observation, drawing conclusions, and presentations, can improve students' science literacy [50]. Besides that, science education must provide hands on experience through observation, identification, decision making, and drawing conclusions related to science as a process skill. In conclusion students still face several challenges in science learning, including difficulty understanding the material and limited access to learning resources.

2. Students' Need in Science Literacy

Most respondents stated that science literacy should be incorporated into science learning, with responses indicating that it is "very important" and "highly necessary." According to the students, the primary functions of science are to help them understand the environment, care for nature, and maintain health. This suggests that students require

science literacy that is not only conceptually sound but also contextual and applicable. Overall, students expressed hope that science learning would become more engaging, enjoyable, and capable of enriching their ability to understand and apply scientific concepts, processes, and methods to make informed decisions and engage with the world around them. By developing these skills, science education can prepare students to apply scientific concepts, make informed decisions, and engage meaningfully with the world around them, thereby supporting the well-being of individuals and communities [51–52]. It is in line with [53] that worksheets offer an alternative for enhancing students' science literacy.

3. Students' Preferences for Differentiated Learning Approaches

The findings indicate that students possess diverse learning preferences. Several students reported that they have a better understanding of concepts through hands on practice, visual media, or educational games. These results highlight the need for differentiated instruction that accommodates various learning styles. Students' interests and engagement preferences are further illustrated in Fig. 5. and Fig. 6.

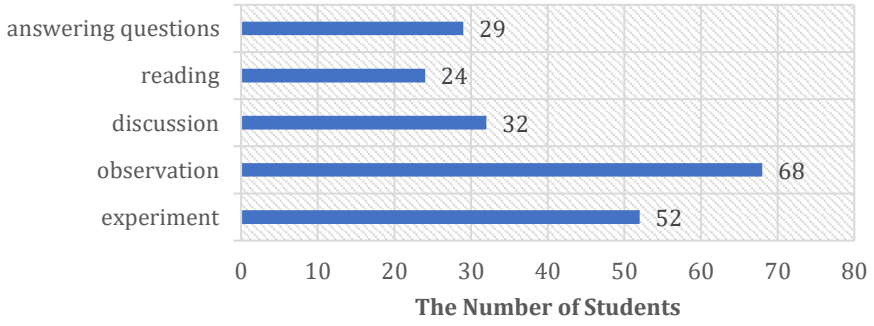


Fig. 5. Students' Interests in Learning Activities

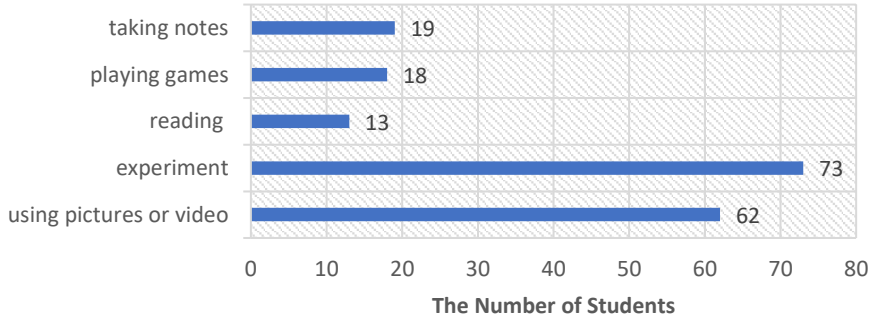


Fig. 6. Students' Preferences and Engagement in Science Learning

For the sake of students' preferences and interests above, students need media to support their learning in science, it can be seen in Fig. 7.

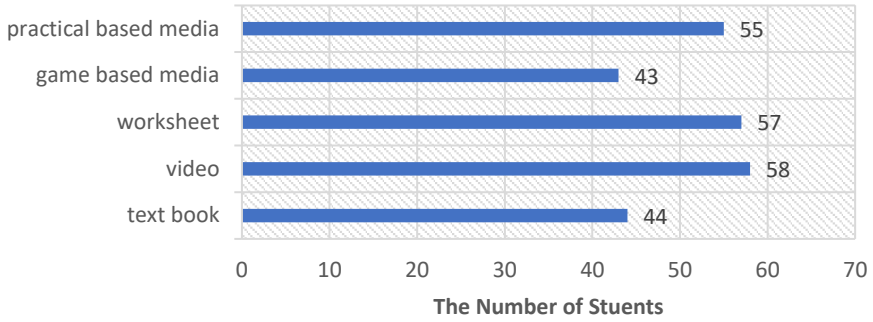


Fig. 7. Students' Requirements in Learning Media

These findings are in line with [54] who state that various media and teaching approaches, such as inquiry models, textbooks, web media, and augmented reality, can improve students' science literacy. Besides that, differentiated learning materials can effectively boost students' interest and engagement in science subjects [40]. For instance, by facilitating media to students' needs is a differentiated learning strategy that can improve students' science literacy [55]. Thus, facilitating some media to students' needs is a differentiated learning strategy that can improve students' science literacy.

4. Students' Needs for the Integration of Ethnoscience into Science Learning

Based on interviews with several fourth-grade students, subsequently reinforced by questionnaire results, it was found that the majority of students expressed enjoyment when classroom learning was connected to local culture. They indicated that the integration of local culture and indigenous knowledge into science learning was "highly necessary." Some students even reported firsthand experiences observing scientific practices embedded in traditional life. Ethnoscience-based learning improves students' critical, creative, and systematic thinking skills and fosters a love for students' culture and environment [56]. Thus, integration of ethnoscience improves students' science literacy and helps them apply scientific knowledge to solve real-life problems, as shown in Fig 8.

This is supported by Dewi and Wardani [57] who believe that emotional and environmental stimuli are directly proportional to learning interest, so that local culture can maintain motivation and cognitive learning processes if implemented effectively. However, students stated that science learning and cultural context are rarely linked. This creates a mismatch in the optimisation of science literacy, which requires a contextual approach, especially in local culture.

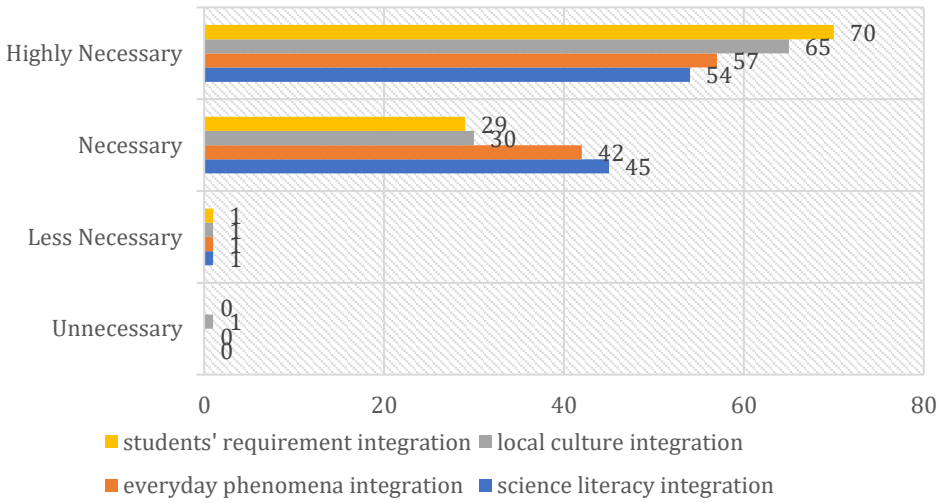


Fig. 8. Students' Responses to the Design of Science Instruction

Additionally, students' high interest cannot be adequately accommodated despite their strong desire to explore it. Sutawan and Winangun [58] argue that to enhance science literacy, it is necessary to strengthen understanding and retention through the integration of local cultures into science education. The students also expressed that they prefer learning methods that emphasise easier understanding and full interaction. This response highlights that an interactive learning environment and student-centred learning can be designed more effectively through the integration of learning that accommodates individual needs and through cultural content in the surrounding environment.

C. Teachers' Needs Analysis

1. Current Condition of Science Instruction

In-depth interviews and a questionnaire conducted with 16 elementary school teachers revealed that current practices in teaching science remain predominantly conventional and teacher-centered. Instructional designs are largely characterized by expository approaches, emphasizing lectures, question-and-answer sessions, and assignments. Inquiry-based or project-based learning models, critical for fostering scientific thinking, are rarely implemented.

The lack of innovation in instructional approaches is a significant contributing factor to students' low levels of science literacy, as consistently demonstrated by international assessments such as PISA. Teachers in this study further identified several critical challenges that exacerbate these conditions, as illustrated in Fig 9.

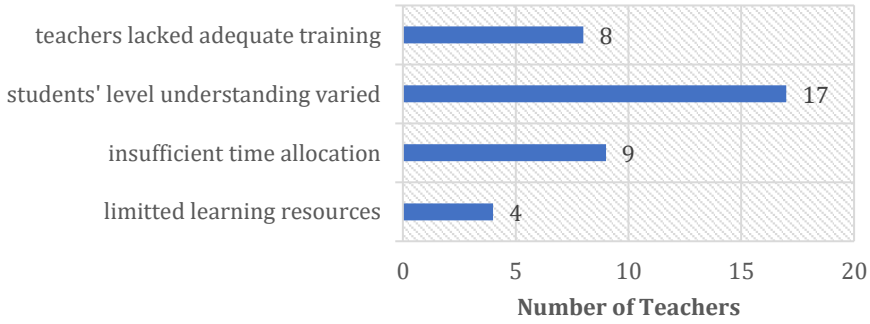


Fig. 9. Current Condition of Science Teaching from the Teachers' Perspective

These instructional limitations hinder the development of students' critical thinking, observational skills, and ability to draw data-based conclusions, core components of scientific literacy. In addition, the lack of adaptive teaching strategies to accommodate student diversity and the limited integration of scientific values such as objectivity, curiosity, and scientific skepticism present substantial pedagogical challenges.

Given these findings, there is an urgent need for the development of a science learning model that is not only responsive to student diversity, through differentiated instruction, but also integrates local context (ethnoscience) to ground scientific knowledge in students' real-life environments. Such a model has the potential to enhance student engagement, motivation, and, ultimately, their science literacy substantively and sustainably. [59] suggested that differentiated instruction practices, which are designed in a culturally responsive manner, and how they are integrated with teacher competencies and classroom management strategies in different cultural contexts, should be addressed and conducted. Research on Project-Based Learning (PjBL) has consistently demonstrated significant improvements in students' science literacy when compared to conventional instructional approaches. In experimental settings, the implementation of PjBL has been shown to result in higher science literacy test scores, indicating its effectiveness in supporting students' understanding and application of scientific concepts [60]. Beyond these cognitive outcomes, studies on differentiated instruction further suggest that PjBL not only enhances scientific literacy but also promotes learner autonomy across diverse educational contexts [61].

All respondents in this study reported an understanding of the concept of differentiated instruction, indicating a level of teacher readiness to implement such approaches in classroom practice. However, during further discussion, teachers acknowledged several challenges in implementing differentiation, including: 1) large class sizes; 2) wide variations in student ability levels; and 3) limited time and flexible instructional materials as shown in Fig. 9. Consequently, teachers expressed the need for a

differentiated science instructional design that emphasizes feasible strategies for personalized learning without overburdening teachers technically. This is in line with [62], science teachers in Indonesia have a desire to implement differentiated instruction, but they face challenges in consistently applying it, such as school facilities. To facilitate such learning, instructional materials that integrate these approaches require technology and AI tools aid the teaching process by enriching the learning content and can enhance educators' work, improving students' knowledge and skills [63].

2. The Need for Ethnoscience Integration in Science Learning

Based on the analysis of both teacher and student needs, all respondents emphasized the importance of strengthening science literacy in alignment with the current curriculum by incorporating differentiated instruction. This underscores a growing awareness of the need to tailor learning processes to students' diverse needs, interests, and abilities within a single classroom. In addition, integration with ethnoscience in science learning is considered important by teachers. This approach connects science to local culture and indigenous knowledge, making the material more contextual and relevant to students' lives. Ethnoscience integration is believed to enhance students' scientific literacy by linking scientific concepts to everyday cultural practices, thus fostering a deeper understanding and application of science knowledge. Teacher responses to the proposed instructional design are summarized in Fig 10.

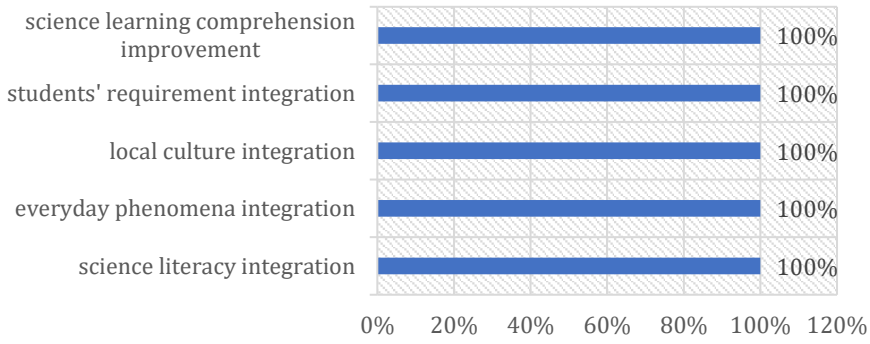


Fig. 10. Teachers' Responses to the Design of Science Learning

Teachers identified the integration of scientific literacy into science instruction as essential and called for more robust implementation. This demand arises in light of the consistently low performance of Indonesian students in international assessments such as the PISA, with science literacy scores declining from 396 in 2018 to 383 in 2022 [64–65]. The findings also reflect a growing awareness among educators of the need to implement scientific literacy through supportive pedagogical approaches, specifically, differentiated instruction and ethnoscience integration.

Through the survey results, all teacher respondents need (100%) to implement differentiated learning in science classes because previous findings prove that a differentiated approach provides an effective strategy to accommodate the diverse learning profiles and characteristics of students [66]. This is in line with Mardati et al. [67], which differentiated learning prioritizes students' individual needs, granting them the autonomy to develop their potential according to their learning styles while promoting diversity within the classroom. These integrated dimensions can enhance student engagement and conceptual mastery when implemented inclusively.

In addition to differentiated learning, teachers also strongly approve of the ethnoscience approach in science education. Ethnoscience refers to scientific understanding within a community that is rooted in human interaction with the natural environment and passed down from generation to generation [68]. In the context of education, ethnoscience plays an important role as a means of contextual education that integrates cultural elements into the learning process [69]. Ethnoscience can be integrated into science learning with the help of learning tools and strategies, such as using contextual learning modules [70], simple practical activities [71], or student worksheets [72]. Based on empirical evidence, ethnoscience has been proven to contribute to strengthening conceptual understanding, motivating students, and making science learning more meaningful. Additionally, critical and creative thinking are developed through ethnoscience while optimising students' sensitivity to the appreciation of local wisdom [25].

Through the explanation above, it is known that the differentiated approach becomes one of the interesting options capable of generating effective pedagogical strategies in accommodating every student's needs in science learning. When the combination of differentiated learning and ethnoscience is implemented, it will create an approach that not only optimizes student engagement but also develops meaningful learning experiences for students. Supporting this, Darmayanti and Yuliani [73] shows from their study results that through local scientific issues integrated with differentiated learning, significant improvements in student participation and achievement can be created.

Based on the findings above, there is a strong theoretical connection between differential instructions, the integration of ethnoscience, and the improvement of science literacy among elementary school students. However, this research is limited in scope, as it only focuses on the combined application of different instructions and ethnoscience. Nevertheless, this dual approach offers promising potential to address the current shortcomings in teaching science to enhance students' science literacy. As a result, there is an urgent need for the development of a learning model that systematically integrates

different instructions and ethnoscience in science. Such a model must be accompanied by adequate teacher training and support mechanisms to ensure effective and sustainable implementation in the context of elementary schools.

Conclusion

The findings underscore a pressing need, identified by both students and elementary school teachers in Surakarta, for an instructional model that combines differentiated science approaches that facilitate media to students' needs and ethnoscience. Such integration is considered vital for fostering meaningful improvements in science literacy among elementary students.

Limitation and Suggestions

A key limitation of this study is its restricted scope, concentrating solely on the integration of ethnoscience and differentiated instruction as the primary means to enhance science literacy. While this dual approach offers promising potential, future research should consider incorporating additional pedagogical frameworks to capture a more comprehensive understanding of factors influencing science literacy.

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Conflict of Interest

The authors declare no conflict of interest.

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