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Integrating STEM and Deep Learning in Renewable Energy Learning to Foster Elementary Students' Scientific Literacy

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Abstract: This study examined the implementation of STEM-based Deep Learning in fostering elementary school students' scientific literacy on the topic of renewable energy. A quantitative approach with a one-group pretest-posttest design was employed. The participants were 29 sixth-grade students from an elementary school in East Jakarta. Data were collected using a 20-item scientific literacy test covering conceptual and contextual understanding of renewable energy and were analyzed using the Rasch Model with the stacking technique in Winsteps. The results showed an overall increase in students' scientific literacy after the learning intervention, as indicated by higher posttest measures compared to pretest measures for most students. STEM-based Deep Learning was implemented through contextual and project-based activities that engaged students in exploring renewable energy concepts, collaborating in groups, assembling simple renewable energy models, and presenting their work. These learning experiences encouraged students to connect scientific concepts with real-life situations and actively participate in the learning process. The findings suggest that STEM-based Deep Learning can support the development of scientific literacy in elementary science learning, particularly on renewable energy topics. Further studies involving larger samples and comparison groups are recommended to strengthen the evidence regarding its effectiveness.

Keywords: Deep learning; Elementary school; Renewable energy; Scientific literacy; STEM

Introduction

Scientific literacy has become increasingly essential in the twenty-first century, as it emphasizes conceptual understanding, critical thinking, reasoning, and the ability to solve problems based on evidence (Jgunkola & Ogunkola, 2013). Through scientific literacy, students are expected to apply the knowledge gained from classroom learning to real-life situations, particularly in responding to rapid developments in science and technology (Resi & Sihotang, 2023). In line with this view, the Ministry of Education and Culture, as cited in Herlinawati et al. (2024), states that learning processes should foster critical thinking, creativity, communication, and collaboration, which are commonly referred to as the 4C skills. However, the results of the 2022 Programme for International Student Assessment (PISA) indicate that Indonesian students' scientific literacy achievement remains low (NCES, 2022). Many students still perceive science as a subject that requires memorization of concepts rather than a learning process that involves scientific reasoning and deeper thinking, particularly in topics that require contextual understanding and reasoning skills, such as energy and the environment (Dinata et al., 2025). At the elementary school level, science learning is often still teacher-centered, resulting in limited opportunities for students to actively construct knowledge and develop scientific literacy skills (Fitria & Setiyawati, 2024). Internal factors, such as low learning motivation, as well as external factors, including limited learning resources and instructional approaches, further contribute to this

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problem (Suri et al., 2025). These conditions indicate the need for learning approaches that promote deeper conceptual understanding and meaningful engagement with scientific knowledge (Kwangmuang et al., 2021).

Within the current implementation of the Merdeka Curriculum, learning is expected to be student-centered and oriented toward meaningful understanding rather than rote memorization (Prahastina et al., 2024). Nevertheless, classroom practices often remain focused on content acquisition, limiting students' opportunities to analyze, reflect on, and apply concepts in authentic contexts (Ahmad et al., 2025). In response to this challenge, the Indonesian Ministry of Education has introduced the Deep Learning approach, which emphasizes meaningful, conscious, and enjoyable learning experiences that enable students to develop a comprehensive understanding of concepts and their interrelationships (Fitriani et al., 2026). In the context of this study, the term Deep Learning refers to the pedagogical approach promoted within the Indonesian education system rather than the concept of Deep Learning in artificial intelligence. Through this approach, students are encouraged to analyze, connect, and reflect on knowledge, thereby reducing reliance on memorization and fostering deeper conceptual understanding (Fadhlurahman & Firmansyah, 2026). Such characteristics make the approach particularly relevant to science learning, including renewable energy topics that require students to understand scientific concepts, real-world applications, and environmental impacts (Zainil et al., 2025).

The implementation of Deep Learning can be strengthened through the integration of STEM (Science, Technology, Engineering, and Mathematics), which equips students with multidisciplinary skills for solving real-world problems and developing holistic conceptual understanding (Indrasti & Paidi, 2025). STEM learning is commonly implemented through Project-Based Learning (PjBL), where students collaboratively design and create products or solutions related to authentic problems (Utomo et al., 2025). However, the value of STEM learning does not lie solely in producing projects. Rather, meaningful STEM activities require students to investigate scientific phenomena, analyze evidence, evaluate alternative solutions, and reflect on the concepts underlying their projects. Through these processes, STEM provides opportunities for students to engage in deeper learning experiences while simultaneously developing critical thinking, collaboration, communication, and creativity (Sukmawati et al., 2025). Therefore, integrating STEM with the Deep Learning approach has the potential to support both conceptual understanding and scientific literacy development.

Previous studies have reported positive effects of both Deep Learning-oriented instruction and STEM learning on students' scientific literacy. Rikianto et al. (2025) found that Deep Learning improved students' conceptual understanding, science process skills, and scientific attitudes through meaningful learning experiences and reflection. Similarly, Setiawan et al. (2025) reported that STEM learning integrated with the Sustainable Development Goals (SDGs) enhanced elementary students' environmental literacy and socio-ecological awareness. Despite these promising findings, studies that integrate Deep Learning and STEM within a single instructional framework, particularly in renewable energy learning at the elementary school level, remain limited. Furthermore, most previous studies have relied primarily on conventional pretest-posttest score comparisons, providing limited information regarding individual changes in students' abilities.

Classroom observations conducted in a sixth-grade elementary classroom in Jakarta revealed that many students tended to depend on direct answers from the teacher rather than independently exploring available learning resources. Even when the required information had been provided in learning materials, students frequently asked for answers instead of locating, interpreting, and utilizing the information on their own. This tendency suggests difficulties in analyzing scientific information and drawing conclusions from scientific texts, which are important components of scientific literacy. These findings indicate the need for instructional approaches that not only engage students in hands-on activities but also encourage them to construct meaning, reflect on evidence, and apply scientific concepts independently.

Based on these considerations, this study investigates the implementation of STEM-based Deep Learning in fostering scientific literacy among sixth-grade elementary school students on the topic of renewable energy. The novelty of this study lies in the integration of the Indonesian Deep Learning approach with STEM learning to promote meaningful conceptual understanding and scientific literacy development. In addition, students' scientific literacy is examined using Rasch Model analysis, allowing a more detailed evaluation of individual ability changes beyond conventional score-based approaches. This study is important because scientific literacy remains a persistent challenge in elementary science education, while empirical evidence regarding the combined implementation of STEM-based Deep Learning and its contribution to scientific literacy development is still limited.

Method

Research Subjects

The main instrument used in this study was a scientific literacy test administered as both a pretest and a posttest. The test was developed based on the topic of renewable energy in the IPAS subject for sixth-grade elementary school students. The instrument consisted of 20 items covering two aspects: 10 items related to conceptual understanding and 10 items related to contextual understanding of the material. Through this instrument, students' scientific literacy was measured based on their ability to understand renewable energy concepts, identify energy-related problems, interpret scientific information, determine appropriate solutions, and draw conclusions from cases related to renewable energy. The test items covered cognitive levels ranging from C2 to C6 and included Higher Order Thinking Skills (HOTS) components related to renewable energy concepts and their applications in everyday life.

Research Instrument

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Research Procedure

This study was carried out through several interconnected stages, beginning with instrument preparation, followed by the administration of the pretest, the implementation of the learning treatment, and the analysis of students' learning outcomes. These stages were arranged to ensure that the research process was conducted systematically and that the results could represent changes in students' abilities before and after the treatment.

The first stage involved preparing the research instrument in the form of a scientific literacy test on the topic of renewable energy. The instrument was designed based on the learning objectives and indicators of scientific literacy, covering conceptual and contextual understanding. The instrument was reviewed and validated by the research supervisor to ensure its alignment with the learning objectives, scientific literacy indicators, and renewable energy content used in this study. Following the validation process, students were given a pretest to identify their initial level of scientific literacy before the implementation of STEM-based Deep Learning. The pretest results served as the baseline data for examining students' abilities prior to the treatment.

The next stage was the implementation of STEM-based Deep Learning. During this stage, students were guided to explore renewable energy concepts through learning activities that emphasized active participation, discussion, collaboration, and reflection. Students worked in groups to complete STEM-based project activities and develop their understanding of renewable energy concepts. After the treatment was completed, students were given a posttest using the same scientific literacy indicators to measure changes in their abilities. The pretest and posttest results were then analyzed using the Rasch Model stacking technique to determine changes in students' scientific literacy after the implementation of the learning approach.

Research Treatment

The treatment consisted of the implementation of STEM-based Deep Learning on the topic of renewable energy. On the first day, students completed a pretest to identify their initial level of scientific literacy. On the second day, students participated in STEM-based learning activities designed to introduce renewable energy concepts through exploration, discussion, collaboration, and project-oriented activities.

Students were divided into five groups and engaged in assembling simple renewable energy teaching aids prepared by the researcher. The projects included a mini solar-powered helicopter, a miniature house with a solar-powered turbine, a battery-powered traffic light model, a battery-powered mini carousel, and a simple device demonstrating the conversion of motion energy into electrical energy. During the activity, students were encouraged to observe how the devices worked, discuss the scientific principles involved, and relate the concepts to real-life applications of renewable energy.

After completing the projects, representatives from each group presented their work and explained the renewable energy concepts underlying the operation of the teaching aids. These presentation and discussion activities provided opportunities for students to communicate ideas, exchange perspectives, and strengthen their understanding of scientific concepts. Following the learning activities, students completed a posttest to examine changes in their scientific literacy after participating in the STEM-based Deep Learning activities.

Figure 1. Students assemble a renewable energy teaching aid

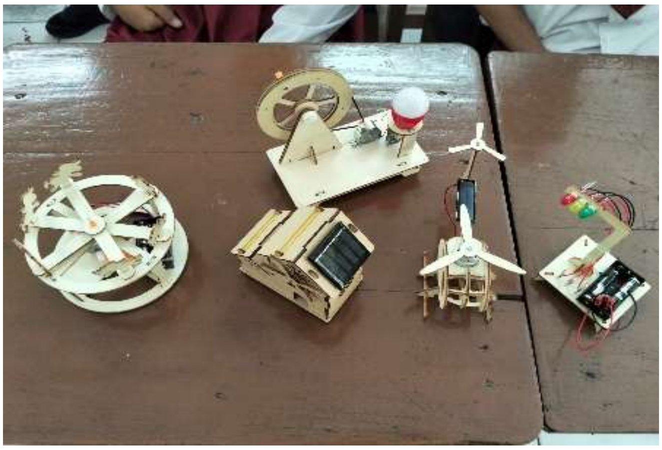

Figure 2. The final product of the renewable energy project

Data Analysis Technique

The pretest and posttest data were analyzed using the Rasch Model with the stacking technique assisted by the Winsteps application (Laliyo et al., 2022). The stacking technique was used to compare students' abilities before and after the treatment on the same measurement scale, namely the logit scale. In this technique, the pretest and posttest responses were arranged vertically, allowing each student to appear twice in the dataset while each item appeared only once. This procedure enabled changes in individual students' abilities to be examined more clearly.

The analysis focused on person measures, standard errors, fit statistics, person reliability, and item reliability. Changes in scientific literacy were identified by comparing pretest and posttest person measures. A higher posttest measure indicated improvement in scientific literacy, whereas a lower posttest measure indicated a decline in performance after the intervention. Therefore, the Rasch Model stacking technique was employed to provide a more detailed interpretation of changes in students' scientific literacy following the implementation of STEM-based Deep Learning on the topic of renewable energy.

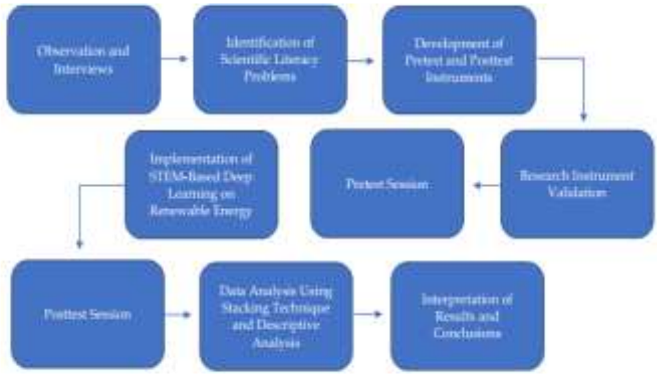

Figure 3. Research procedure

Result and Discussion

Changes in Students' Scientific Literacy

Data analysis was conducted using the Rasch Model with the stacking technique in Winsteps. The analysis was based on the pretest and posttest results of 29 sixth-grade students in class VI-B at an elementary school in East Jakarta. Through the stacking procedure, each student contributed two measurement points, representing their pretest and posttest performance. This approach enabled the comparison of students' scientific literacy before and after the implementation of STEM-based deep learning on the topic of renewable energy.

Based on Table 1, most students showed higher posttest measures than pretest measures after participating in STEM-based Deep Learning on the topic of renewable energy. Of the 29 students, 23 students demonstrated improvement, 3 students remained at the same level, and 3 students obtained lower posttest measures. The highest increase was achieved by student S20, whose measure increased by 2.22, followed by S28 with an increase of 1.94. Students S11 and S23 also showed notable improvements of 1.63. These results indicate that most students benefited from the learning activities and were able to develop their scientific literacy after the intervention.

The increase in students' measures may be explained by the characteristics of Deep Learning, which emphasizes meaningful learning through active engagement and the connection between prior knowledge and new concepts (Alhammadi, 2021). During the learning process, students explored renewable energy concepts through discussion, project activities, and presentations, enabling them to construct understanding more actively. This finding is also consistent with constructivist theory, which states that knowledge is built through interaction with the environment and social collaboration (Susilawati et al., 2026). Through group-based STEM activities, students were encouraged to analyze information, exchange ideas, and solve problems collectively, which may have contributed to the improvement of their scientific literacy.

Table 1. Person Measure of Students' Scientific Literacy in the Pretest and Posttest

Person	Measure Pretest	S.E. Pretest	Measure Posttest	S.E. Posttest	Measure Difference
S01	0.94	0.51	1.90	0.65	0.96
S02	1.53	0.58	2.39	0.76	0.86
S03	4.40	1.83	3.16	1.04	-1.24
S04	0.94	0.51	0.94	0.51	0.00
S05	2.39	0.76	3.16	1.04	0.77
S06	2.39	0.76	3.16	1.04	0.77
S07	1.90	0.65	2.39	0.76	0.49
S08	0.22	0.47	0.94	0.51	0.72
S09	4.40	1.83	3.16	1.04	-1.24
S10	1.21	0.54	1.53	0.58	0.32
S11	-0.94	0.51	0.69	0.49	1.63
S12	3.16	1.04	4.40	1.83	1.24
S13	2.39	0.76	1.90	0.65	-0.49
S14	-0.69	0.49	0.69	0.49	1.38
S15	4.40	1.83	4.40	1.83	0.00
S16	1.53	0.58	1.90	0.65	0.37
S17	1.90	0.65	2.39	0.76	0.49
S18	0.69	0.49	1.90	0,65	1.21
S19	0.94	0.51	1.21	0.54	0.27
S20	0.94	0.51	3.16	1.04	2.22
S21	0.45	0.48	0.94	0.51	0.49
S22	0.69	0.49	1.90	0.65	1.21
S23	1.53	0.58	3.16	1.04	1.63
S24	0.00	0.47	0.94	0.51	0.94
S25	4.40	1.83	4.40	1.83	0.00
S26	-0.69	0.49	0.00	0.47	0.69
S27	1.21	0.54	1.90	0.65	0.69
S28	0.45	0.48	2.39	0.76	1.94
S29	0.69	0.49	1.21	0.54	0.52

The findings are also in line with previous studies showing that meaningful and contextual learning can enhance conceptual understanding, science process skills, and scientific attitudes (Nafi'ah & Faruq, 2025). Furthermore, STEM learning integrates science, technology, engineering, and mathematics in real-world contexts, allowing students to apply scientific concepts to authentic situations (Nurfazlina et al., 2025). In this study, students assembled simple renewable energy models and explained their functions, providing opportunities to interpret scientific information and communicate their understanding, both of which are important components of scientific literacy (Wang & Wang, 2023).

However, several students showed no change (S04, S15, and S25), while S03, S09, and S13 obtained lower posttest measures. Students S03 and S09 initially achieved the highest pretest measure and showed lower posttest measures, whereas S15 and S25 maintained the same high measure in both tests. This pattern may be associated with the ceiling effect phenomenon, in which students with very high initial performance have limited room for measurable improvement because the instrument is not sufficiently difficult to distinguish higher levels of ability (Chen & Schunn, 2025). Therefore, these findings should be interpreted cautiously and may reflect limitations of the instrument rather than an actual decline in students' scientific literacy.

Tendency of Improvement after the Treatment

To provide a clearer overview of students' ability changes after the treatment, the changes in students' scientific literacy were grouped into three categories: increased, unchanged, and decreased.

Table 2. Categories of Students' Ability Changes

Category of Change	Number of Students	Percentage
Increased	23	79.31%
Unchanged	3	10.34%
Decreased	3	10.34%
Total	29	100%

Based on Table 2, 23 students (79.31%) experienced an increase in ability, 3 students (10.34%) remained unchanged, and 3 students (10.34%) experienced a decrease. These findings indicate that most students showed improvement in scientific literacy following the implementation of STEM-based Deep Learning on the topic of renewable energy.

The improvement observed in the majority of students is consistent with the principles of Deep Learning, which emphasize meaningful learning, active engagement, and the connection between new knowledge and prior understanding (Syafril & Junaidin, 2025). Through learning activities that involved exploration, discussion, project work, and presentation, students were encouraged to construct their own understanding rather than merely memorize information (Azzahrah et al., 2026). Such experiences enabled students to interpret scientific information and relate scientific concepts to real-life situations, which are important aspects of scientific literacy (Putra et al., 2025).

In addition, the integration of STEM may have strengthened students' understanding by connecting science concepts with technology, engineering, and mathematics in a contextual learning environment (Suryani et al., 2023). During the project activities, students assembled simple renewable energy models and examined how the devices functioned, allowing them to apply scientific reasoning in solving practical problems. This finding supports previous studies showing that STEM-based learning can promote scientific literacy and environmental awareness when learning activities are linked to authentic issues and everyday contexts (Pada et al., 2025). Similar results were also reported by Adanur-Sönmez et al. (2025), who found that STEM learning encourages students to engage actively in problem-solving and develop a deeper understanding of scientific concepts through real-world applications.

Data Feasibility in the Rasch Model Analysis

The feasibility of the data was examined through the Rasch Model summary statistics, including person and item measures, fit statistics, reliability, and separation values.

Table 3. Summary Statistics of Person and Item in the Rasch Model

Aspect	N Input	N Measured	Mean Measure	Infit MNSQ	Outfit MNSQ	Separation	Reliability
Person	58	58	1.82	1.00	0.96	1.14	0.57
Item	20	20	0.00	0.99	0.96	1.48	0.69

Based on Table 3, all 58 person data and 20 items were successfully analyzed. The 58 person data were obtained from 29 students who completed both the pretest and posttest. The mean person measure was 1.82, indicating that students' average ability was above the average item difficulty level, which was centered at 0.00. This finding suggests that, in general, the students were able to respond to the test items appropriately and demonstrated a level of scientific literacy that exceeded the average difficulty of the instrument.

The summary statistics showed mean Infit MNSQ and Outfit MNSQ values close to 1.00 for both persons and items. These values provide a general description of the overall response patterns obtained from the measurement. However, model fit cannot be determined solely from the mean fit statistics and requires further examination through individual person-fit and item-fit analyses (Olivares & Montaño, 2013). Therefore, the fit statistics reported in this study are interpreted descriptively as part of the overall measurement results rather than as definitive evidence of model fit.

The person reliability value was 0.57 with a person separation index of 1.14, while the item reliability value was 0.69 with an item separation index of 1.48. According to Rasch measurement theory, reliability and separation indices reflect the consistency of measurement and the ability of an instrument to distinguish different levels of person ability and item difficulty (Aini et al., 2026). The relatively low person reliability and separation values indicate that the instrument had limited power to differentiate students into distinct ability groups. This condition may have been influenced by the relatively small sample size and the limited range of item difficulty included in the test. Consequently, the findings should be interpreted as indicating general trends in students' scientific literacy development rather than highly precise estimates of individual ability differences. Similar limitations have been reported in small-sample Rasch studies, where measurement precision is often constrained by the number of respondents and item characteristics (Santoso et al., 2025). Future studies are encouraged to involve larger samples and a wider range of item difficulties to obtain more stable measurement results.

Relationship between Students' Initial and Final Abilities

The relationship between students' initial and final abilities was examined through the empirical line plot generated from the stacking analysis.

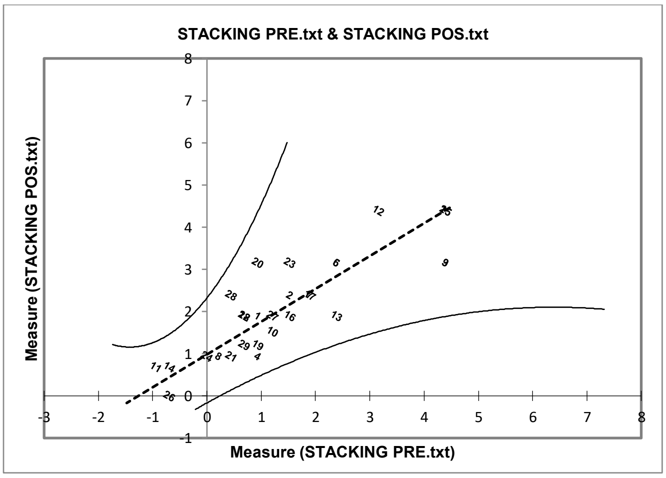

Figure 4. Plot-empirical line of pretest and posttest stacking results

Figure 4 presents the empirical line plot generated from the stacking analysis. The horizontal axis represents students' pretest measures, while the vertical axis represents their posttest measures. The distribution of data points shows a general tendency for posttest measures to be higher than pretest measures, indicating an overall positive trend in students' scientific literacy after the implementation of STEM-based deep learning.

The observed trend suggests that learning activities integrating STEM and deep learning may support students in developing a better understanding of renewable energy concepts. Through project-based and contextual experiences, students were encouraged to explore scientific concepts, discuss ideas collaboratively, and relate learning content to everyday situations

(Pratama et al., 2025). Such learning experiences are consistent with previous studies reporting that contextual STEM learning can contribute to the development of scientific literacy and higher-order thinking skills among elementary school students (Susilawati et al., 2025).

Overall, the results suggest a positive trend in students' scientific literacy following the implementation of STEM-based deep learning on renewable energy. Although several students showed unchanged or lower measures, most students demonstrated improvement, indicating the potential of this approach to support meaningful science learning in elementary school settings.

Conclusion

The implementation of STEM-based deep learning on the topic of renewable energy was carried out through contextual and project-based learning activities that engaged students in exploring concepts, collaborating in groups, assembling simple renewable energy models, and presenting the results of their work. These activities enabled students to connect scientific concepts with real-life situations and participate actively in the learning process. The findings indicate that students' scientific literacy improved following the implementation of STEM-based deep learning. Through the integration of STEM and meaningful learning experiences, students were encouraged to understand scientific concepts, interpret scientific information, and apply their knowledge in the context of renewable energy. These results suggest that STEM-based deep learning has the potential to support the development of scientific literacy in elementary science learning. Future research is recommended to involve larger samples, longer implementation periods, and comparison groups to provide a more comprehensive understanding of the effectiveness of STEM-based deep learning in fostering students' scientific literacy.

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Author Contributions
Conceptualization, N.D. and W.S.; methodology, N.D. and W.S.; software, N.D.; validation, W.S.; formal analysis, N.D.; investigation, N.D.; resources, N.D.; data curation, N.D.; writing—original draft preparation, N.D.; writing—review and editing, W.S.; visualization, N.D.; supervision, W.S.; project administration, N.D. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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