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A STEM-based student worksheet utilizing local waste with SDGs orientation to improve scientific literacy

Nurul Istiani[1], Hanik Malichatin[2*]
[1,2]Science Education Department, Universitas Islam Negeri Sunan Kudus, Kudus, Indonesia
**Correspondence: hanikm@uinsuku.ac.id*

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Abstract

This study aims to develop a STEM-based LKPD that utilizes local waste aligned with SDGs to improve seventh-grade students' scientific literacy. This research was motivated by the low scientific literacy of students, particularly in contextual environmental pollution material. The method used is Research and Development (R&D) with the 4D development model (Define, Design, Develop, Disseminate).the research subjects were 34 student of class VII B at a junior high school in Kudus. Instruments used include expert validation questionnaires, user response questionnaires, and scientific literacy tests. Data analysis techniques employed descriptive statistics for feasibility assessment (converted to percentages), Normalized Gain (N-Gain) for measuring scientific literacy improvement, and thematic analysis for qualitative data from observations and interviews. The validation results show that the LKPD is highly feasible with a score 83.62% from material experts and 85 % from media experts. User responses indicated a feasibility level of 94%, and the improvement of scientific literacy based in the N-gain test was 0.689 (medium category). These results indicate that the integration of SDGs issues and the use of local waste in a STEM approach can connect science learning to real-life contexts, making the develop of LKPD feasible for classroom use, which represents a new integration model of STEM and SDGs in waste-based contextual learning.

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Introduction

The rapid development of science and technology in the 21st century has brought significant changes to the competency requirements of students. In the context of science education, students are not only expected to master scientific concepts cognitively, but also to be able to apply this knowledge to solve real-life problems creatively and responsibly. One of the key competencies needed to face these global challenges is scientific literacy. Scientific literacy encompasses the ability to understand scientific phenomena, analyze evidence-based information, and make decisions related to social and environmental aspects of everyday life (Bybee, 2014). Individuals with high scientific literacy will be able to think critically, communicate scientifically effectively, and actively participate in a knowledge-based society (Fives, H., Huebner, W., Birnbaum, A. S., & Nicolich, 2014).

Although scientific literacy has become a primary focus of modern education, various international studies indicate that the level of scientific literacy of students in Indonesia remains relatively low. According to the 2018 and 2022 Programme for International Student

Assessment (PISA) reports, Indonesian students' scientific literacy scores remain below the OECD average (Schleicher, 2019). This situation indicates that science learning in schools has not fully succeeded in fostering scientific and applied thinking skills. Learning is still oriented towards memorizing concepts and solving routine problems that do not require logical reasoning and critical reflection on environmental phenomena (Yore, L., 2012). As a result, students are less able to connect scientific concepts to real-world situations, even though these abilities are at the heart of scientific literacy.

In addressing these challenges, a learning model is needed that integrates theory and practice while fostering higher-order thinking skills. The Science, Technology, Engineering, and Mathematics (STEM) approach is one effective strategy for addressing these needs. This approach emphasises interdisciplinary integration and provides inquiry-based, experimental, and engineering learning experiences, enabling students to understand how scientific concepts are applied in everyday life (Margot, K. C., & Kettler, 2019). Through STEM-based activities, students are encouraged to collaborate, think critically, and innovate in solving real problems in their environment (Kim, H., Jiyoon, P., & Lee, 2021). Thus, STEM-based learning not only strengthens concept mastery but also shapes comprehensive 21st-century competencies

Although the STEM approach has been widely implemented, most of its implementation in Indonesia is still limited to simple projects that fail to connect local contexts with global issues relevant to students' lives. For instance, research by (Sari, M., & Nugroho, 2020) revealed that STEM implementation in Indonesian schools is often confined to basic activities that do not link local contexts with global issues such as climate change or sustainability, thereby reducing its effectiveness in fostering comprehensive science literacy. In fact, learning that integrates local contexts has been proven to be more meaningful because it provides students with direct experiences to understand and overcome problems in their environment (Karpudewan, 2021). One effort to provide contextual learning is by utilizing local waste as a learning resource. Organic waste such as tofu pulp, banana peels, and cassava peels are materials that are easily found in the students' environment and have great potential to be used as experimental media. Through the utilization of local waste, students can develop ecological awareness, understand the concept of recycling, and practice scientific thinking skills in a concrete manner (Nugraha, A., Sari, M., & Hidayat, 2022).

The use of local waste in learning is also in line with the principles of Education for Sustainable Development (ESD), which emphasizes the importance of the interrelationship between science, the environment, and sustainable development. In this case, the integration of STEM-based learning with the Sustainable Development Goals (SDGs) is a strategic and relevant approach. The SDGs, particularly point 12 on sustainable consumption and production, demand awareness of responsible resource and waste management (Madzime, C., & Sibanda, 2023). Therefore, the application of SDG-oriented science learning not only increases students' scientific knowledge but also shapes their environmental awareness and social responsibility (Sihombing, 2024). The integration of STEM and SDGs in the local context makes science learning more meaningful because students learn through activities that are not only scientific but also oriented towards sustainability.

One concrete form of implementation of this approach is the development of teaching materials in the form of Student Worksheets (LKPD) that serve as guides for scientific

exploration. STEM-based LKPDs provide opportunities for students to learn actively through observation, experimentation, and analysis of experimental results. Various studies show that the use of STEM-based LKPD can improve students' critical thinking, science literacy, and creativity (Patonah, R., Nurjanah, S., & Suryani, 2021). However, most of the LKPD development has not explicitly integrated sustainability issues and the local environmental context. For example, research by (Sari, M., & Nugroho, 2020) found that most STEM LKPD in Indonesia remain generic and focused on cognitive aspects, without connecting to sustainability issues such as waste management or environmental conversation. A similar finding was reported in an international study by (Wang, H. H., Moore, T. J., Roehrig, G. H., & Park, 2019), which showed that STEM LKPD generally lack integration of local contexts and ecological values, so they do not fully foster ecological awareness and sustainability values in students. This condition indicates a research gap that needs to be bridged, namely the development of LKPDs that are not only oriented towards mastery of scientific concepts but also connect science learning with social and environmental responsibility.

To strengthen this argument, a review of recent shows that the develoment of STEM based LKPD has become a focus of international research. For instance, a study by (Kelley, T. R., & Knowles, 2016) found that LKPD integrating STEM with local contexts increases student engagement and understanding of science concepts. Additionally, research by (Wang, H. H., Moore, T. J., Roehrig, G. H., & Park, 2019) emphasizes that STEM based LKPD oriented towards SDGs can shape sustainability competencies, as seen in incresead environmental awareness among students through waste recycling projects. However, in Indonesia, studies such as those by (Sari, M., & Nugroho, 2020) indicate that most STEM LKPS still lack integration of local elements and SDGs, limiting their effectiviness in building science literacy and environmental awareness. Another study by (Johnson, C. C., & Adams, 2018) confirms that LKD combining STEM with local waste utilization not only enthances critical thinking skill but also encourages student participation in global sustainability issues. Thus, the state of the art demonstrates an urgent need for the development of more holistic LKPD.

The main innovation of this research lies in the integration of three important dimensions, namely the STEM approach as a conceptual framework, the use of local waste as a source of contextual learning, and the orientation of SDGs as the basis for learning values. The synergy of these three aspects is expected to create a learning model that is more holistic, applicable, and relevant to the needs of science education today. This approach not only teaches students to understand scientific phenomena, but also trains them to think systematically, innovate, and participate in environmental conservation.

Based on the rationalization and analysis of the research gap, this study focuses on developing STEM-based Student Worksheets (LKPD) utilizing local waste oriented towards SDGs to improve students' science literacy. This study is expected to produce valid, interesting, and effective teaching materials that support contextual and sustainable science learning. In addition to providing practical contributions to teachers and students, the results of this study are also expected to enrich the literature in the field of science education through innovative teaching materials that integrate scientific, environmental, and sustainable development values. Thus, this research not only focuses on the development of learning products but also on strategic efforts to build an educational ecosystem that supports science literacy, environmental

awareness, and the achievement of sustainable development goals. Through a contextualized STEM approach utilizing local waste, it is hoped that students will not only understand scientific concepts theoretically but also be able to apply them to create real solutions to environmental problems in their surroundings.

Method

This study uses a research and development approach with a 4D model (Define, Design, Develop, Disseminate) proposed by (Thiagarajan, S., Semmel, D. S., & Semmel, 1974). This model was chosen because it is effective in producing valid, practical, and effective learning tools in line with 21st-century learning needs. The product developed was a STEM-based Student Worksheet (LKPD) that utilized local waste materials such as tofu pulp, banana peels, and cassava peels, and was oriented towards the Sustainable Development Goals (SDGs). The research was conducted at SMP IT Assa'idiyyah Kudus in the even semester of the 2024/2025 academic year with 34 students in class VII B, consisting of 19 boys and 15 girls, who were selected using purposive sampling because the school is located close to the source of local waste used as the learning context.

The research began with a definition stage to identify needs and problems through observation and interviews with science teachers. The analysis results showed low science literacy among students (with an average score of 56% based on initial tests aligned with PISA indicators; (Schleicher, 2019)) and a lack of contextual teaching materials, as reported by the teacher who stated limitations in access to materials relevant to the local environment, supported by evidence from international assessments such as the Programme for International Student Assessment (PISA) 2022, which reported Indonesia's science literacy score at 398, indicating below average performance compared to global standards (OECD, 2023). Furthermore, previous studies have highlighted deficiencies in contextual science education in Indonesian schools, including limited use of real world applications in teaching materials, such as study by (Kasse, A., & Atmojo, 2022), which confirms limitations in science teaching materials across Indonesian school. Analysis of student characteristics, curriculum, and concepts relevant to environmental pollution, STEM, and SDGs was also conducted at this stage.

The design stage involved compiling student worksheets containing concept maps, teaching materials, simple experiments using local waste, and evaluations based on science literacy indicators (Schleicher, 2019). Specific tools and instruments employed in product development incluced Canva software for designing visual layouts and illustrations, Microsoft Word for content structuring, and reference materials from educational resources to ensure alignment with STEM integration and SDG goals. The student worksheets were designed to integrate elements of science, technology, engineering, and mathematics in solving real-word problems.

The development stage was executed through expert validation of the material and media to assess content, languange, appearance, and integration of STEM and SDG elements. Validation involved three experts for material aspects and three for media aspeccts, ensuring transparency and reproducibility of the methodological framework. The validation results indicated that the LKPD met the criteria of being highly feasible with minor improvements,

which were subsequently implemented. Following this, a limited trial was conducted with the students to evaluate readability and appeal, before being tested o all student in class VII B during the dissemination stage. Field trials were carried out in several science learning sessions with the LKPD as the primary guide for learning activities.

The research design used a one-group pretest–posttest to measure improvements in science literacy before and after the use of LKPD (Sugiyono, 2019). The improvement analysis was performed using the Normalized Gain formula from (Hake, 1999):

$$g = \frac{(\text{Spost} - \text{Spre})}{(Smax - Spre)}$$

with S_{post} as the average posttest score, S_{pre} as the pretest score, and S_{max} as the maximum score. The g value is categorized as high if it is ≥ 0.7, moderate if it is between 0.3 and 0.7, and low if it is ≤ 0.3. Quantitative data was obtained from the validation results conducted by expert validators, while qualitative data was obtained from observations and interviews during the learning process. The validation results to determine the suitability of the product were then converted into percentages using the following formula:

$$g = \frac{\sum X}{N \text{ x } Xmax} \quad \text{(Riduwan, 2015)}$$

Meanwhile, qualitative data were analyzed thematically (Miles, M. B., Huberman, A. M., & Saldaña, 2014) to obtain an in-depth picture of student engagement. The reliability of the instrument was tested using Cronbach's Alpha (Cortina, 1993) with a high reliability criterion of $\alpha > 0.8$.

The entire research process was conducted in accordance with educational research ethics based on the guidelines of the American Educational Research Association. All participants were involved voluntarily, and data confidentiality was maintained. Through this approach, it is hoped that the STEM-based LKPD developed will not only be valid and practical, but also effective in improving science literacy through contextual learning that is relevant to real life and oriented towards sustainable development.

Results and Discussion

This study aims to develop STEM-based Student Worksheets (LKPD) that utilize local waste and are oriented towards sustainable development goals (SDGs), as well as to determine their feasibility and effectiveness in improving students' science literacy. To achieve these objectives, this study follows the 4D model stages, namely Define, Design, Develop, and Disseminate. The research results were assessed based on three aspects: the LKPD development process, product feasibility based on expert validation and user response, and improvements in student science literacy after using the LKPD.

The development of teaching materials that integrate STEM and environmental issues is considered important in responding to the challenges of 21st-century learning (Widana, I. M., Suartama, I. K., & Parmiti, 2020). This is in line with the study by Patonah et al., which found that STEM-based worksheets can improve students' creative thinking skills through active engagement in learning (Patonah, R., Nurjanah, S., & Suryani, 2021). Meanwhile, the integration of STEM and the SDGs shows significant potential in strengthening students'

scientific skills at all levels of education. Yalçın (2024) stated that design-based STEM activities can substantially and sustainably improve 21st-century competencies, such as life and career skills, innovation and learning abilities, and digital literacy, even in preschool children. Through the integration of real-world problems, students can not only build meaningful scientific models but also apply them to analyze environmental, social, and economic issues aligned with the Sustainable Development Goals (SDGs) (Kurniawan et al., 2025)

STEM-Based LKPD Development Process

In the Define stage, researchers conducted a needs analysis through observation, interviews with science teachers, and curriculum review. The results of the analysis showed that science learning in schools was not yet contextual and there was still minimal student involvement in exploratory activities. This is reinforced by statements from the science teacher at SMP IT Assa'idiyyah Kudus, who stated that *"Science learning in our school is still lacking in contextuality, students rarely participate in real world exploration activities such as using local materials, and the lack of teaching materials that connect science concepts with environmental problems makes it difficult for students to understand the relevance of the material"* (Amir, n.d.). Therefore, worksheets were developed that integrate the STEM approach and the use of local waste, such as tofu pulp, banana peels, and cassava peels, which are available in the students' environment. This is reinforced by the findings of Hanifha et al., which emphasize the importance of integrating local contexts into learning to increase environmental awareness and scientific literacy (Hanifha, N., Prasetyo, Z., & Ramli, 2023).

The Design stage focuses on designing LKPDs that are tailored to the characteristics of students and material requirements, involving detailed activities such as brainstorming sessions with the research team to outline content structure, creating initial drafts of concept maps and STEM integrated materials using Microsoft Word for text formatting, designing visual elements and illustrations with Canva software for enhanced appeal, and incorporating practical activities like making steamed cakes from local waste through step by step procedural guides aligned with SDGs. LKPDs are designed to include concept maps, STEM and SDGs-based materials, practical activities, reflections, and evaluations. One of the main activities in LKPDs is making steamed cakes using local waste materials (Figure 1). Based on Figure 1, students learn to make sponge cake from tofu dregs, banana peels, and cassava peels. This activity introduces students to STEM concepts, including weighing ingredients and calculating costs. Scientifically, students understand how to address environmental pollution by processing unused materials into valuable materials, in line with SDGs 12.



Figure 1. Main Activities in LKPDs

Research by Zahro et al. supports that simple experiment-based activities such as this are effective in improving students' conceptual understanding and science literacy (Zahro, F., Hidayati, L., & Kurniasih, 2024). Meanwhile, the Develop stage involves validation by media experts and subject matter experts. After revision, the LKPD is tested on a limited basis and then field tested. This stage aims to determine the feasibility and quality of the LKPD being developed. Arrohman et al (2022) proved that the 6E cycle learning model based on STEM, which was also used in the development of the LKPD, can encourage students to think scientifically and evaluate environmental phenomena systematically. The final stage was limited product dissemination to teachers and students at SMP IT Assa'idiyyah Kudus. This dissemination aimed to introduce and provide direct access to the use of the LKPD as an innovative teaching material integrated with the STEM approach and oriented towards the Sustainable Development Goals (SDGs).

Product Suitability Based on Expert Validation and Student Responses

After the LKPD product is developed, validation is carried out by a material expert validator to determine its feasibility. Aspects assessed in terms of the material of the STEM-based LKPD product include the appropriateness of the content, language, presentation, and context, which includes 14 indicators. In addition, validation is also carried out by a media expert to assess the feasibility of the STEM-based LKPD product in terms of media. Aspects assessed in terms of media include appearance, suitability for learning media, accessibility, and content design. Relevant input is needed to ensure that the media in the STEM-based LKPD product meets educational standards and is in accordance with expected learning needs.

The results of media expert validation of STEM-based LKPD products are displayed in graph form in Figure 1, which visualizes the percentage of assessments from four main aspects, namely appearance, suitability, accessibility, and content design. These assessments were given by three validators who are competent in the field of learning media. The purpose of this graph

visualization is to provide a comprehensive overview of the strengths and weaknesses of the products that have been developed. From the analysis results, it is known that the suitability aspect obtained the highest score with a percentage of 97%, indicating that the material in the LKPD is relevant and appropriate for STEM-based science learning needs. The accessibility aspect also showed excellent results of 93%, indicating that the LKPD is easily accessible and usable by students. Furthermore, the content design aspect scored 76%, indicating that the content structure is quite systematic but still has room for improvement.

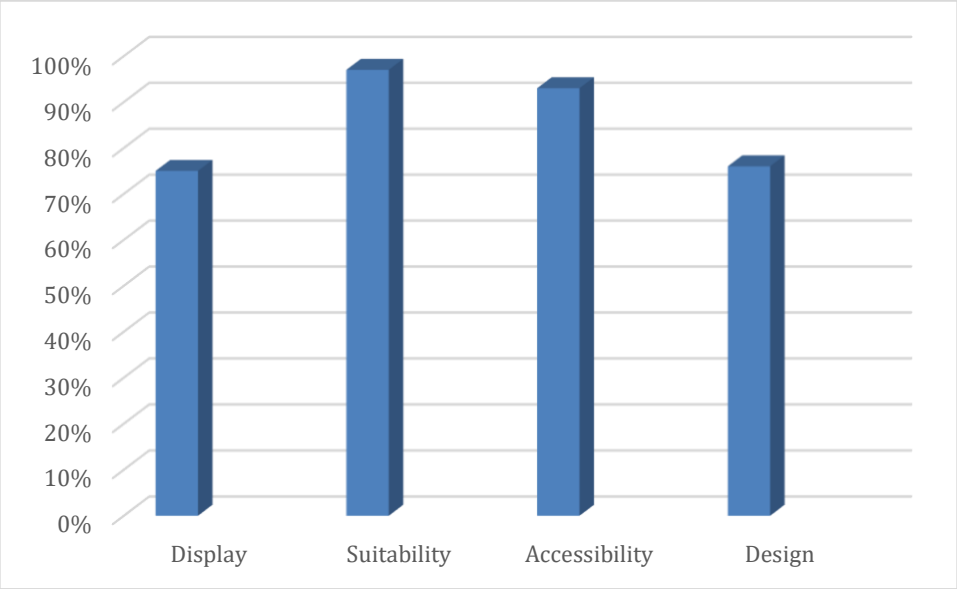


Figure 2. Percentage of Feasibility Scores by Media Experts

Meanwhile, the display aspect received the lowest percentage, namely 75%. Although still in the acceptable category, this score indicates the need for improvements in visual aspects, such as layout, color selection, and overall aesthetics, to make the product more attractive and interactive for students. Overall, this validation chart supports the evaluation results which state that the STEM-based LKPD developed is classified as "highly acceptable" in terms of media suitability. By making improvements to the appearance aspect, this product has the potential to make an optimal contribution to the contextual learning process that promotes science literacy and environmental awareness among students.

The material feasibility of STEM-based LKPD utilizing local waste oriented towards SDGs can be determined through validation results conducted by material experts. This validation was carried out by three validators who are competent in their fields. Each validator filled out an assessment instrument in the form of a validation sheet, which contained a number of statements related to aspects of STEM-based LKPD product development. The material expert validation sheet instrument consists of four main aspects, namely content feasibility, language, presentation, and context, which are detailed into 14 indicator statements. The feasibility data obtained from the material expert validation process can be seen in detail in Table 1.

Table 1. Percentage of Feasibility Scores by Media Experts

No.	Validator	Aspek (%)			
		content suitability	Language	Presentation	Contextual
1	Validator I	95	90	87	87
2	Validator II	80	80	80	80
3	Validator III	80	85	80	80
Average		85	85	82	82
Total average		83,62			
Criteria		Highly suitable			

Based on the data in Table 1, the results of the STEM-based LKPD product feasibility test from the material aspect show that over all the product has met the criteria of "highly feasible" for use in learning. The assessment was carried out by three expert material validators with a primary focus on the content feasibility aspect, namely the extent to which the material presented in the LKPD is in accordance with curriculum standards, scientific concepts, and relevance to the real lives of students. Validator 1 gave a score of 95%, indicating a very high level of content feasibility and suggesting that the material has been very well organized and is relevant. Validators 2 and 3 each gave a score of 80%, which is also classified as highly suitable. On average, the overall suitability of the material reached 85%, reflecting that the content of the LKPD is in line with learning needs, supports the strengthening of science concepts, and is relevant to the STEM approach and SDG goals.

Thus, Table 1 reinforces the evidence that, in terms of content, this STEM-based LKPD has met the eligibility standards, although minor improvements are still recommended to ensure that the material is more optimal in building students' science literacy and critical thinking skills. The validation results show that the LKPD is considered very feasible for use. These findings are in line with the results of research by Suryani et al., which states that STEM-based e-LKPD can increase students' readability and attractiveness, as well as strengthen scientific concept understanding through attractive visualizations and contextual exploratory activities. (Patonah, R., Nurjanah, S., & Suryani, 2021). Student responses also showed that LKPD helped them understand the connection between science and everyday life. This was reinforced by Souza et al., who revealed that students were more interested and found it easier to understand concepts when using STEM-based teaching materials than conventional textbooks. (Souza, N. M. de, Andrade, R. M., & Pereira, 2025).

The Effectiveness of LKPD in Improving Science Literacy

Based on the results of the study, the development of STEM-based LKPDs utilizing local waste oriented towards SDGs has proven to be effective in improving students' science literacy. This effectiveness can be seen from the improvement in student learning outcomes after using LKPDs, especially in understanding the concept of environmental pollution in a contextual and applicable manner. Students showed high enthusiasm, active involvement in learning, and the ability to explain scientific phenomena better.

The results obtained from student responses reinforce these findings, with an average score of 94%, which falls into the “very good” category. Detailed response indicators include: content suitability (95% positive, indicating alignment with curriculum and ease of understanding), visual appeal (96% positive, reflecting attractive illustrations and layout), languange clarity (93% positive, showing simple and accessible wording), and overall usability (94% positive, demonstrating effectiveness in facilitating learning activities). The LKPD is considered to help students understand the material, improve readability, and facilitate creativity and innovation. In terms of science literacy competency, students were able to identify scientific problems and explain scientific phenomena based on their daily experiences, although their ability to use scientific evidence still needed to be strengthened. Overall, this LKPD product has proven to be effective in improving science literacy because it combines the STEM approach, SDGs content, and local contexts that are close to the lives of students. In addition, the attractive visual appearance, systematic material structure, and the inclusion of literacy questions and self-evaluation make this LKPD a learning medium that can develop critical, reflective, and scientific thinking skills in junior high school/MTs students.

This is consistent with the results of research by Rahmawati and Widodo, which shows that project-based LKPD development can significantly improve students' science literacy through active involvement in scientific observation and investigation (Rahmawati, & Widodo, 2020). Students experienced difficulties in the aspect of using scientific evidence, and this indicates the need for learning based on thinking systems. Shofatun et al., in their research, underlined the importance of STEM learning designs that emphasize system thinking so that students are able to integrate scientific information logically and critically (Shofatun, A., Muslimin, & Putri, 2024). This statement is in line with the challenges found in this study, namely the weak ability of students to interpret and use data as a basis for scientific decision making. Therefore, to improve the effectiveness of LKPD in building comprehensive science literacy, further development can be directed at strengthening system thinking through activities that require evidence analysis, information synthesis, and scientific reflection in each step of learning.

Conclusion

This study produced a STEM-based Student Worksheet (LKPD) utilizing local waste oriented to the Sustainable Development Goals (SDGs) which was proven to be valid, practical, and effective in improving students' scientific literacy on environmental pollution material. The validation results of material experts and media experts were declared very feasible, from student responses obtained results with very feasible criteria while from the results of the N-Gain analysis obtained very high criteria as evidenced by an increase in students' scientific literacy abilities. This shows that the LKPD is suitable for use in science education. The novelty of this study lies in the integration of three main components of the STEM approach, utilization of local waste, and SDGs orientation, which makes science learning more contextual, applicable, and relevant to global sustainability issues. The developed LKPD not only improves conceptual understanding but also fosters ecological awareness and social responsibility among students. Based on the results of this study, it is recommended that science teachers implement STEM-SDGs-based LKPD as an alternative contextual teaching material in the Independent

Curriculum, and for future researchers to develop similar models in other fields and levels of education by expanding the digitalization aspect or integration of interactive learning technology.

Credit Authorship Contribution Statement

Nurul Istiani: conceptualization, methodology, data collection, formal analysis, and writing - review - editing. **Hanik Malichatin**: conceptualization, writing - review - editing, formal analysis, supervision.

References

Arrohman, D. A., Wahyuni, A. L. E., Wilujeng, I., & S. (2022). Implementasi penggunaan LKPD pencemaran air berbasis STEM dan model learning cycle 6E terhadap kemampuan literasi sains. *Jurnal Pendidikan Sains Indonesia*, *10*(2), 279–293. https://doi.org/https://doi.org/10.24815/jpsi.v10i2.23584

Bybee, R. W. (2014). The case for STEM education: Challenges and opportunities. *Science Education*, *98*(4), 549–580. https://doi.org/https://doi.org/10.1002/sce.21115

Cortina, J. M. (1993). What is coefficient alpha? An examination of theory and applications. *Journal of Applied Psychology*, *78*(1), 98–104. https://doi.org/https://doi.org/10.1037/0021-9010.78.1.98

Fives, H., Huebner, W., Birnbaum, A. S., & Nicolich, M. (2014). Developing a measure of scientific literacy for middle school students. *Science Education*, *98*(4), 549–580. https://doi.org/https://doi.org/10.1002/sce.21115

Hake, R. R. (1999). Analyzing change/gain scores. *American Educational Research Association Division D, Measurement and Research Methodology*.

Hanifha, N., Prasetyo, Z., & Ramli, M. (2023). Efektivitas modul IPA berbasis STEM dan ESD terhadap literasi sains dan kesadaran lingkungan siswa SMP. *Jurnal Pendidikan IPA Indonesia*, *12*(1), 45–54. https://doi.org/https://doi.org/10.15294/jpii.v12i1.63711

Johnson, C. C., & Adams, J. D. (2018). STEM education in the United States: A review of the literature. *Journal of Research in Science Teaching*, *55*(6), 742–762. https://doi.org/https://doi.org/10.1002/tea.21459

Karpudewan, M. (2021). Using local environmental issues in enhancing primary school students' scientific literacy and environmental citizenship. *International Journal of Science Education*, *43*(3), 350–370. https://doi.org/https://doi.org/10.1080/09500693.2020.1865583

Kasse, A., & Atmojo, I. (2022). Integrasi STEM dalam Pembelajaran IPA: Tantangan dan Peluang di Sekolah Menengah. *Prosiding Seminar Nasional Pendidikan IPA*, *5*(1), 45–58.

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *Nternational Journal of STEM Education*, *3*(1), 11. https://doi.org/https://doi.org/10.1186/s40594-016-0046-z

Kim, H., Jiyoon, P., & Lee, H. (2021). Designing problem-based STEM activity using community issues to enhance elementary students' scientific practices. *Journal of Research in Science Teaching*, *58*(2), 283–308. https://doi.org/https://doi.org/10.1002/tea.21649

Kurniawan, H. E., Saputro, S., Suranto, & Ramli, M. (2025). The Effects of Integrating STEM Design Thinking Into Education for Sustainable Development on Students' Scientific Modeling Skills. *Journal of Balitic Science Education*, *24*(5). https://doi.org/https://doi.org/10.33225/jbse/25.24.935

Madzime, C., & Sibanda, M. (2023). Exploring SDG 12 through science education in rural schools. *African Journal of Science, Technology, Innovation and Development*, *15*(2), 197–205. https://doi.org/https://doi.org/10.1080/20421338.2022.2116587

Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: A systematic literature review. *International Journal of STEM Education*, *6*(2). https://doi.org/https://doi.org/10.1186/s40594-018-0151-2

Miles, M. B., Huberman, A. M., & Saldaña, J. (2014). *Qualitative Data Analysis: A Methods Sourcebook* (3rd ed.). CA: SAGE Publications.

Nugraha, A., Sari, M., & Hidayat, T. (2022). STEM-based learning using local waste materials to promote students' creative thinking and ecological awareness. *Jurnal Pendidikan IPA Indonesia*, *11*(3), 400–408. https://doi.org/https://doi.org/10.15294/jpii.v11i3.57701

OECD. (2023). PISA 2022 Results (Volume I): The State of Learning and Equity in Education. In *OECD Publishing*.

Patonah, R., Nurjanah, S., & Suryani, H. (2021). Pengaruh LKPD berbasis STEM terhadap kemampuan berpikir kreatif siswa SMP. *Jurnal Pendidikan Dan Pembelajaran Sains*, *2*(2), 93–99. https://doi.org/https://doi.org/10.31227/osf.io/gnm62

Rahmawati, & Widodo, W. (2020). Pengembangan LKPD berbasis proyek dalam meningkatkan literasi sains siswa SMP. *Jurnal Pendidikan IPA*, *5*(3), 154–162. https://doi.org/https://doi.org/10.36709/jip.v5i3.19832

Riduwan. (2015). *Dasar-dasar statistika*. Alfabeta.

Sari, M., & Nugroho, A. (2020). Challenges in implementing STEM education in Indonesian schools. *Jurnal Pendidikan Sains Indonesia*, *8*(1), 45–56. https://doi.org/https://doi.org/10.21009/jpsi.v8i1.12345

Schleicher, A. (2019). PISA 2018: Insights and Interpretations. *OECD Publishing*.

Shofatun, A., Muslimin, & Putri, D. L. (2024). STEM learning design to train students' system thinking skills in science literacy. *Journal of Physics: Conference Serie*, *2713*(1). https://doi.org/https://doi.org/10.1088/1742-6596/2713/1/012007

Sihombing, B. (2024). *Model Pengembangan 4D (Define , Design , Develop , dan Disseminate) dalam Pembelajaran Pendidikan Islam*. *4*, 11–19.

Souza, N. M. de, Andrade, R. M., & Pereira, J. T. (2025). Students' perceptions of conventional textbooks vs. STEM-based learning resources. *International Journal of Science Education*, *47*(3), 123–136. https://doi.org/https://doi.org/10.1080/09500693.2025.1132761

Sugiyono. (2019). *Metode Penelitian Kualitatif, Kuantitatif, dan R&D*. Alfabeta.

Thiagarajan, S., Semmel, D. S., & Semmel, M. I. (1974). *Instructional development for training teachers of exceptional children: A sourcebook*. Indiana Univeristy.

Wang, H. H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2019). STEM integration: Teacher perceptions and practice. *Ournal of Science Education and Technology*, *28*(5), 573–585. https://doi.org/https://doi.org/10.1007/s10956-019-09778-8

Widana, I. M., Suartama, I. K., & Parmiti, D. A. M. (2020). Literasi sains dan keterampilan abad 21 dalam pembelajaran IPA berbasis proyek. *Jurnal Pendidikan Indonesia*, *9*(1), 1–12. https://doi.org/https://doi.org/10.23887/jpi-undiksha.v9i1.23455

Yalçın, V. (2024). Design-oriented thinking in STEM education: Exploring the impact on preschool children's twenty-first-century skills. *Science and Education*, *33*(4), 901–922. https://doi.org/https://doi.org/10.1007/s11191-022-00410-7

Yore, L., D. (2012). Science literacy for all: More than a slogan, ideology or rally flag! *Journal of Science Education and Technology*, *21*(4), 566–574. https://doi.org/https://doi.org/10.1007/s10956-012-9377-8

Zahro, F., Hidayati, L., & Kurniasih, E. (2024). Pengaruh model POGIL pada materi

pemanasan global terhadap kemampuan literasi sains. *Biochephy: Journal of Science Education*, *1*(1), 1–8. https://doi.org/https://doi.org/10.35719/biochephy.v1i1.101