Kasuari: Physics Education Journal 7(2) (2024) 431-445
P-ISSN: 2615-2681
E-ISSN: 2615-2673

Kasuari: Physics Education Journal (KPEJ)
Universitas Papua
Web: http://jurnal.unipa.ac.id/index.php/kpej

Transformation of Sustainability Science Education: PISA 2025 Science Framework and ESD on E-Worksheets Science in the Context of the Role of Peatland in Global Warming Phenomenon

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Abstract: *Global warming remains a critical global challenge that affects multiple dimensions of life and demands immediate, coordinated action. Peatlands, which have a dual capacity to either mitigate or exacerbate global warming, are increasingly subject to degradation. Addressing this issue requires a transformative approach to science education, emphasizing sustainability. This transformation can be achieved through the development of e-worksheets that integrate the PISA 2025 Science Framework and Education for Sustainable Development (ESD). This study aims to design e-worksheets for science education that incorporate these frameworks, with a focus on elucidating the role of peatlands in the global warming phenomenon. The research adopts a development research methodology based on the Rowntree model, involving 12 tenth-grade students from a state high school in South Sumatra during the 2023/2024 academic year as participants in the product evaluation phase. The evaluation method is driven by Tessmer's formative evaluation paradigm, which includes self-evaluation, expert review, one-to-one evaluation, and small group evaluation. Interviews, walkthroughs, and questionnaires are among the data collection methods used. The analysis results show that the expert review phase produced an average validation score of 94.2%, which is classified as extremely valid. Furthermore, the one-to-one and small group evaluation stages yielded average practicality values of 86.25% and 97.5%, respectively, classifying them as extremely practical. These findings suggest that the produced e-worksheets, which are geared toward the PISA 2025 Science Framework and ESD, are both valid and practicable for classroom use, particularly in terms of improving students' understanding of the essential role of peatlands in the global warming catastrophe.*

Keywords: *ESD, global warming, peatlands, PISA 2025 science framework, science education*

Transformasi Pendidikan IPA Berkelanjutan: Orientasi *Framework* Sains PISA 2025 dan ESD pada E-LKPD IPA dalam Konteks Peran Lahan Gambut dalam Fenomena Pemanasan Global

Abstrak: Pemanasan global saat ini merupakan isu utama yang memengaruhi berbagai aspek kehidupan dan menjadi perhatian serius di seluruh dunia. Lahan gambut, yang memiliki potensi memberikan dampak positif maupun negatif terhadap pemanasan global, semakin mengalami kerusakan. Oleh karena itu, diperlukan transformasi pendidikan IPA yang berkelanjutan, salah satunya melalui pengembangan E-LKPD yang berfokus pada kerangka sains PISA 2025 dan prinsip Pendidikan untuk Pembangunan Berkelanjutan (ESD). Penelitian ini bertujuan untuk mengembangkan E-LKPD mata pelajaran IPA yang berorientasi pada kerangka sains PISA 2025 dan ESD, dengan mengintegrasikan peran lahan gambut dalam fenomena pemanasan global yang nyata. Penelitian ini mengadopsi metodologi penelitian pengembangan berdasarkan model Rowntree, yang melibatkan 12 siswa kelas sepuluh dari sebuah sekolah menengah atas negeri di Sumatera Selatan pada tahun ajaran 2023/2024 sebagai partisipan dalam tahap evaluasi produk. Metode evaluasi ini didorong oleh paradigma evaluasi formatif Tessmer, yang meliputi evaluasi diri, tinjauan ahli, evaluasi satu lawan satu, dan evaluasi kelompok kecil. Wawancara, peninjauan, dan kuesioner adalah beberapa metode pengumpulan data yang digunakan. Hasil analisis menunjukkan

bahwa tahap tinjauan ahli menghasilkan skor validasi rata-rata 94,2%, yang diklasifikasikan sebagai sangat valid. Selanjutnya, tahap evaluasi satu lawan satu dan kelompok kecil menghasilkan nilai rata-rata kepraktisan masing-masing 86,25% dan 97,5%, yang diklasifikasikan sebagai sangat praktis. Temuan ini menunjukkan bahwa E-LKPD yang dihasilkan, yang disesuaikan dengan Kerangka Kerja Sains PISA 2025 dan ESD, valid dan praktis untuk digunakan di kelas, terutama dalam hal meningkatkan pemahaman siswa tentang peran penting lahan gambut dalam bencana pemanasan global.

Kata kunci: ESD, *framework* sains PISA 2025, lahan gambut, pemanasan global, pendidikan IPA

INTRODUCTION

Global warming is one of the most pressing issues facing the world today (Pickle & Dincer, 2020; Santos & Bakhshoodeh, 2021). If not addressed, global temperatures are expected to rise by 1.4°C to 5.8°C by 2100 relative to 1990 levels (Kumar et al., 2023; Miloud, 2024). Greenhouse gas emissions are a major contributor to global warming (Lamb et al., 2022; Nong et al., 2021). Conservation and sustainable management of peatland ecosystems is a promising technique for reducing these emissions. Peatlands have a unique ability to sequester and store up to 550 gigatons of carbon (GtC), accounting for roughly 30% of the world's terrestrial carbon stock (Lippmann et al., 2022; Ulya et al., 2022).. However, these habitats are increasingly threatened, notably by forest fires (Goldstein et al., 2020; Harrison et al., 2020).

Indonesia experienced a devastating forest fire event between January and October 2023, during which approximately 109,000 hectares of forest and peatland in South Sumatra Province were destroyed. The degradation and loss of peatlands result in substantial carbon emissions, thereby intensifying the global warming phenomenon (Mishra et al., 2021; Ribeiro et al., 2021). This situation emphasizes the urgent need for educational techniques that raise students' awareness and understanding of the crucial role peatland conservation plays in preventing global warming and addressing relevant scientific ideas. Such efforts align with findings by Tibola et al., (2020) who emphasize the importance of fostering environmental sensitivity in students through consistent and ongoing education, aiming to preserve ecosystems that are vital for disaster mitigation. A promising approach to achieving this goal is integrating the PISA Science Framework 2025 and Education for Sustainable Development (ESD). These frameworks are designed to equip students with the competencies needed to comprehend and address global environmental challenges, including global warming and ecosystem preservation.

The PISA Science Framework highlights the significance of applying scientific literacy to everyday life, focusing on students' ability to solve problems and make informed, sustainable decisions (Deta et al., 2023). Previous research by Hardinata et al., (2018), demonstrated the effectiveness of implementing the PISA 2015 framework in junior high school science education through lesson study, which significantly enhanced students' scientific literacy. The latest iteration, the PISA Science Framework 2025, aligns closely with ESD objectives, advocating for the integration of sustainable development principles into educational curricula (Deta et al., 2024). This synergy underscores the potential for educational innovation to empower students in addressing global environmental issues and fostering sustainable practices.

The integration of effective educational approaches in learning requires the support of various components, one of which is the availability of appropriate learning tools, such as student worksheets (Muskita et al., 2020; Yurtyapan & Kandemir, 2021). Beyond traditional print formats, these worksheets have evolved into digital versions known as e-worksheets (Hanum & Amini, 2023; Hasibuan et al., 2024). The utilization of e-worksheets in the learning process has proven to enhance the appeal of subjects often

perceived as challenging, such as science, thereby addressing classroom challenges and fostering greater student engagement (Toli & Kallery, 2021; Utami et al., 2020). Research conducted by The Tithing & Men's (2022) further substantiates this, demonstrating that the application of e-worksheets in science education significantly boosts students' interest in learning. These findings highlight the critical need for incorporating e-worksheets into science instruction to optimize learning outcomes. Additionally, prior studies, such as those by Nurhasanah et al., (2022), successfully developed ESD-based e-worksheets for science education, exemplified by their water purification e-worksheets incorporating a virtual field trip simulation accessible via TopWorksheets. This evidence underscores the potential of e-worksheets to transform science learning into a more interactive and meaningful experience, particularly when aligned with sustainable education principles.

Although the development of ESD-based or ESD-oriented e-worksheets has been explored by various researchers, field observations indicate that the application of e-worksheets adhering to sustainability principles remains extremely limited, particularly in the context of integrating the role of peatlands in mitigating global warming into classroom learning. Insights from an interview with a science teacher at a high school in South Sumatra revealed that science instruction has yet to fully incorporate ESD-oriented learning or align with the PISA 2025 Science Framework. Furthermore, the use of e-worksheets specifically designed based on the PISA 2025 Science Framework and ESD principles has not been implemented in the classroom. The e-worksheets currently utilized in science education are predominantly STEM-oriented, without addressing critical topics such as the extensive peatland ecosystems of South Sumatra and their dual role in the global warming phenomenon. This gap in instructional materials has resulted in many students lacking awareness of the mechanisms through which peatlands contribute to global warming and their potential positive and negative impacts. This underscores a pressing need for the development and integration of ESD-based e-worksheets that focus on these essential themes, thereby enhancing students' understanding of sustainability and the interconnectedness of environmental systems.

Interviews conducted with several students reveal that the majority still lack understanding of the role of peatlands in global warming. Consistent with the teacher's feedback during the interviews, students also indicated that the science learning implemented in the classroom has not yet integrated ESD-oriented approaches or aligned with the PISA 2025 Science Framework. Furthermore, the learning tools, particularly e-worksheets, currently utilized in science classes are generic and do not adhere to these advanced educational paradigms. Students noted that the e-worksheets used in their learning are visually unappealing and tend to be monotonous, leading to disengagement and a lack of enthusiasm for studying science in class. These findings emphasize the need for the development of innovative e-worksheets that incorporate principles of ESD and the PISA 2025 Science Framework. Such materials would enhance the learning experience by fostering deeper student engagement and promoting a more comprehensive understanding of sustainability and global environmental issues.

Based on the background presented, previous studies, and field observations, it becomes evident that developing student worksheets oriented towards the PISA 2025 Science Framework and ESD is crucial for integration into science learning. However, a review of the existing literature indicates a lack of research on e-worksheets that holistically integrate both the PISA 2025 Science Framework and ESD principles into a unified product, particularly within the context of peatlands' role in global warming. In response to this gap, this study aims to develop a science e-worksheet designed to align

with the PISA 2025 Science Framework and ESD, focusing specifically on the role of peatlands in addressing global warming. The resulting e-worksheet is expected to meet criteria for validity and practicality, providing students with relevant scientific knowledge while empowering them to act as proactive agents in environmental conservation. This research contributes not only to the theoretical advancement of science education but also offers practical tools to tackle critical environmental challenges. The development of such an e-worksheet represents a step forward in transforming science education into a sustainable model, addressing the growing demand for curricula that are both responsive and relevant to contemporary global challenges.

METHOD

This study followed a Development Research methodology, with the Rowntree development model serving as its framework. The model comprises three main phases: planning, development, and evaluation. Tessmer's formative assessment methodology was used to carry out the evaluation phase.

Research Subject and Object

The subjects in this study are 12 students in class X of South Sumatra State High School for the 2023/2024 school year who play a role in the product development evaluation stage. The object of this study is science e-worksheets which is oriented to framework PISA 2025 science and ESD in the context of the role of peatlands in the global warming phenomenon.

Research Procedure

The development research by Rowntree used in this study was carried out in three stages, including: planning, development, and evaluation. A clearer description of the e-worksheets development procedure carried out in this study is described in the following Figure 1.

Data Collection Techniques

Questionnaires, walkthroughs, and interview approaches were used in the data collection process. In order to comprehend field settings that highlight the significance of developing e-worksheets, an interview technique was used during the needs analysis stage with one science teacher and five students. Walkthrough Using validation sheets as a data collecting method, it is used to validate and evaluate goods created by specialists. Tables 1, 2, and 3 show the grid of validation tools for e-worksheets that follow Depdiknas (2008) guidelines.

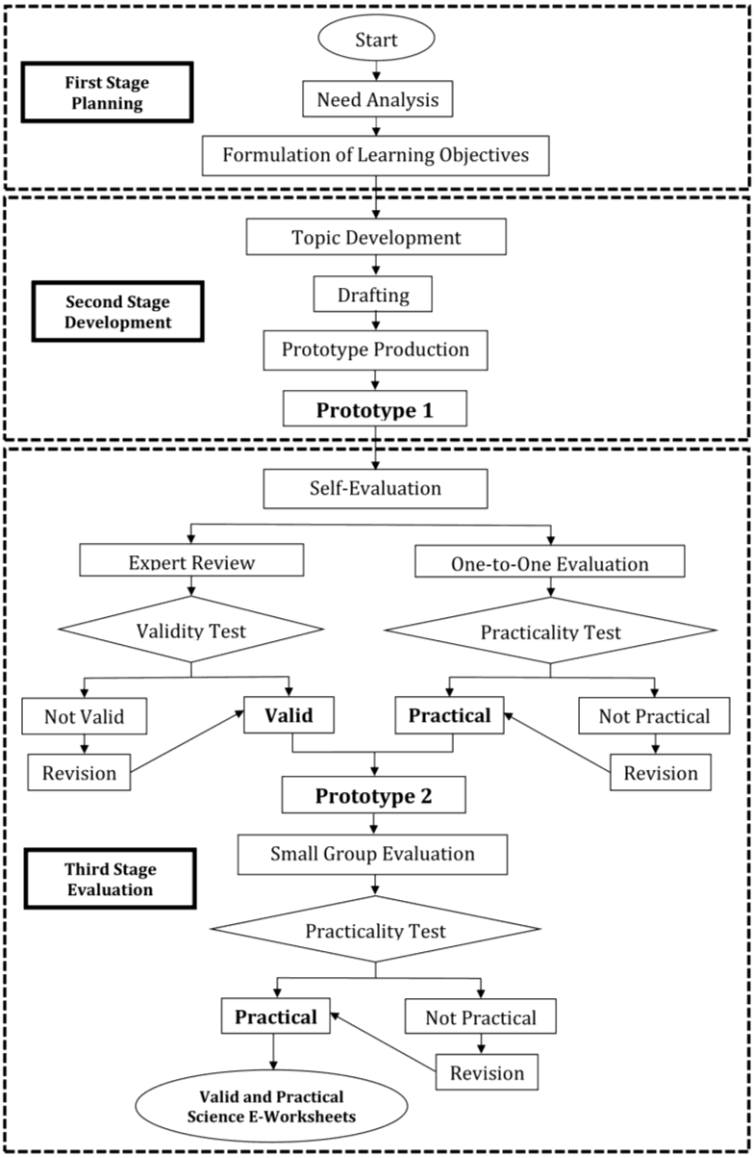

Figure 1. E-Worksheets Development Procedure

Table 1. Content Validation Instrument Grid

No	Aspects	Indicators	Number of Statements	Statement Number
1	Use of Language	Quality of language use	2	1,2
		Quality of sentence structure	3	3,4,5
2	Content of Materials and Questions	Relevance of materials and questions to learning outcomes	2	6,7
		Relevance of material and questions to indicators	2	8,9
		Relevance of materials and questions to learning objectives	2	10,11
		Relevance of materials and	2	12,13

No	Aspects	Indicators	Number of Statements	Statement Number
		questions to aspects of the PISA 2025 science framework		
		Relevance of materials and questions to ESD aspects	2	14,15
3	Presentation of Materials and Questions	Display of materials and questions	2	16,17

Table 2. Media Validation Instrument Grid

No	Aspects	Indicators	Number of Statements	Statement Number
1	Media Design	Quality of the media displayed	2	1,2
		The quality of the displayed text	2	3,4
		Display of e-worksheets teaching materials	5	5,6,7,8,9
		Layout	1	10
2	Use of Language	Quality of language use	2	11,12
3	Ease of Use	Ease of use of e-worksheets teaching materials	3	13,14,15

Table 3. Practitioner Response Validation Instrument Grid

No	Aspects	Indicators	Number of Statements	Statement Number
1	Use of Language	Quality of language use	3	1,2,3
		Quality of sentence structure	2	4,5
2	Contents of Question Material	Relevance of the question material	3	6,7,8
3	Media Design	Quality of the media displayed	2	9,10
		The quality of the displayed text	2	11,12
		Display of e-worksheets teaching materials	4	13,14,15,16
		Layout	1	17
4	Presentation of Materials and Questions	Display of materials and questions	1	18
5	Ease of Use	Ease of use of teaching materials	2	19,20

The questionnaire method was used to analyze students' attitudes toward the practicality of using e-worksheets, particularly throughout the one-to-one and small group evaluation stages. The data received from this questionnaire will be used to refine the e-worksheet prototype. The questionnaire had many statements, a rating scale, and a place for suggestions. The researchers followed the instructions supplied by the Ministry

of National Education Depdiknas (2008) while designing the student response questionnaire, which are shown in the Table 4.

Table 4. Student Response Questionnaire Instrument Grid

No	Indicators	Number of Statements	Statement Number
1	Display of teaching materials	4	1,2,3,4
2	Language use	1	5
3	Ease of use	2	6,7
4	Content of material and questions	3	8,9,10

Data Analysis Techniques

The data analysis methods employed in this study encompass walkthrough data analysis and the analysis of questionnaire responses. The results from the walkthrough data analysis, collected from the validators, will be examined thoroughly and descriptively to inform revisions to the product prototype. The validation sheet provided to the validators is structured using a Likert scale with five response categories, the details of which are presented in Table 5.

Table 5. Validation Value Category

Categories Answer	Statement Score
Excellent	5
Good	4
Enough	3
Bad	2
Very Not Good	1

(Sugiyono, 2021)

The validation results of the validators will be explained in the form of a table. Then the average of the statement score is found by finding the percentage of achievement of the instrument as a whole with the following Formula (1).

$$Percentage = \frac{\text{The sum of the scores for each indicator}}{\text{The sum of all indicators for each item}} \times 100\% \quad (1)$$

The overall percentage that has been generated from the validator is then adjusted to several categories of expert validation results seen in Table 6 below.

Table 6. Expert Validation Result Category

Percentage (%)	Validity Category
$86 \leq EVR \leq 100$	Highly Valid
$70 \leq EVR < 86$	Valid
$56 \leq EVR < 70$	Less Valid
$0 < EVR < 56$	Invalid

(Wiyono, 2015)

The questionnaire responses collected during the one-to-one and small group evaluation stages, using a Likert scale, are intended to assess the usability of the e-

worksheets being built. The information gathered from these questionnaires is then organized into a table and expressed as percentages. The resulting % values are divided into several degrees of product practicality based on student replies, as shown in Table 7.

Table 7. Product Practicality Result Categories

Percentage (%)	Categories Practicality
$86 \leq PPR \leq 100$	Very Practical
$70 \leq PPR < 86$	Practical
$56 \leq PPR < 70$	Less Practical
$0 < PPR < 56$	Impractical

(Wiyono, 2015)

RESULT

The results of the research on the development of e-worksheets for science subjects oriented to the PISA 2025 science framework and ESD in the context of the role of peatlands in the global warming phenomenon were obtained in three stages, which can be explained as follows.

Results of Planning Stage

The planning stage of this development research goes through various processes that start with a needs analysis. Based on the results of the needs analysis conducted with interviews with several students, it was found that many students did not understand the important role of peatlands in mitigating global warming, especially their ability to absorb carbon. In addition, science learning in the classroom has not implemented a continuing education-oriented approach and the PISA 2025 Science Framework. The use of learning tools such as e-worksheets in science learning is also still very common and has not been oriented to the aspects of the PISA 2025 Science Framework and ESD. Students revealed that the e-worksheets used had a less attractive and monotonous appearance, causing boredom in science learning. To overcome this problem, it is necessary to develop teaching materials in the form of e-worksheets that are oriented to the PISA 2025 Science Framework and ESD in the context of the role of peatlands in global warming. After the needs analysis, the next step is to formulate learning objectives by analyzing the science syllabus for class X of high school, aspects of the PISA 2025 Science Framework, and ESD aspects. Learning objectives are developed from the learning outcomes in the Independent Curriculum that are in accordance with these two aspects. Based on this analysis, the learning objectives on the subject of global warming in peatland ecosystems were obtained.

Results of Development Stage

The development phase of this study consists of several essential processes, including topic conception, drafting, and the fabrication of a product prototype. The e-worksheets' topics were chosen to correspond to the Science Class X Independent Curriculum syllabus. Following the selection of relevant topics, an Outline of Teaching Materials was developed to serve as a framework for drafting the e-worksheets. During the prototyping stage, the e-worksheets prototype was constructed alongside the preparation of various evaluation instruments. These tools were designed to assess the validity of the content, the validity of the media, and the practicality of the e-worksheets being developed. The final step in this phase involved producing prototype 1, which will

undergo further testing in subsequent stages, along with the development of a validation sheet to evaluate the outcomes of the prototype in the next phase.

Figure 2. E-worksheets display oriented to the Science Framework 2025 and ESD

Results of Evaluation Stage

The evaluation phase of this study employs a formative evaluation approach using the Tessmer evaluation model, designed to assess both the validity and practicality of the developed e-worksheets, specifically Prototype 1.

Self-Evaluation

Prior to validation by the expert, Prototype 1 undergoes a self-evaluation phase. During this phase, the researcher conducts an internal review of the prototype, examining the content and media within the e-worksheet to ensure the accuracy and correctness of the developed material. Following this self-assessment, Prototype 1 and the evaluation tools created in the previous phase are reviewed by a supervisor, who provides feedback and recommendations for improvement. The prototype is then revised based on the provided feedback and re-submitted for further consultation. Once Prototype 1 and the evaluation tools are deemed satisfactory and approved by the supervisor, the next phase, the expert review, is initiated.

Expert Review

The expert review phase involves engaging experts as validators to assess the e-worksheets (prototype 1) developed by the researcher. This phase aims to evaluate the validity of the e-worksheets, focusing on the accuracy of the content/material and media. The feedback and recommendations provided by the validators on the validation sheet serve as the foundation for revising Prototype 1. The results of the expert validation are presented in Table 8.

Table 8. Results of Validation Assessment by Validators

Validator	Assessed Aspects	Average Score	Percentage (%)	Comments and Suggestions
Validator 1 (Content/ Material Aspect)	Use of Language	5	100	It would be better if there was a real picture in the experimental activities and in the evaluation section it was shown on which questions were in accordance with the aspects of the PISA 2025 framework.
	Content of Materials and Questions	4,7	94	
	Presentation of Materials and Questions	4,5	91,8	
Average Validation of Content/Material Aspects		**4,73**	**94,6**	
Validator 2 (Media Aspect)	Media Design	4,6	92	The e-worksheets that was made was very good. However, the background and writing have the same color, causing difficulties to read.
	Use of Language	4,5	90	
	Ease of Work	4,33	86	
Average Media Aspect Validation		**4,47**	**89,33**	
Validator 3 (Practitioner)	Use of Language	5	100	The e-worksheets presented is quite good and very easy to understand. The material is quite perfect and easy to learn. However, it is recommended that the font color is made not similar to the background color.
	Contents of Question Material	5	100	
	Media Design	4,67	93,4	
	Presentation of Materials and Questions	5	100	
	Ease of Use	5	100	
Average Practitioner Validation		**4,93**	**98,68**	
Average Total Validation		**4,71**	**94,2**	

Based on table 8, prototype 1 still needs to be improved as per the comments and suggestions from the validators. From the assessment conducted by the validator, the average percentage of the total assessment was 94.2%. Based on Table 6, this percentage shows that prototype 1 falls into the category of highly valid validity.

One-to-One Evaluation

The one-to-one evaluation stage was conducted to assess the practicality of Prototype 1 by ensuring that students could easily understand the content of the e-worksheets and provide constructive feedback for further improvement. This stage involved testing the e-worksheets prototype on three students from class X at South Sumatra State High School

who had previously studied science subjects. The students were selected based on their academic performance, representing high, moderate, and low academic abilities. During the evaluation, the students were given the opportunity to engage with the e-worksheets prototype, from completing learning activities to answering evaluation questions. At the end of the session, they were asked to complete a questionnaire to provide feedback on their experience with Prototype 1. The results of the student responses to the questionnaire are presented in Table 9.

Table 9. Results of the One-to-One Evaluation Stage

Indicator	Average Score	Percentage (%)
Display of teaching materials	4,58	91,57
Language use	4,00	80
Ease of use	4,33	86,67
Content of material and questions	4,33	86,67
Overall Average	**4,31**	**86,25**

According to Table 9, the overall assessment of the student response questionnaire has an average percentage of 86.25%. According to the criteria in Table 7, prototype 1 of the created science e-worksheets is considered very practical. In addition to delivering a practical assessment of prototype 1, students are expected to make comments and ideas. Furthermore, prototype 1 was updated based on the validators' evaluations and student replies. Prototype 1 will be revised to prototype 2 before being evaluated again during the small group evaluation.

Small Group Evaluation

In this evaluation stage, Prototype 2 will be tested on nine students from class X at South Sumatra State High School, grouped into three categories based on their academic abilities. Each group will review and discuss the content of Prototype 2, as well as engage in the learning and evaluation activities included in the product. Following the activities, students will complete a questionnaire to provide feedback on their experience with Prototype 2. The results of the student responses to the questionnaire at this stage are presented in Table 10.

Table 10. Small Group Evaluation Stage Assessment Results

Indicator	Average Score	Percentage (%)
Display of teaching materials	4,78	95,56
Language use	5,00	100
Ease of use	4,83	96,67
Content of material and questions	4,89	97,78
Overall Average	**4,88**	**97,5**

Referring to Table 10, the average percentage of the overall evaluation of the student response questionnaire for the e-worksheets prototype 2 reached 97.5%. According to the practicality criteria outlined in Table 7, prototype 2 can be categorized as highly practical. Moreover, students provided feedback and suggestions for further refinement, leading to the development of the finalized version of the e-worksheets. Based on these findings, it can be concluded that the science e-worksheets, designed in alignment with the PISA 2025 science framework and ESD within the context of the role of peatlands in

the global warming phenomenon, have been validated as both valid and practical for classroom implementation. The e-worksheets can be accessed via the following link: https://bit.ly/ELKPDIPAFrameworkSainsdanESD.

DISCUSSION

Based on data analysis and development research findings, the researcher's e-worksheets product has been validated as both valid and practical. The average score from the student response questionnaire at the one-to-one evaluation stage was 86.25%, and at the small group evaluation stage, it increased to 97.5%, indicating an 11.25% improvement in the product's usability. These results align with previous studies, such as the research by Nurmasita et al. (2023) in their study "Development of e-worksheets Based on Problem Based Learning (PBL) on Redox Reaction Material " which also demonstrated an increase in practicality, with a 2.2% improvement from the one-to-one evaluation to the small group evaluation. Similarly, research by Riani et al., (2021) in "Development of Edmodo-Assisted Guided Inquiry-Based LKS to Improve the Understanding of Physics Concepts of Class X Science Students" showed a 1% increase in practicality from the one-to-one evaluation to the small group evaluation.

E-worksheets, which has become the final product, certainly has advantages and disadvantages (Febriansyah et al., 2021). The advantage of science e-worksheets that has been developed in this study compared to previous relevant research is that this study combines aspects of Framework PISA Science 2025 and ESD aspects in the development of science e-worksheets, which ensures that the products developed not only improve students' science literacy according to international standards, but also equip them with the knowledge and skills to contribute to sustainable development. In contrast, many previous studies have tended to focus on only one of these aspects, be it improving science literacy or environmental education, without integrating the two holistically. In addition, this research focuses on the specific context of peatland ecosystems and global warming, which are very relevant and urgent environmental issues. Previous research by Barati et al. (2023) showed that environmental issues in general without linking them to specific ecosystems that have a critical role in global warming mitigation. By focusing on peatlands, this research makes a more specific and applicable contribution, helping students understand the importance of peatland ecosystems in sequestering carbon and reducing global warming. Meanwhile, the weakness of this science e-worksheets is that it has not passed the field test.

The development of this e-worksheet aims to facilitate a significant transformation in the science learning process at the high school level. Designed to enhance students' science literacy, this e-worksheet offers a more engaging and relevant approach to learning. It integrates the PISA 2025 Science Framework, which emphasizes the scientific competencies necessary to address future global challenges, alongside the principles of ESD, which equips students with the knowledge and skills required for sustainable development. In the context of global warming, particularly concerning peatland ecosystems, this e-worksheet provides a comprehensive understanding of the critical role peatlands play in carbon sequestration and mitigating greenhouse gas emissions. Students are encouraged not only to grasp fundamental scientific concepts but also to apply them in real-world contexts that resonate with their environment (Sari et al., 2023; Iklashi et al., 2019). This approach shifts learning from being purely theoretical to more practical and contextual, allowing students to better understand the profound impact of human activities on the environment. Furthermore, the use of e-worksheets offers flexibility in learning, catering to individual student needs (Dewi et al., 2019;

Marisda et al., 2022). Through electronic platforms, educational materials are accessible anytime and anywhere, enabling students to learn at their own pace. This approach fosters inclusive learning, allowing students from diverse backgrounds and abilities to engage with and comprehend the material more effectively.

CONCLUSION

The findings of this study indicate that the e-worksheets designed for science education, which align with the PISA 2025 Science Framework and incorporate principles of Education for Sustainable Development (ESD) focusing on the role of peatlands in the global warming phenomenon, demonstrate the following attributes: (1) a very valid classification, with an overall average validation score of 94.2%, and (2) a highly practical classification, with average practicality scores of 86.25% during the one-to-one evaluation phase and 97.5% during the small group evaluation phase. These outcomes underscore the potential of the developed e-worksheets as an effective instructional tool for science education. It is therefore suggested that further research be undertaken to examine the effectiveness of these e-worksheets through field testing, enabling an assessment of their suitability for broader educational applications.

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