Implementation of thermodynamics liveworksheet to measure students' environmental literacy

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Abstract
Environmental problems can be mitigated through education, particularly by integrating environmental issues into the learning process to foster environmental awareness and responsibility. Such integration requires innovative learning media that encourage active student participation. Therefore, this study aimed to measure students' environmental literacy through the implementation of e-worksheets. The study employed a Research and Development (R&D) approach using the ADDIE model, consisting of analysis, design, development, implementation, and evaluation stages. Learning needs were identified during the analysis phase, while the design and development phases focused on creating e-worksheets that were validated by three expert lecturers before being implemented in a classroom setting. The effectiveness of the e-worksheets was evaluated based on students' reflections and responses after their use. The results indicate that e-worksheets effectively support the measurement of environmental literacy by promoting active participation and collaborative problem-solving among students. The findings suggest that e-worksheets are an effective digital learning medium for assessing environmental literacy and enhancing student engagement. Their implementation can provide an alternative teaching material that supports more interactive, contextual, and learner-centered learning. In addition, e-worksheets help students connect learning concepts with real-life environmental phenomena, thereby facilitating deeper understanding and meaningful learning experiences.

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1. Introduction

Learning in the 21st century requires students to have a range of skills relevant to future challenges, including the ability to think critically, creatively, and adaptively in response to technological developments (Herlinawati et al., 2024; Korol & Vorotnitsky, 2022; Sari et al., 2022). One particularly important skill is problem solving, especially in the context of an increasingly complex digital age. Problem-solving skills relevant to technological developments are embodied in computational thinking, which is the ability to reason systematically, break down problems, create data representations, and develop solutions that can be automated (Herlina et al., 2025; Musengimana et al., 2025; Winarto et al., 2025). strategic solutions to problems and critically evaluate alternative solutions, students must also be able to analyze facts and test various assumptions that arise during the scientific investigation process (Saputri et al., 2025).

Problem-based learning model has become one of the approaches considered effective in developing problem-solving skills, especially when integrated with sustainability contexts such as education for sustainable development (Dawana et al., 2024; Tursynkulova et al., 2023). The implementation of ESD-integrated PBL has been proven to have a positive impact on students' environmental literacy on the topic of energy (Hariyono Eko et al., 2024; Jauhariyah et al., 2021; Zulfah et al., 2024). This integration enables students to become more solution-oriented in addressing environmental issues and has been proven to increase environmental awareness (Pangsuma et al., 2024; Yusliani & Yanti, 2020). In addition, the use of digital media contextualized

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with environmental issues strengthens the relevance of learning and increases student engagement (Sudarmaji, 2025).

In supporting the effectiveness of PBL and ESD-based learning, student worksheets, especially electronic-based ones, play an important role as learning media that can guide students towards exploratory, collaborative, and investigation-based activities (Qiroah & Lestari, 2024; Shin, 2023). According to Arifa (2023) There are three essential characteristics of worksheets that can encourage problem-solving and CT skills, namely the use of contextual issues that are close to everyday life, the use of various types of media, and the provision of diverse learning activities. In physics education, digital platform that utilizes PBL has been proven effective in assessing and improving students' problem-solving skills (Saputri et al., 2025). digital platform is also considered a solution for acquiring 21st-century skills because it provides active, flexible, and technology-integrated learning experiences (Zahara et al., 2021).

Environmental literacy, as one of the important competencies of the 21st century, also needs to be instilled through contextual and problem-based teaching materials. Environmental literacy not only includes students' understanding of ecological concepts, but also their understanding of social, economic, and environmental issues in the context of balancing human needs and environmental sustainability (Kabylbek et al., 2025; Zulfah et al., 2024). The use of digital platform has been proven to support this aspect by demonstrating an increase in students' problem-solving abilities (Harnisch et al., 2014; Saputri et al., 2025). Help students develop CT skills and problem-solving abilities more effectively (Herlina et al., 2025). Digital platform based on the ExPRession model is known to improve communication and collaboration skills in physics learning (Sari et al., 2021), while other E-worksheet have been proven to improve students' critical thinking skills (Zahara et al., 2021).

Among the various topics in physics, thermodynamics is particularly relevant to be integrated into learning that emphasizes environmental and sustainability issues. Thermodynamics deals with fundamental concepts of energy, heat, temperature, and energy transfer, which are closely related to various phenomena occurring in everyday life. Therefore, understanding thermodynamics is essential for students to develop an understanding of how energy is transferred and transformed in natural and technological systems. However, the abstract nature of thermodynamic concepts and the difficulty of directly observing microscopic processes can make the topic challenging for students to understand. This condition highlights the pedagogical need for learning approaches that can connect thermodynamic concepts with meaningful real-world contexts. Previous studies also reinforce the importance of using digital platform in learning (Saputri et al., 2025). The use of PBL-based PhET simulation e-worksheets has shown an improvement in students' communication skills (Irwandani et al., 2023; Herlina et al., 2025).

Thermodynamic principles can be directly observed in various environmental phenomena and everyday situations. For example, heat transfer through conduction, convection, and radiation occurs in the heating of the Earth's surface, while energy transformations and thermal equilibrium are involved in atmospheric processes and changes in environmental temperature. These phenomena demonstrate that thermodynamics is not merely a theoretical concept but is closely connected to environmental conditions and sustainability issues. Therefore, contextualizing thermodynamic concepts through real-world environmental phenomena can help students recognize the relevance of physics in understanding environmental problems and encourage the development of awareness of sustainable practices (Saputri et al., 2025). In addition, the application of the “About, In, & For the Environment” learning approach with the PBL model has been proven to improve environmental literacy, making it an effective alternative approach to increase students' understanding and awareness of environmental issues (Putri et al., 2024).

Although previous studies have shown that the Problem-Based Learning model can support improvements in environmental literacy, its implementation is still limited to the use of conventional teaching materials that are not very interactive (Febriya & Desnita, 2024; Herlanti et al., 2025). There have not been many studies that specifically integrate these two approaches into digital learning media, because the use of digital platform has the potential to increase student engagement through visual presentation, interactive responses, and a more structured problem-solving process. In addition, the multidimensional aspects of environmental literacy, including knowledge, awareness, sensitivity, attitudes, and behavior, have not been widely studied through comprehensively designed

digital platform. This gap indicates the need for further research on how PBL-based e- worksheet implementation can effectively improve students' environmental literacy. Therefore, this study aims to evaluate the effectiveness of e- worksheet in improving environmental literacy as a whole.

2. Method

This research used is Research and Development (R&D) research. R&D research is a research and development method that can be interpreted as a scientific way to research, design, produce, and test the validity of the products that have been produced (Deta et al., 2025). The development model used is the ADDIE model. The ADDIE model consists of five main stages, namely Analysis, Design, Development, Implementation, and Evaluation. The research flow can be seen in Figure 1.

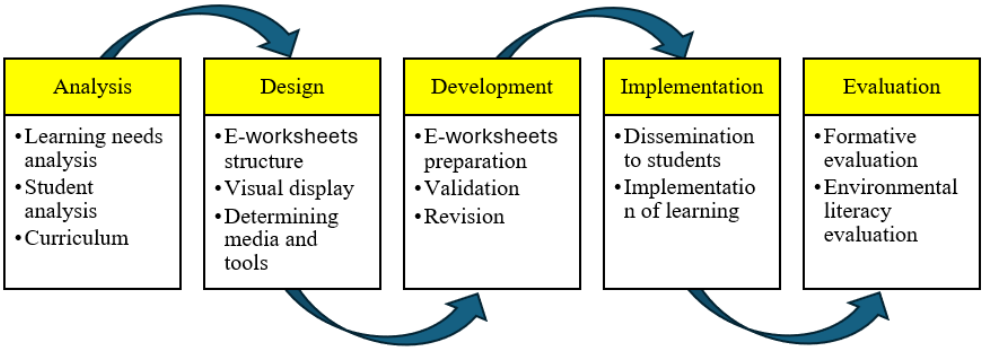


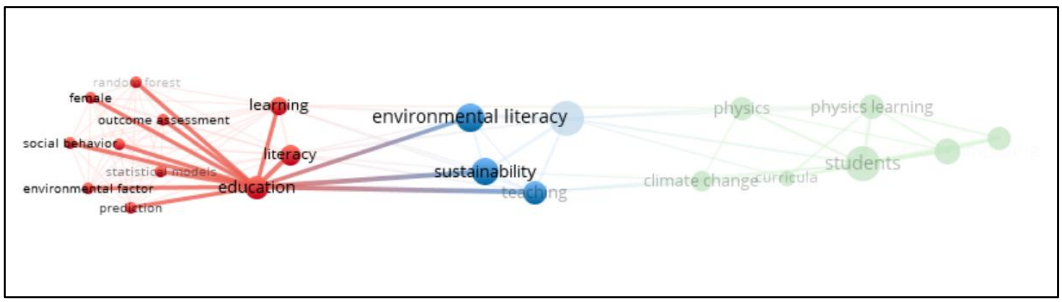
Figure 1. ADDIE Research Flow

3. Results and Discussion

They should be combined. The study results should be clear and concise. Restrict the use of tables and figures to depict data that is essential to the message and interpretation of the study. The results should be presented in a logical sequence in the text, tables and illustrations. The part of result exposes the findings obtained from research data which is related to the hypotheses. The results should summarize (scientific) findings rather than providing data in great detail. The discussion should explore the significance of the results of the work. Explains the findings obtained from research data along with theory and similar research comparison. Make the discussion corresponding to the results, but do not reiterate the results. The following components should be covered in discussion: How do your results relate to the original question or objectives outlined in the Introduction section (what/how)? Do you provide interpretation scientifically for each of your results or findings presented (why)? Are your results consistent with what other investigators have reported (what else)? Or are there any differences?. Include in the discussion the implications of the findings and their limitations, how the findings fit into the context of other relevant work, and directions for future research.

3.1. Study Literature

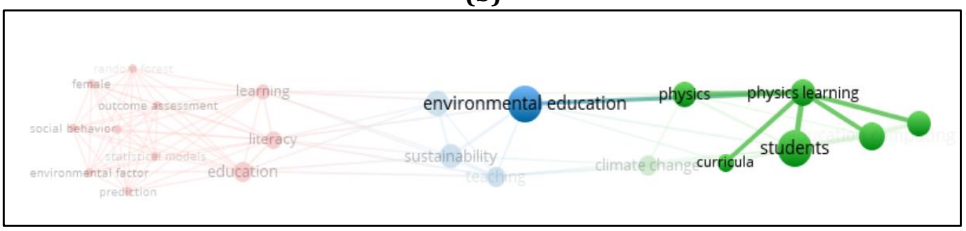
Results of VOSviewer Analysis (a) Focused on Education, (b) Focused on Environmental Literacy, (c) Focused on Physics Learning can be seen in Figure 2.



(a)



(b)



(c)

Figure 2. Results of Vosviewer Analysis (a) Focused on Education, (b) Focused on Environmental Literacy, (c) Focused on Physics Learning.

The results of the bibliometric analysis in Figure 2 show that research on environmental literacy and physics education is quite strong. Figure 2(a) focuses on education with two types of dot connectors, namely red and blue. The red connectors are linked to literacy, learning, outcome assessment, social behavior, and environmental factors. Figure 2(b) focuses on environmental literacy with two types of connectors: red and blue. The red connectors are linked to education and literacy, while the blue connectors are linked to sustainability and teaching. Figure 2(c) focuses on physics learning and is connected with two types of connectors: blue and green. The blue connectors are linked to environmental education, while the green connectors are linked to physics, students, and the curriculum. Overall, the bibliometric distribution map shows the integration of environmental literacy in sustainable physics education.

3.2. Concept analysis

The Jolotundo Spring has a lower temperature than some other areas, even during the dry season, and the volume of water flowing or coming out of the stone sculptures in the Jolotundo Spring experiences constant flow so that the volume or discharge will remain the same at all times and in all seasons. The low temperature at Jolotundo Spring occurs due to natural cooling, which converts energy when hot air carrying a lot of heat enters the Jolotundo Spring environment and is released into the system in the form of water in the Jolotundo Spring pool, where it reaches thermal equilibrium. The water in the pool acts as a double energy absorber by storing cold stably and through evaporation. The evaporation process requires a large amount of energy, namely latent heat. Because the heat from the air is used for other forms of heat, the air that was initially hot reaches thermal equilibrium. This can be written in Equation (1).

$$Q_{air\ sensibel} = Q_{evaporation} + Q_{water\ sensible} + Q_{conduction} + Q_{radiation} \quad (1)$$

To understand the equation clearly, read Table 1 for further explanation.

Table 1. Explanation of the Formula

Equation	Impact
$Q_{air\ sensibel}$	Air cooling with hot air temperatures dropping drastically due to thermal equilibrium
$Q_{evaporation}$	Water evaporation cooling (m.L)
$Q_{water\ sensible}$	The thermal mass of a large body of water stores the heat it receives without significantly raising the water temperature
$Q_{conduction}$	The stability of cold water continuously absorbs heat from the lower parts of the earth or aquifers, keeping the material cool
$Q_{radiation}$	Regulating the heat cycle

3.3. Desain and Development e-worksheet

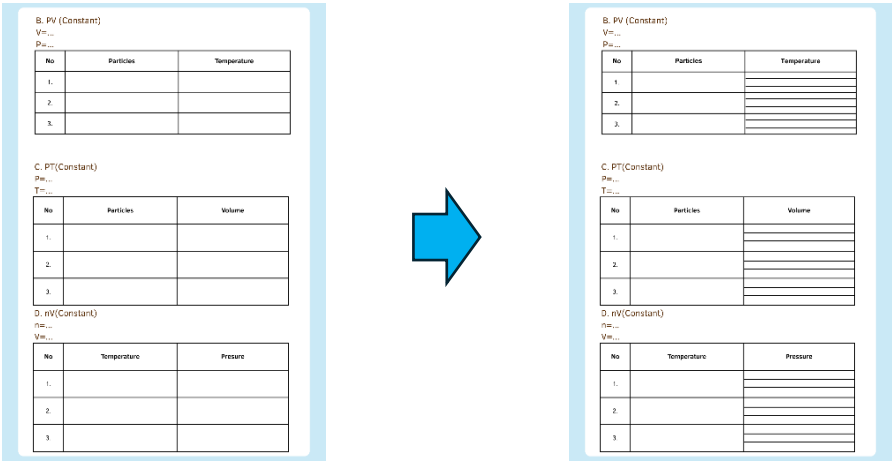
The analysis stage is used to analyze the requirements and concepts that will be used as guidelines, after which the worksheet is designed and developed. The development of the worksheet

design shows the cover to be filled in by the group and the names of the group members, reading material to provide an orientation to the problem, then the students are directed to formulate the problem after reading the material, then the students are directed to conduct experiments from the preparation of tools and materials, the experimental procedure, the experimental table, to reflection questions to test the students' understanding after conducting the experiment, and finally drawing conclusions. After developing the design, validation is carried out. The e-worksheet to be used is validated by three expert lecturers. The validation results can be seen in Table 2.

Table 2. The Validation Results

Validator	Score	Category
1	81%	Strongly Valid
2	84%	Strongly Valid
3	95%	Strongly Valid

Based on the validator's results, the e-worksheet created is feasible to implement but requires minor improvements. The development of the e-worksheet using the LiveWorksheet website involves several stages of design and validation. After validation by experts, revisions are made according to the suggestions given. The revisions given by the validators can be seen in Figure 3.



(a) **(b)**

Figure 3. Revision of Worksheet Design Development (a) Initial Display and (b) Display After Revision

The validator suggested repeating the experiment on the data to validate the measurements taken by the students. Figure 3(a) shows that at the beginning of the worksheet, no repetition was done, but in Figure 3 (b), it has been revised by repeating each component three times.

3.4. Implementation e-worksheet to student

Testing the results of the e-worksheet created by applying it to students. The e-worksheet created was applied to students with guidance during the process. The e-worksheet was completed in groups. The results of the e-worksheet application can be seen in Figure 4.



(a) **(b)** **(c)**

Figure 4. Display (a) The Experiment Page, (b) The Worksheet, And (c) The Collection Page.

The e-worksheet was given to students with guidance and supervision during the assignment, which was carried out in groups to encourage collaboration among students. Figure 4(a) shows the completion of e-worksheets in groups with a clear division of tasks, where two students act as observers, one student acts as a timer, other students record the results of the experiment, and they discuss the reflection questions. Figure 4(b) shows the e-worksheet display for students. Figure 4 (c) show the collection page by filling in the name, group, and school subject. The web-based e-worksheet can be filled in directly by students, saving paper and making it easier for them to complete the task. In addition, the use of digital tools helps to motivate students because it is done in an educational way that attracts their attention. In particular, items involving the interpretation of heat transfer, energy transformation, and thermal equilibrium within environmental phenomena may be more challenging because students need to integrate multiple concepts simultaneously. These variations indicate that students' performance was influenced not only by their conceptual knowledge but also by the complexity of the context and reasoning required by each item.

Petirtaan Jolotundo provides an authentic environmental context for learning thermodynamics through observable natural phenomena. The spring-water environment at the site can be connected to thermodynamic concepts, including temperature, heat transfer, energy, and thermal equilibrium. The interaction between water and its surrounding environment involves energy exchange and heat transfer, providing opportunities for students to observe and interpret thermodynamic processes in a real environmental setting. Contextualizing thermodynamics through the natural phenomena of Petirtaan Jolotundo enables students to connect abstract physics concepts with phenomena in their surroundings. Furthermore, this contextualization encourages students to recognize the relationship between physical processes and environmental conditions, thereby supporting the development of environmental literacy.

The application of e-worksheets in learning can be used as an active and effective learning medium to measure students' environmental literacy. The use of e-worksheets containing environmental phenomena then directs students to investigate and interpret experimental data linked to contextual problems until they complete reflection questions that demonstrate their level of understanding, awareness and attitude towards the environment. The implementation of e-worksheets encountered a minor obstacle during its application, namely when there was an error message during data collection. This was due to an unstable internet connection.

This study has several limitations that should be considered when interpreting the findings. The implementation of the e-worksheets was conducted within a specific learning context, with thermodynamics and Petirtaan Jolotundo serving as the main physics and environmental contexts. Therefore, the findings may have limited generalizability to other physics topics or environmental settings. In addition, the number of participants was limited, and the implementation focused on a specific digital learning platform. Future research should involve larger and more diverse samples, apply the e-worksheets to different physics topics and environmental contexts, and compare different digital learning platforms to examine its effectiveness across broader learning conditions.

4. Conclusion

The implementation of e-worksheets can be concluded as effective in measuring students' environmental literacy, as it encourages students to take an active role in analyzing problems, designing experiments, and drawing conclusions in depth. The use of digital platforms also increases students' engagement in learning physics, particularly in conducting experiments that are often perceived as difficult and challenging. Environmental literacy in this study is reflected in three aspects, namely knowledge, attitude, and behavior. The knowledge aspect is shown through students' understanding of environmental issues, the attitude aspect is indicated by environmental awareness, care, and positive responses toward conservation efforts, while the behavior aspect is reflected in students' ability to make responsible decisions and apply environmentally friendly actions in daily life. The findings of this study also have important implications for physics instructors, as the e- worksheets provides an alternative learning resource that integrates thermodynamic concepts with authentic environmental phenomena. By utilizing Petirtaan Jolotundo as a contextual learning setting, physics instructors can help students connect abstract physics concepts with real-world environmental conditions, thereby promoting more meaningful learning and strengthening environmental literacy across cognitive, affective, and behavioral domains. Therefore, physics instructors are encouraged to implement contextual digital learning that links physics concepts with local environmental phenomena and provides opportunities for students to observe, interpret, and reflect on environmental issues from a physics perspective.

Author Contributions

All authors have equal contributions to the paper. All the authors have read and approved the final manuscript.

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Declaration of Conflicting Interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Data Availability

The datasets generated during and/ or analysed during the current study are available from the corresponding author on reasonable request.

Declaration on AI Use

The authors declare that no artificial intelligence (AI) or AI-assisted tools were used in the preparation of this manuscript.

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