

## Development of PjBL–ESD E-Module to Improve Disaster Literacy for Higher Education Students

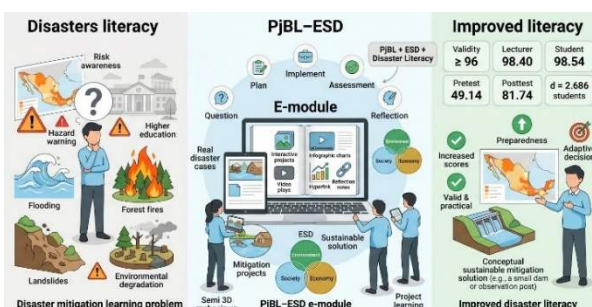
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### ABSTRACT

The relatively low level of students' disaster literacy indicates that disaster education in higher education has not yet been optimally implemented, particularly due to lecturer-centered approaches, limited contextual learning, and insufficient use of digital learning resources. This study aimed to develop and evaluate the validity, practicality, and preliminary effectiveness of an e-module based on Project-Based Learning integrated with Education for Sustainable Development (PjBL–ESD) to enhance students' disaster literacy. This study employed a Research and Development (R&D) method using the 4-D model. The validity of the e-module was assessed through expert review covering content, media, and pedagogical aspects. Practicality was evaluated through questionnaires administered to lecturers and students, focusing on ease of access, time efficiency, and ease of use. The preliminary effectiveness test involved a one-group pretest–posttest design analyzed using a paired-sample t-test. The effectiveness test involved 38 students enrolled in the Environmental Science and Disaster Mitigation course. The results showed that the PjBL–ESD e-module achieved a very high level of validity ( $\geq 96\%$ ) and demonstrated excellent practicality, with average scores of 98.40% from lecturers and 98.54% from students. The effectiveness test indicated a statistically significant improvement in disaster literacy, with the mean score increasing from 49.14 (pretest) to 81.74 (posttest) ( $p < 0.05$ ). These results suggest that the PjBL–ESD e-module is valid, practical, and has strong potential to improve students' disaster literacy within the context of this study. However, the lack of a control group inherent in the one-group pretest–posttest design constrains the extent to which causal conclusions can be drawn. This study implies that the integration of PjBL and ESD in digital modules can support more contextual and student-centered learning, particularly for disaster mitigation education in higher education.



**Keywords:** PjBL-ESD; e-module; Disaster literacy; Higher education.

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**How to cite:** H. Herdini, A. Abdullah, E. Erviyenni, B. Holiwarni, P.A. Wulandari, S. Nazhifah, and T.S. Sidang, "Development of PjBL–ESD E-Module to Improve Disaster Literacy for Higher Education Students," *Jurnal Kimia dan Pendidikan Kimia (JKPK)*, vol. 11, no. 1, pp.165-183, 2026. [Online]. Available: <https://doi.org/10.20961/jkpk.v11i1.115576>

Received: 2026-02-04

Accepted: 2026-04-23

Published: 2026-04-30

## INTRODUCTION

Higher education plays a crucial role in preparing future generations to address complex global challenges through knowledge, innovation, and responsible decision-making. In recent years, the increasing frequency and intensity of natural

disasters, driven by climate change, environmental degradation, and socio-ecological vulnerability, have become major global concerns that require urgent educational responses [1][2]. In disaster-prone countries such as Indonesia, this challenge is particularly pressing because

disaster risk is not merely a natural phenomenon but a multidimensional issue that demands scientific understanding, social awareness, and adaptive capacity. Within this context, one of the most important educational concerns is the still relatively low level of disaster literacy among university students, which may limit their ability to respond effectively to disaster risks.

In this study, disaster literacy refers to a set of competencies encompassing conceptual understanding of disasters, risk interpretation, preparedness behavior, mitigation awareness, and adaptive decision-making in disaster situations. This construct is important because disaster education should not stop at the transmission of factual knowledge; rather, it should equip learners with the capacity to interpret hazards, evaluate risks, and make appropriate decisions in real-life contexts. Empirical studies consistently show that disaster literacy among students and prospective teachers remains at a moderate to low level, particularly in terms of risk interpretation, preparedness behavior, and adaptive decision-making [3][4]. For instance, recent studies indicate that students often possess basic conceptual knowledge about disasters but still struggle to translate that knowledge into concrete mitigation actions and context-sensitive responses [4]. This condition reflects a persistent gap between knowledge acquisition and practical competence in disaster education. Moreover, disaster literacy has been shown to be significantly associated with disaster preparedness and resilience, reinforcing its importance as a key educational outcome [5].

Addressing this issue requires a shift in disaster education in higher education from traditional knowledge transmission toward the development of higher-order competencies such as critical thinking, systems thinking, anticipatory skills, and evidence-based decision-making. This need is closely aligned with the framework of Education for Sustainable Development (ESD), which is particularly relevant to disaster education because it emphasizes the interconnectedness of environmental, social, and economic systems underlying disaster risks. ESD encourages learners to understand how disasters are shaped not only by physical hazards but also by patterns of human activity, environmental management, vulnerability, and sustainability practices. Therefore, integrating ESD into disaster education can help students view disasters in a broader systems perspective and foster more responsible, future-oriented, and sustainability-conscious responses [6][7].

Despite this strong theoretical foundation, the implementation of disaster and environmental education in higher education remains suboptimal. Several studies report that teaching practices are still predominantly lecturer-centered, insufficiently contextual, and minimally supported by digital technologies [8][9]. Such conditions limit students' opportunities to engage in authentic inquiry, collaborative problem-solving, and real-world application of knowledge. In the context of disaster learning, this is particularly problematic because disaster-related competencies require students to analyze real situations,

interpret multiple forms of information, and formulate contextually appropriate mitigation strategies. In addition, recent reviews suggest that disaster education programs often fail to integrate interdisciplinary approaches and real-world problem-solving experiences, thus reducing their impact on students' preparedness and resilience [2][10]. The limited use of technology also indicates the need for digital learning resources that are accessible, interactive, and capable of supporting flexible learning environments.

Project-Based Learning (PjBL) has been widely recognized as a promising pedagogical approach to address these limitations. PjBL facilitates active, collaborative, and inquiry-based learning by engaging students in authentic tasks and real-world problem-solving, thereby supporting the development of critical thinking, communication, and other essential 21st-century skills [11][12]. At the same time, ESD-based instructional approaches have been shown to enhance sustainability awareness and environmental literacy among students [7][13]. In disaster education, experiential and technology-enhanced approaches, including digital simulations, contextual multimedia, and interactive learning modules, have demonstrated considerable potential for improving disaster literacy and preparedness [14][15][16]. However, these approaches are often implemented separately, resulting in fragmented instructional practices that do not fully address the complexity of disaster education.

Previous studies have tended to examine these domains in isolation. Existing research often focuses on PjBL as a pedagogical model, ESD as a sustainability framework, or disaster literacy as a learning outcome, without systematically integrating these three elements within a single instructional design. There is still limited research that combines project-based pedagogy, sustainability-oriented learning, and disaster literacy development in higher education through a technology-supported learning resource. Furthermore, although recent studies have highlighted the importance of integrating environmental management into disaster education, this dimension remains underexplored in instructional design research [2][10]. This reveals a conceptual gap in the design of disaster education learning tools.

Another important gap lies in the limited empirical evaluation of innovative learning tools. Although a number of studies have developed disaster education media, contextual multimedia, or digital platforms, many of them assess only one aspect of quality, such as media feasibility or learning outcomes, without providing a more comprehensive evaluation of validity, practicality, and effectiveness within a coherent pedagogical framework [14]-[18]. Thus, the gap is not only conceptual but also methodological. There remains a need for an instructional innovation that is not only theoretically integrated but also systematically developed and evaluated through a research and development framework.

In response to these gaps, this study develops a technology-supported e-module that integrates Project-Based Learning and Education for Sustainable Development to support disaster literacy learning in higher education. The distinctive contribution of this study lies in the combination of project-based pedagogy, sustainability-oriented competencies, and disaster literacy within a single digital instructional design, accompanied by a systematic evaluation of its validity, practicality, and preliminary effectiveness using a Research and Development approach. Rather than claiming strong causal proof, this study is intended to provide an evidence-based preliminary evaluation of the potential of the developed e-module for disaster literacy learning.

Therefore, this study aims to: (1) develop a PjBL–ESD-based e-module for environmental science and disaster mitigation learning; (2) evaluate its validity and practicality as a learning resource; and (3) examine its potential effectiveness in improving students' disaster literacy.

## **METHODS**

This study employed a Research and Development (R&D) approach using the 4-D model adapted from Thiagarajan [19], which consists of four stages: define, design, develop, and disseminate. In this study, the 4-D model was specifically used as the framework for developing the e-module. The effectiveness of the developed e-module was evaluated only at a preliminary level using a pre-experimental one-group pretest–posttest design, in which students' disaster literacy was measured before and after the

implementation of the e-module. This design was selected due to practical constraints, such as limited class availability and the exploratory nature of the product trial, making it more feasible than a quasi-experimental design with a control group. Although this design allows the examination of learning gains following the intervention, it does not permit strong causal inference because no comparison group was included.

### **1. Participants**

The participants in this study consisted of three groups involved at different stages of development. First, two experts were involved in the validation process: one content expert and one media expert. They were selected purposively based on their academic qualifications and professional experience in chemistry/environmental education and instructional media design. Each expert held at least a master's degree and had prior experience in reviewing or validating educational products. The content expert evaluated the relevance, accuracy, construction, language, and pedagogical alignment of the e-module, while the media expert focused on layout, visual design, accessibility, and interactivity. Thus, pedagogical validation was not conducted by a separate third validator, but was integrated into the content expert's review.

Second, five lecturers and 30 undergraduate students participated in the practicality and readability testing. The lecturers were actively teaching environmental or science-related courses, while the students were in their second or third year of study and had prior exposure to

environmental science learning. These participants were selected to assess whether the e-module was feasible, accessible, and understandable for actual classroom users.

Third, the effectiveness test involved 38 undergraduate students enrolled in the Environmental Science and Disaster Mitigation course. They were selected using purposive sampling to ensure the relevance of the intervention to disaster and sustainability topics. The students involved in the practicality test were different from those involved in the effectiveness test. In addition, pilot participants used for item analysis were not included in the main effectiveness-test group.

## 2. Development Procedure

The development procedure followed the four stages of the 4-D model: define, design, develop, and disseminate.

At the define stage, a needs analysis was conducted through a systematic literature review, two classroom observations, and document analysis to identify existing problems in disaster education. The literature review focused on studies published within the last 5–10 years related to disaster literacy, Education for Sustainable Development (ESD), project-based learning, and digital learning resources. The aim was to identify conceptual and instructional gaps relevant to disaster education in higher education.

The classroom observations were conducted in two environmental science course sessions and focused on teaching methods, student engagement, use of instructional media, and the extent to which

disaster and sustainability content was integrated into classroom activities. Observation data were recorded using field notes and guided observation sheets to ensure consistency.

The document analysis covered the Semester Learning Plan (RPS), course syllabi, teaching materials such as textbooks, PowerPoint slides, and worksheets, as well as assessment instruments used by lecturers. This analysis aimed to examine the alignment between learning outcomes (CPMK and sub-CPMK), instructional strategies, and assessment practices, and to determine whether disaster literacy and sustainability principles were explicitly incorporated. The needs analysis was guided by three criteria: (1) relevance of the content to disaster and sustainability issues, (2) the degree of student engagement and interactivity in learning activities, and (3) the availability and quality of digital learning resources. The results indicated that existing materials were predominantly text-based, lacked contextual disaster cases, and did not sufficiently support active and project-based learning.

Learner analysis was also conducted to examine students' prior knowledge, learning characteristics, and understanding of disaster and sustainability issues through pretest results and questionnaire data. The aspects examined included conceptual understanding, risk awareness, and student learning preferences. In addition, task and concept analyses were conducted to map learning outcomes and develop a structured conceptual framework of disaster and environmental topics. These analyses served

as the basis for formulating instructional objectives aligned with Bloom's taxonomy.

At the design stage, the structure and format of the e-module were determined through a systematic instructional design process. The content structure was developed by aligning the course learning outcomes (CPMK and sub-CPMK), disaster literacy indicators, and essential concepts in disaster and environmental science. These components were then organized into coherent learning units representing major topics in the course.

The e-module was designed according to the syntax of Project-Based Learning (PjBL), including problem orientation, problem analysis, project planning, project implementation, and reflection/evaluation. The ESD framework was integrated by embedding environmental, social, and economic sustainability dimensions into each learning unit. This was operationalized through contextual disaster cases such as floods, forest fires, and land degradation, reflective questions that encouraged critical thinking and responsible decision-making, and project tasks that required students to propose sustainable mitigation solutions.

PjBL components were translated into learning activities that required students to: identify real-world disaster problems, collect and analyze relevant data, develop mitigation strategies, and present and reflect on proposed solutions. Each project task was accompanied by clear instructions, expected outputs, and assessment rubrics to guide student work and maintain alignment with learning objectives.

Prior to prototype construction, a storyboard was developed to map the sequence of content, page layout, navigation flow, visual elements, and interactive features such as hyperlinks, embedded videos, and reflective questions. The storyboard served as the design blueprint and was reviewed informally through expert consultation focusing on content accuracy, instructional coherence, and logical flow.

The digital design followed multimedia learning and usability principles, including coherence, signaling, redundancy avoidance, and user control/navigation principles. Typography, color schemes, and visual hierarchy were standardized to improve readability and user experience. The e-module was developed using Canva as the main design platform and published through Heyzine to enable page-flipping effects, hyperlink integration, and access across smartphones, tablets, and computers.

At the develop stage, the prototype underwent expert validation, practicality testing, and iterative revision. Expert validation focused on content quality, media presentation, and pedagogical alignment. The validation results and qualitative feedback were used as the basis for the first revision cycle. This cycle focused primarily on correcting inaccuracies or oversimplifications in disaster-related concepts, improving the alignment between learning objectives and activities, and enhancing layout clarity and visual organization. For example, some sections explaining mitigation strategies were revised by adding more scientifically accurate explanations and clearer connections to sustainability principles. Dense text sections

were also reorganized into more segmented layouts supported by diagrams and highlighted key points.

The second revision cycle was conducted after practicality and readability testing involving lecturers and students. Feedback at this stage focused more on usability and learning experience. Revisions included simplifying project instructions, improving the clarity of step-by-step activities, and strengthening navigation features. For instance, project guidelines initially presented in paragraph form were reformulated into structured steps supported by icons and checklists. Navigation was also improved through the addition of clickable links between sections and clearer headings.

In prioritizing revisions, conceptual and content-related issues were addressed first to ensure scientific accuracy and alignment with disaster literacy indicators. These were followed by pedagogical improvements, particularly in refining the PjBL activity flow, and then by media and usability enhancements such as typography, layout consistency, and interactivity. Substantial changes occurred between the initial prototype and the final version, including: restructuring the sequence of topics to improve conceptual progression, integrating more contextual disaster case studies, refining project-based tasks with clearer instructions and rubrics, and enhancing visual and interactive elements such as icons, diagrams, and hyperlinks.

At the disseminate stage, the finalized e-module was implemented in a classroom setting for preliminary effectiveness evaluation. The intervention was conducted

over four meetings, each lasting approximately 100 minutes, for a total duration of about four weeks. The learning topics covered basic disaster concepts, types and causes of disasters, disaster risk and mitigation strategies, and the integration of sustainability principles into disaster management.

The implementation followed the PjBL approach, in which students worked in groups to analyze real-world disaster cases, identify key problems, collect relevant information, and propose feasible mitigation strategies based on environmental, social, and economic considerations. Project progress was monitored through periodic check-ins, guided discussions, and lecturer feedback in each meeting. The implementation was conducted by a single lecturer to ensure instructional consistency and minimize variability in teaching practices. The disaster literacy pretest was administered immediately before the first learning session, while the posttest was given immediately after the final session. The final product was then prepared for limited digital dissemination through online platforms such as Heyzine, although broader dissemination beyond the trial class was not carried out within the scope of this study.

### **3. Instruments**

The instruments used in this study included expert-validation sheets, practicality and readability questionnaires, and a disaster literacy test.

The disaster literacy test consisted of 20 multiple-choice items designed to measure four dimensions of disaster literacy:

(1) conceptual understanding of disasters, (2) risk awareness and interpretation, (3) mitigation strategies, and (4) adaptive decision-making skills. Each dimension was represented by five items. Each item had one correct answer and was scored dichotomously, with 1 for a correct answer and 0 for an incorrect answer. Thus, the total raw score ranged from 0 to 20 and was converted into a scale of 0–100 for ease of interpretation.

Content validity of the disaster literacy test was assessed using Aiken's V based on expert judgment. The judgment process involved the same two validators who reviewed the e-module, and the items were rated using a 5-point relevance scale ranging from 1 (not relevant) to 5 (highly relevant). The resulting Aiken's V values ranged from 0.83 to 0.95, indicating high content validity.

Construct validity was examined using corrected item-total correlation analysis on pilot test data. All items showed correlation coefficients greater than 0.30, indicating that all test items met the validity criterion. Reliability was measured using Cronbach's alpha coefficient, resulting in  $\alpha = 0.82$ , which indicates good internal consistency.

The expert-validation sheets for the e-module assessed three aspects: material/content, media, and pedagogy. The material-validation sheet covered indicators such as content relevance, conceptual accuracy, construction, and language. The media-validation sheet assessed module size, cover design, layout, readability, visual clarity, and interactivity. The pedagogical-validation sheet examined the alignment

between learning activities, PjBL–ESD syntax, and disaster literacy outcomes.

The practicality and readability questionnaires were administered to lecturers and students after they used the module. These questionnaires measured three main aspects: ease of access, time efficiency, and ease of use. All validation and practicality instruments used a 5-point Likert scale ranging from 1 (very poor) to 5 (very good). Percentage scores were interpreted using the following criteria: 81–100% = very good, 61–80% = good, 41–60% = fair, 21–40% = poor, and 0–20% = very poor.

#### **4. Data Analysis**

Quantitative data were analyzed using descriptive and inferential statistics. Descriptive statistics, including mean scores and percentages, were used to evaluate the validity and practicality of the e-module. Percentage scores were calculated using the formula:  $\text{obtained score} / \text{maximum score} \times 100\%$ . The resulting percentages were then interpreted according to the criteria: 81–100% = very good, 61–80% = good, 41–60% = fair, 21–40% = poor, and 0–20% = very poor.

To assess the preliminary effectiveness of the e-module, a paired-sample t-test was conducted to compare students' pretest and posttest scores at a significance level of  $\alpha = 0.05$ . Prior to hypothesis testing, the normality of the score distributions was examined using the Shapiro–Wilk test. Effect size was also calculated using Cohen's d to determine the magnitude of the learning improvement, with

interpretation criteria of small (0.2), medium (0.5), and large (0.8) [20].

Cohen's *d* was calculated using the following formula:

$$d = \frac{M_{post} - M_{pre}}{SD_{pooled}}$$

All statistical analyses were performed using IBM SPSS Statistics version 25. Qualitative data obtained from open-ended responses were analyzed thematically to support the interpretation of the quantitative findings.

## 5. Research Ethics

This study was conducted in accordance with ethical principles for educational research involving human participants. Prior to data collection, all participants were informed about the purpose of the study, the voluntary nature of their participation, and the confidentiality of their responses. Informed consent was obtained from all lecturers and students involved in the validation, practicality, and effectiveness stages. Participant identities were anonymized during data processing and reporting to maintain confidentiality. The study involved no physical or psychological risk to participants, and all data were used solely for research purposes.

## RESULT AND DISCUSSION

### 1. Final Product Profile

The final product of this study is a Project-Based Learning and Education for Sustainable Development (PjBL-ESD)-based e-module developed for the Environmental Science and Disaster Mitigation course. The product was designed in response to several learning needs

identified during the preliminary analysis, including the limited integration of sustainability perspectives in disaster learning, the underutilization of digital technology in classroom instruction, and the relatively low level of students' disaster literacy and sustainability awareness. As a digital learning resource, the e-module was intended not merely to present content, but to provide a structured learning environment that enables students to engage actively with real-world disaster issues.



Figure 1. Cover of e-module

The developed e-module demonstrates how Project-Based Learning can be strengthened through the integration of Education for Sustainable Development. Unlike conventional PjBL, which often emphasizes cognitive and procedural outcomes such as teamwork, project design, and product creation, the PjBL-ESD approach integrates environmental, social, and economic dimensions into the learning process [21][22][23]. This integration positions the module not only as a learning tool but also as a framework for fostering sustainability-oriented thinking and decision-making in disaster contexts. Such a design is particularly relevant because disaster problems are inherently multidimensional

and require students to think beyond hazard recognition toward questions of vulnerability, resilience, and sustainable mitigation.

The e-module was structured in alignment with the Outcome-Based Education (OBE) curriculum implemented in the Chemistry Education Study Program, FKIP Universitas Riau. Its components include a cover (Figure 1), foreword, introduction, user instructions, learning

guidance, developer profile, CPL, CPMK, Sub-CPMK, indicators, learning objectives, learning materials, learning activities, and bibliography. The product was designed using Canva and published through Heyzine, allowing access via smartphones, tablets, and computers in a flipbook format. This web-based and device-flexible format increases accessibility and supports more flexible learning environments.

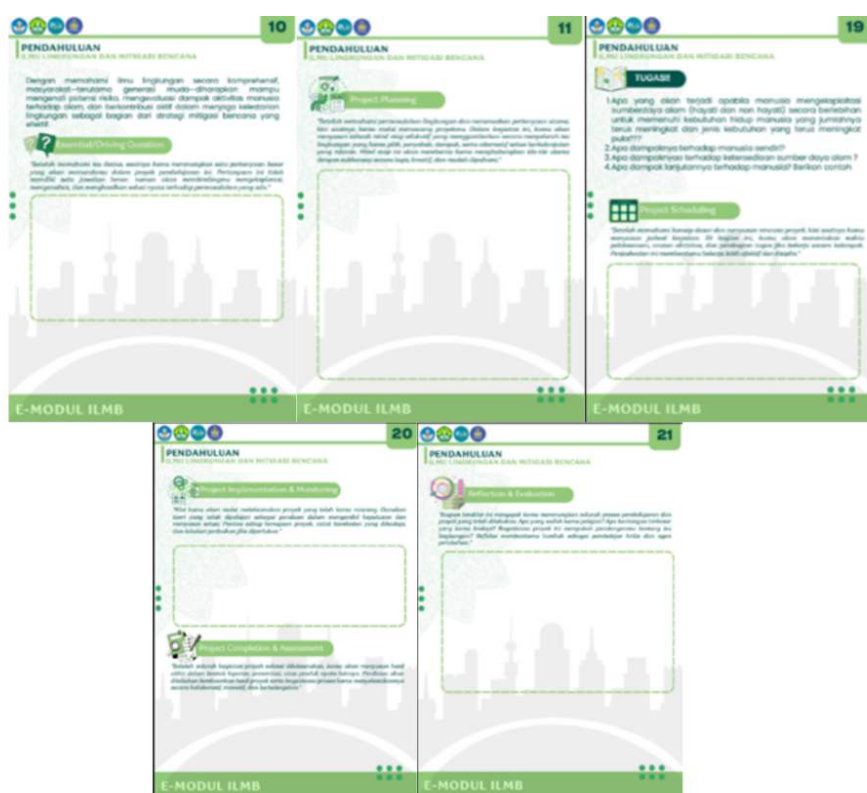


Figure 2. PjBL-ESD syntax of e-module

In pedagogical terms, the e-module integrates the syntax of PjBL with ESD principles through six major stages: Essential Question, Project Planning, Project Scheduling, Project Implementation and Monitoring, Project Completion and Assessment, and Reflection and Evaluation (Figure 2). Through these stages, students are guided to examine disaster issues contextually, formulate sustainability-based

solutions, implement project activities, and evaluate the relevance of their responses to disaster literacy and sustainable development. Environmental, social, and economic aspects of sustainability are embedded systematically throughout the module to encourage students to consider disaster issues from multiple perspectives.

This orientation indicates that the e-module is pedagogically designed to support

student-centered and contextual learning. Rather than positioning students as passive recipients of information, the module encourages them to analyze authentic disaster cases, construct understanding through inquiry and collaboration, and develop feasible mitigation ideas grounded in sustainability principles. Such integration is particularly important in disaster education, which requires not only conceptual understanding but also the capacity to make responsible decisions in complex environmental and social contexts. Therefore, the combination of PjBL and ESD provides a meaningful framework for developing disaster literacy alongside higher-order thinking and sustainability-oriented competencies.

Overall, the final product is an interactive digital learning resource designed not only to support course content delivery, but also to strengthen students' disaster

literacy, critical thinking, problem-solving skills, and sustainability awareness through a technology-supported learning approach. Additionally, it encourages active engagement with real-world disaster issues and supports more meaningful.

## 2. Product Quality Based on Expert Validation

Expert validation showed that the developed e-module had a high level of product quality. As presented in Table 1, the content validation component reached 97.23%, media validation reached 97.67%, and pedagogical validation reached 96.96%, all of which fall into the "Very Good" category. These results indicate that the module content was relevant to the course objectives, the media presentation was clear and functional, and the PjBL–ESD syntax was well aligned with disaster-literacy learning outcomes.

**Table 1.** Results of expert validation

No	Aspect	Average Score	Maximum Score	Percentage (%)	Category
<b>Content Validation</b>					
1	Content/ learning	24	25	96%	Very Good
2	Construction	14.67	15	97.8%	Very Good
3	Language	19.67	20	98.33%	Very Good
<b>Total content assessment</b>		58.34	60	97.23%	Very Good
<b>Media Validation</b>					
4	E-module Size	10	10	100%	Very Good
5	E-module Cover Design	34	35	97.14%	Very Good
6	Content Design	53.67	55	97.57	Very Good
<b>Total media assessment</b>		97.67	100	97.67%	Very Good
<b>Pedagogical Validation</b>					
7	E-module in accordance with PjBL-ESD syntax	29.33	30	97.76%	Very Good
8	Learning Alignment with Disaster Literacy and Sustainable Awareness	24	25	96%	Very Good
<b>Total pedagogical assessment</b>		53.33	55	96.96%	Very Good

In practical terms, these results suggest that the module was not only technically feasible, but also instructionally

coherent for classroom use. High content validation indicates that the learning materials are scientifically accurate, relevant

to disaster and sustainability issues, and appropriately structured to support intended learning outcomes. High media validation shows that the module's visual presentation, layout, and accessibility features were considered effective for digital learning. Similarly, strong pedagogical validation suggests that the sequence of activities, learning flow, and integration of PjBL–ESD principles were consistent with the intended objective of fostering disaster literacy.

These findings are important because a digital learning module should not only be visually attractive, but also pedagogically meaningful and content-valid. In the context of disaster education, content accuracy is essential because students are expected to develop reliable conceptual understanding and sound mitigation awareness. At the same time, clear design and pedagogical coherence are necessary to support students' engagement with complex and multidisciplinary learning materials. Therefore, the high validation scores indicate that the developed module successfully aligns instructional design, content delivery, and learning objectives into a coherent product.

These findings are consistent with previous higher education studies emphasizing the integration of sustainability dimensions into learning objectives and curricula [23], as well as studies showing that interactive digital media can enhance conceptual understanding and retention [24]. Thus, the validation results do not merely confirm the feasibility of the product, but also indicate that the e-module is suitable for supporting effective and meaningful learning in disaster and sustainability contexts.

### 3. Product Practicality and Usability

The practicality test also produced very positive results. As shown in Table 2, lecturers rated the module at 98.40%, while students rated it at 98.54%, both categorized as "Very Good." High scores were obtained across ease of access, time efficiency, and ease of use. This pattern indicates that users perceived the module as easy to operate across devices, efficient to use during learning, and supportive of paperless and technology-enhanced instruction. The consistency between lecturer and student responses further strengthens the argument that the module is operationally feasible in the target course.

**Table 2.** Practicality results from lecturers and students

No	Aspect	Average Score	Maximum Score	Presentation (%)	Category
<b>Lecturers</b>					
1	Ease of Access	14.6	15	97.33	Very Good
2	Time Efficiency	10	10	100	Very Good
3	Ease of Use	24.6	25	98.4	Very Good
<b>Total Score</b>		49.2	50	98.4	Very Good
<b>Students</b>					
1	Ease of Access	14.7	15	98	Very Good
2	Time Efficiency	9.9	10	99	Very Good
3	Ease of Use	24.67	25	98.68	Very Good
<b>Total Score</b>		49.27	50	98.54	Very Good

The practicality findings indicate that the e-module is highly usable in real

classroom settings. This is especially important in disaster education, where

learning often involves complex, multidisciplinary, and context-dependent content. A module that is difficult to access or cumbersome to use may hinder rather than support students' engagement with disaster-related learning tasks. In contrast, the very high ratings for ease of access and time efficiency suggest that the e-module can facilitate learning without creating unnecessary technical or procedural burdens. This usability aspect is pedagogically important because students are more likely to focus on the substance of learning when the medium itself is accessible and easy to navigate.

Its web-based format also supports flexible and paperless learning, which is consistent with the sustainability orientation of ESD [25]. In addition, the use of videos, infographics, and interactive features appears to make disaster-related content easier to understand and more engaging for learners [24]. These findings are in line with previous studies highlighting the contribution of digital learning tools to more flexible, efficient, and environmentally responsible learning practices [25].

Nevertheless, the practicality results should also be interpreted with awareness of the module's contextual limitations. Because the module depends on stable internet access, its implementation may be more challenging in educational settings with limited technological infrastructure. This limitation directly affects practicality, particularly in contexts where digital connectivity is uneven. Therefore, although the module demonstrates high usability in the present study, broader implementation may

require adaptation through offline or hybrid formats.

#### 4. Final Effectiveness Test on Disaster Literacy

The limited effectiveness test involving 38 undergraduate students showed a clear improvement in disaster literacy scores after the module was implemented. As presented in Table 3, the mean pretest score was 49.1397 (SD = 10.67760), while the mean posttest score increased to 81.7366 (SD = 6.36547). This substantial increase indicates that students achieved markedly higher scores after participating in learning using the developed e-module. In addition, the lower standard deviation in the posttest suggests that student performance became more homogeneous, indicating more consistent mastery of the measured competencies across participants.

Before inferential analysis was performed, normality assumptions were examined using the Shapiro–Wilk test. As shown in Table 4, both the pretest and posttest data met the normality requirement, with significance values of 0.171 and 0.116, respectively. This indicates that the score distributions were sufficiently normal to justify the use of a paired-sample t-test.

The paired-sample t-test results presented in Table 5 confirmed a statistically significant difference between pretest and posttest scores ( $t = 16.558$ ;  $df = 37$ ;  $p = 0.001$ ). This indicates that the increase in students' disaster literacy scores after the intervention was unlikely to have occurred by chance.

**Table 3.** Descriptive Statistics

	Mean	N	Std. Deviation
Pretest	49.1397	38	10.67760
Posttest	81.7366	38	6.36547

**Table 4.** Test of Normality

	Kolmogorov-Smirnov		Shapiro-Wilk	
	df	Sig.	df	Sig.
Pretest	38	.200	38	.171
Posttest	38	.014	38	.116

**Table 5.** Paired Sample t-Test Results

	Mean	Std. Deviation	T	df	Sig. (2-tailed)
Posttest - Pretest	31.40316	11.69148	16.558	37	0.001

To strengthen the interpretation of the statistical findings, the effect size was calculated using Cohen's *d*, resulting in a value of 2.686, which is categorized as large [20]. This suggests that the observed improvement is not only statistically significant but also educationally meaningful in terms of the magnitude of change.

The effectiveness results provide strong preliminary evidence of the pedagogical value of the developed e-module. The substantial increase in students' scores suggests that the module contributed meaningfully to their understanding of disaster concepts, risk awareness, mitigation strategies, and adaptive decision-making. In educational terms, this improvement reflects not only better recall of information but also stronger conceptual mastery and greater readiness to apply knowledge in disaster-related contexts. The large effect size

reinforces this interpretation by indicating that the magnitude of learning improvement was considerable rather than trivial.

This improvement can be understood from constructivist and social-constructivist perspectives, in which students actively build understanding through authentic tasks, inquiry, collaboration, and reflection. Project-Based Learning has consistently been associated with the development of higher-order thinking, scientific literacy, and problem-solving skills [26][27][28]. When combined with ESD, the learning process becomes more contextual and value-oriented because students are encouraged to examine disaster issues not only in scientific terms but also in relation to sustainability, social responsibility, and decision-making [23][29]. In this study, students did not merely receive information about disasters; they engaged in project-based activities that required them to identify problems, analyze contextual cases, propose solutions, and reflect on the sustainability implications of their ideas. This type of learning experience likely contributed to the observed gains in disaster literacy.

These findings are also consistent with previous research showing that sustainability-based disaster education can improve preparedness, contextual understanding, and risk-response capacity [30]. Thus, the improvement observed in this study can reasonably be interpreted as reflecting the benefits of a structured learning design that integrates inquiry, collaboration, sustainability-oriented thinking, and digital learning support.

However, these findings should be interpreted cautiously. Although the results

show strong improvement, the use of a one-group pretest–posttest design does not allow for strong causal inference. It cannot be concluded with certainty that the observed gains were caused solely by the e-module intervention, since no comparison group was used. Therefore, the effectiveness evidence should be regarded as preliminary, and further research using more rigorous quasi-experimental or experimental designs is recommended.

### 5. Implications and Limitations

The findings of this study suggest that the developed e-module has strong potential for wider implementation in environmental science and disaster mitigation learning. Its relative advantage, compatibility with digital learning environments, and ease of trial indicate that it may support broader dissemination through online platforms, institutional repositories, and lecturer training, which is in line with previous work on innovation diffusion in educational technology adoption [31]. From a pedagogical perspective, the module offers a promising approach for integrating project-based pedagogy, sustainability-oriented learning, and disaster literacy development within a single digital resource. This makes it particularly relevant for higher education contexts that seek to promote more contextual, student-centered, and competency-based learning.

At the same time, several limitations should be acknowledged. First, the study involved a limited sample within a single institutional context, which may reduce the generalizability of the findings. Second, the

one-group pretest–posttest design constrains causal interpretation of the effectiveness results. Third, the measurement of disaster literacy in this study focused primarily on cognitive and decision-oriented aspects, while affective, behavioral, and long-term preparedness outcomes were not comprehensively examined. In addition, the module's dependence on internet access may limit its usability in settings with weaker technological infrastructure.

Future studies are therefore recommended to involve larger and more diverse samples, apply more rigorous or longitudinal research designs, and examine broader outcomes such as attitudes, preparedness behavior, and long-term sustainability competencies. Developing offline or hybrid versions of the module may also improve accessibility and support implementation in a wider range of educational contexts.

### CONCLUSION

This study developed a Project-Based Learning integrated with Education for Sustainable Development (PjBL–ESD) e-module for the Environmental Science and Disaster Mitigation course in higher education. The development of this e-module was motivated by the limited integration of sustainability perspectives, the underutilization of digital learning resources, and the relatively low level of students' disaster literacy in existing learning practices. The developed product was designed to provide a more contextual, student-centered, and technology-supported learning experience by integrating project-based

pedagogy, sustainability-oriented competencies, and disaster literacy within a single digital instructional resource.

The findings indicate that the developed e-module has a high level of quality, as reflected in the expert-validation results covering content, media, and pedagogical aspects, all of which were categorized as very good. The practicality test also showed highly positive responses from both lecturers and students, indicating that the module is accessible, easy to use, time-efficient, and feasible for implementation in actual classroom settings. These findings suggest that the e-module is not only technically and pedagogically appropriate, but also operationally suitable for supporting disaster and sustainability learning in higher education.

In addition, the preliminary effectiveness test showed a substantial improvement in students' disaster literacy scores after the implementation of the e-module. The increase in posttest scores, supported by a statistically significant result and a large effect size, indicates that the module has strong potential to enhance students' conceptual understanding, risk awareness, mitigation knowledge, and adaptive decision-making in disaster-related contexts. These findings suggest that the structured integration of PjBL and ESD within a digital learning environment can provide a meaningful and educationally valuable approach to strengthening disaster literacy.

Nevertheless, the effectiveness findings should be interpreted with caution. The use of a one-group pretest–posttest design, the relatively limited sample size, the

single-institution context, and the module's dependence on internet connectivity restrict the generalizability of the results and do not allow strong causal inference. Therefore, the effectiveness evidence presented in this study should be regarded as preliminary. Overall, this study contributes to disaster education in higher education by offering a systematically developed and evaluated digital learning innovation that integrates project-based learning, sustainability principles, and disaster literacy. Future studies are recommended to involve larger and more diverse samples, apply more rigorous or longitudinal research designs, and develop offline or hybrid versions of the module to improve accessibility and examine broader outcomes such as preparedness behavior, sustainability awareness, and long-term learning impact.

## ACKNOWLEDGEMENT

We would like to express our sincere gratitude to the *Lembaga Penelitian dan Pengabdian kepada Masyarakat* (LPPM), University of Riau, for the financial support and research facilities provided under contract number LPPM-UNRI/2025/INV//558/397. This support was essential to the successful completion of this research.

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