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Developing a PjBL-Based Biotechnology e-Module to Empower Scientific Literacy and Self-Efficacy Among Senior High School Students

Lara Rimba Cahyani[1]
[1]Universitas Negeri Malang, Indonesia

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ABSTRACT
Within the paradigm of Education for Sustainable Development (ESD), science literacy assumes a pivotal role in endowing students with the knowledge, values, and competencies that underpin sustainability. The 2022 Programme for International Student Assessment (PISA) results demonstrate substandard performance in science. The capacity of students to comprehend scientific concepts is directly proportional to their self-efficacy. The objective of this study is to empower students' scientific literacy and self-efficacy through the development of a PjBL biotechnology e-module. The present development model has been adapted from the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation). The research design employed was a quasi-experimental design of the non-randomized control group pretest-posttest type. The research subjects consisted of 70 grade XII students at SMAN 1 Seputih Mataram, who were selected based on the results of an equivalence test. The e-module has been validated and declared feasible by experts, and its practicality has been demonstrated through trials on students. The effectiveness test results demonstrated an average N-Gain score of 0.69 in science literacy and 0.73 in student self-efficacy. The research findings indicate that the implementation of the PjBL-based biotechnology e-module had a significant impact on improving students' scientific literacy and self-efficacy.

Corresponding Author:
Lara Rimba Cahyani,
Universitas Negeri Malang
Jl. Semarang 5, Ketawanggede, Malang 65145, Indonesia
Email: lara.rimba.2303418@students.um.ac.id

1. INTRODUCTION

The context of Education for Sustainable Development (ESD) focuses not only on the content being learned, but also on the learning methods and learning environment to encourage behavioural changes and actions that support sustainable development. The Kurikulum Merdeka has explicitly integrated ESD into learning outcomes, including those of biology subjects. Consequently, there is a demand for biology teachers to integrate ESD into learning activities [1]. The integration of biotechnology material with ESD competencies is considered to be highly suitable, as it involves techniques or technologies that can be utilised to address the present and future needs of humanity [2]. In order to facilitate comprehension of the subject matter, it is essential to employ pedagogical strategies that are conducive to the assimilation of biotechnology material. One such strategy that has been found to be efficacious is the implementation of literacy activities [3].

Science literacy is a strategic component of ESD, with the objective of equipping the public with the knowledge, values and skills that support sustainability. Science literacy is defined as a person's ability to engage in rational scientific discourse about science, technology, and sustainability to support wise actions [4]. It is imperative that students possess science literacy skills in order to analyse problems, interpret data, and relate them to various scientific facts. These competencies are employed in the decision-making process when confronted with issues pertaining to natural phenomena and their repercussions on human endeavours [5], [6].

The science literacy skills of Indonesian students are substandard. According to the 2022 PISA results, the mean score for literacy was 359, for numeracy, 366, and for science, 383 [7]. The dearth of science literacy among students can be attributed to their inadequate comprehension of fundamental scientific concepts. Concurrently, educators often fail to provide adequate training to students, leaving them ill-equipped to respond to inquiries related to science literacy [8]. The inadequate science literacy exhibited by students can be attributed

to the utilization of inappropriate learning models by educators [9] and the employment of substandard teaching materials [10].

E-modules support a more holistic science learning process, thereby generating positive effects on students' cognitive, affective, and psychomotor learning outcomes as well as increasing their motivation. Research conducted by [11] indicates that the use of e-modules enhances scientific understanding, which in turn significantly improves students' scientific literacy. Furthermore, e-modules serve as a potential alternative teaching material to promote scientific literacy and sustainability awareness among students [12]. However, the effectiveness of e-modules can be further optimized when combined with instructional models grounded in constructivist approaches, which emphasize that learners actively construct their own knowledge through meaningful learning experiences. In this context, Project-Based Learning (PjBL), as defined by [13], is a systematic teaching model that engages students in acquiring knowledge and skills through in-depth investigation of complex, authentic questions and carefully designed tasks and projects. The implementation of PjBL encourages students to become more scientifically literate and environmentally responsible, which ultimately contributes to the enhancement of their scientific literacy.

Science-related learning should foster students' self-efficacy. Self-efficacy is directly proportional to students' ability to understand scientific concepts [14]. Albert Bandura defines self-efficacy as an individual's belief in their ability to act in ways necessary to achieve goals [15]. Research findings on self-efficacy in various countries and in Indonesia are also comparatively low. The results of a meta-analysis in Haiti showed an average self-efficacy percentage of 31.23%, while in the USA it was 22.7% [16]. Revealed that 55% of high school students in Jakarta had low self-efficacy, which had a direct impact on their low learning outcomes [17].

The results of the preliminary test on science literacy knowledge conducted in May 2025 involving 34 twelfth-grade students selected at SMAN 1 Seputih Mataram showed an average score of 63%, which is classified as low, while the results of the needs analysis related to self-efficacy were in the moderate category. These findings indicate that students have the potential for positive self-confidence; however, they still require reinforcement through appropriate learning strategies and interventions that can enhance self-awareness, independence, and consistency in academic achievement. Based on these results, issues were identified regarding the importance of developing teaching materials to empower students' science literacy and self-efficacy..

Based on these findings, innovative efforts are needed in the development of teaching materials that can facilitate the improvement of science literacy while simultaneously strengthening students' self-efficacy. In this regard, previous studies on the development of e-modules and the implementation of Project-Based Learning (PjBL) have been widely explored as innovative approaches to teaching material development. [18] concluded that the PjBL model has been proven to significantly improve students' science literacy and self-efficacy. This study confirms that authentic projects encourage increased self-confidence in solving science problems. The application of digital interactive PjBL-based e-modules significantly improves students' science literacy skills because it encourages students to explore independently, identify problems, and produce project-based solutions [19]

Most of these studies have not comprehensively integrated the four important components, namely e-modules, PjBL, science literacy, and self-efficacy. The separation of focus in these studies indicates a significant gap in the development of digital teaching materials that not only facilitate authentic projects but also simultaneously empower science literacy skills and strengthen students' self-efficacy. Therefore, this research has the urgency to develop digital teaching materials in the form of "*project-based learning* (PjBL)-based biotechnology *e-modules*" that contribute to bringing innovation to science learning. The development of e-modules not only fills theoretical and methodological gaps that have not yet been addressed, but also provides concrete examples of digital learning innovations that are relevant to the demands of the Kurikulum Merdeka and the competency requirements of the 21st century.

2. RESEARCH METHOD

The research approach employed in the development of e-modules is the research and development (R&D) model known as ADDIE. ADDIE is a structured approach to instructional design that encompasses five distinct stages: analysis, design, development, implementation, and evaluation. At the analysis stage (Analyze), validation of performance gaps in the field is conducted, along with the determination of instructional goals, confirmation of student characteristics as the intended users, identification of the required resources, determination of the potential delivery system, and preparation of a project development plan. The design stage (Design) includes conducting a task inventory, composing performance objectives, and determining testing strategies that will be used to assess the achievement of learning objectives.

Furthermore, at the development stage (Development), the e-module content is created, supporting media are selected or developed, and user guidelines for both teachers and students are prepared, followed by formative evaluation. This evaluation involves validation by subject matter experts, media and instructional material experts, learning design experts, as well as biology education practitioners. In addition, the product is tested

progressively through individual trials, small group trials, field trials, and a pilot test. The implementation stage (Implement) is carried out by preparing teachers and students prior to the use of the e-module in the learning process. Finally, the evaluation stage (Evaluate) aims to assess the validity, practicality, and effectiveness of the developed Project-Based Learning-based biotechnology e-module.

The e-module underwent a rigorous validation process involving subject matter experts, media and teaching material experts, and biology education practitioners. This validation process was conducted to assess the module's validity based on a set of predetermined indicators. The practicality assessment was obtained based on the results of e-module trials by students. The implementation stage was carried out to determine the effectiveness of the e-module in empowering students' science literacy and self-efficacy.

The research population consisted of all Grade XII classes at SMAN 1 Seputih Mataram, comprising nine classes with a total of 315 students. The research sample was selected using a purposive sampling technique. The determination of the research sample was carried out after conducting an equivalence test and a discrimination power test across all classes using students' report card scores. The results of the equivalence test showed a value of 0.206 ($\alpha > 0.05$), indicating that the difference in the mean scores between the two groups was not statistically significant. Class XII-5 was assigned as the experimental class, which implemented learning activities using the Project-Based Learning (PjBL)-based biotechnology e-module, while Class XII-6 was assigned as the control class, which used the school textbook based on discovery learning.

3. RESULT AND DISCUSSION

The development of *a project-based learning* (PjBL) biotechnology e-module refers to the ADDIE model [20] with the following stages:

a. *Analysis* Stage

The analysis stage was conducted to identify problems occurring in Biology learning activities. The analysis stage comprised several phases, including the validation of problems in the field, the determination of instructional objectives, the confirmation of student conditions, the identification of necessary resources, the selection of potential delivery systems, and the formulation of a project development plan. The findings of the analysis indicate that the educational curriculum in the field of biology in schools continues to exhibit an incongruity between classroom practices and the requirements of the Kurikulum Merdeka, as well as the learning needs of the 21st century. A paucity of innovative teaching materials exists that have the potential to enhance science literacy and self-efficacy. The preliminary findings indicate that the students' science literacy levels are in the low category, and their self-efficacy levels are in the moderate category. This suggests the necessity for more interactive and contextual learning interventions. The conditions of the audience indicate that the academic aptitudes of the students are relatively homogeneous, yet their engagement and confidence in the learning process remain inadequate. A thorough examination of available resources has been conducted, and the results indicate that there is sufficient material, technological expertise, and human capital available to facilitate the development of the e-module. The efficacy of the learning delivery system through e-modules is predicated on its ability to provide flexible, interactive access that caters to students' diverse characteristics. These findings serve as the foundation for the development of instructional objectives aimed at fostering science literacy and enhancing self-efficacy. Additionally, these findings form the basis for the creation of a project development plan that aims to produce PjBL-based biotechnology e-modules. This initiative is designed to enhance the quality of biology education, while concurrently strengthening students' science literacy and self-efficacy.

b. *Design* Stage

The design stage produced a prototype of a project-based learning (PjBL)-based biotechnology e-module product. The design stage produced a project-based learning (PjBL)-based biotechnology e-module design along with supporting tools, such as teaching modules, student worksheets, science literacy and self-efficacy instruments, validation sheets, student response questionnaires, and observation sheets. The structure of the e-module is systematically designed to include a home page, instructions for use, a table of contents, material descriptions, worksheets in accordance with PjBL syntax, and science literacy and self-efficacy evaluations. Performance objectives are specifically formulated to improve students' ability to understand and apply biotechnology concepts and to strengthen their confidence in completing projects. The testing strategy includes validity testing by experts, practicality testing through student responses, and effectiveness testing through the measurement of science literacy and self-efficacy. The results of this design form a solid foundation for the development of e-modules that are feasible, practical, and effective for use in biology learning.

Table 1. Integration of PjBL with Scientific Literacy and Self-Efficacy

PjBL Syntax Stage	E-Module Component	Scientific Literacy Indicator Developed	Self-Efficacy Indicator Developed
Problem Orientation	Contextual problems and project	Explaining scientific phenomena based on real-world	Confidence in understanding learning tasks

PjBL Syntax Stage	E-Module Component	Scientific Literacy Indicator Developed	Self-Efficacy Indicator Developed
	introduction	biotechnology issues	
Problem Orientation	Contextual problems and project introduction	Explaining scientific phenomena based on real-world biotechnology issues	Confidence in understanding learning tasks
Investigation	Learning materials, worksheets, and experiments	Evaluating and designing scientific inquiry	Confidence in solving problems collaboratively
Product Creation	Project development tasks	Applying scientific concepts in designing biotechnology products/solutions	Confidence in applying knowledge to complete project tasks
Presentation	Presentation and reporting features	Interpreting scientific data and evidence	Confidence in communicating ideas and learning outcomes
Reflection and Evaluation	Self-assessment and feedback features	Making evidence-based decisions and drawing conclusions	Confidence in evaluating personal learning performance

c. *Development* Stage

The e-module was developed through the utilization of the Google Sites and Canva platforms, thereby facilitating the integration of diverse supporting media, including learning videos, links to scientific articles, Google Drive access for supporting files, and Google Forms as a mechanism for evaluation and student feedback. The e-module content is comprehensive, structured, and integrated with science literacy and self-efficacy. The instruments designed to assess science literacy and self-efficacy have been demonstrated to be both valid and reliable, thus ensuring their suitability for implementation. The e-module has been developed for integration into biotechnology educational activities in academic institutions.

Figure 1. Homepage

Figure 2. Instructions for Use

Figure 3. Table of Contents

Figure 4. Learning Activities

Figure 5. Assessment

Figure 6. Teaching Module

All components, from the material, supporting media, teacher and student guidelines, to the assessment tools, were validated by subject matter experts, media experts, learning tool experts, and education practitioners, with the results categorized as highly valid. The validation results table can be found in Table 1 below.

Table 2. E-module Validation Test Results

No	Validation Test	Percentage (%)	Category
1	Subject matter	100	Highly valid

No	Validation Test	Percentage (%)	Category
2	Media and teaching materials	92	Highly valid
3	Biology education practitioners	95	Highly valid

Validation in e-modules is very important to ensure that the e-module meets learning standards and requirements so that the product is suitable for implementation [21]. E-module validation with a percentage above 90% indicates excellent quality, but aspects with scores below 90% require improvement to achieve optimal standards [22]. After revisions based on comments and suggestions from subject matter experts, media and teaching material experts, and field practitioners, the e-module was declared highly valid. A preliminary trial was then conducted to determine student responses regarding the practicality of the e- module. The results of the practicality test are shown in Table 2 below.

Table 3. E-module Practicality Test Results

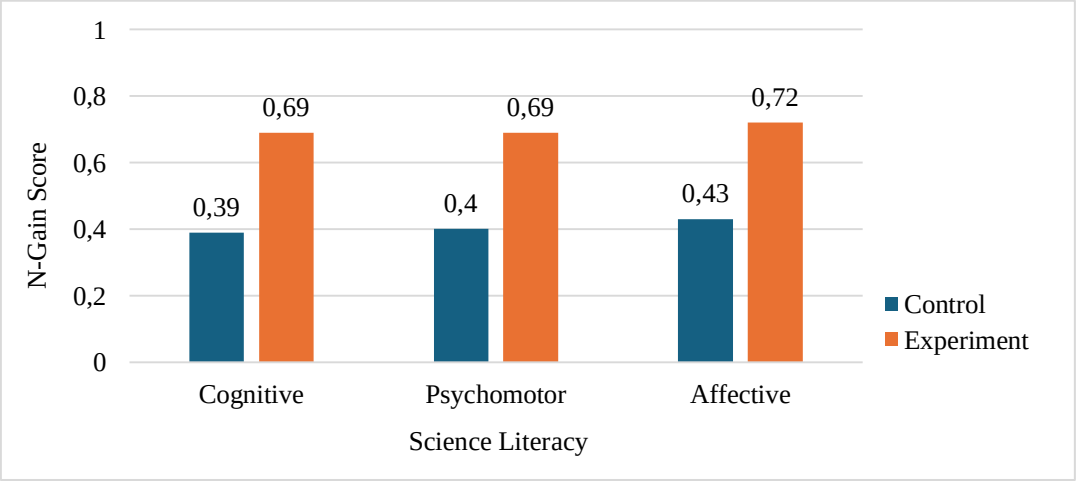
No	Preliminary Test	Subject	Percentage (%)	Category
1	Individual trial	3	88	Very practical
2	Small group trial	8	89	Very practical
3	Field trial	32	91	Very practical

A comprehensive review of the extant literature reveals that e-modules have demonstrated their practicality, ease of use, and appeal in a variety of settings, including individual, small group, and field trials. These modules have also been found to support independent learning. The integration of e-modules, characterized by their high practicality, has been demonstrated to result in a substantial enhancement in learning effectiveness. This high practicality demonstrates that e-modules are straightforward for students to use without necessitating intensive guidance from teachers, thereby supporting student-centered learning. According to [23], practical and interactive e-modules play an important role in increasing students' motivation and scientific thinking skills because they facilitate flexible and adaptive learning to individual learning styles.

d. Implementation Stage

The implementation stage aims to determine the effectiveness of the project-based learning (PjBL) biotechnology e-module in empowering students' science literacy and self-efficacy. Learning took place in two equivalent classes. The experimental class used the e-module with learning activities based on PjBL syntax, while the control class used textbooks. The results of the implementation showed a significant improvement in the experimental class compared to the control class.

Figure 7. N-gain Results for Science Literacy



The experimental class showed an increase in science literacy competence in the aspects of knowledge (N-Gain 0.69), skills (N-Gain 0.69), and attitude (N-Gain 0.72). All indicators in the three aspects experienced a more consistent and stronger increase compared to the control class.

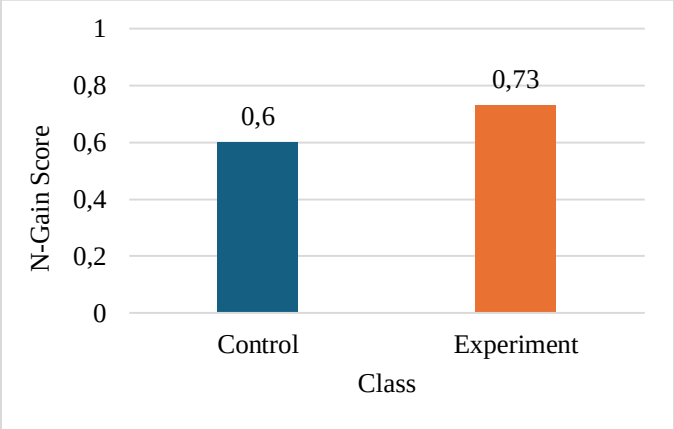


Figure 8. N-gain Result for *Efficacy*

Students' self-efficacy also increased significantly with an N-Gain of 0.73, which is in the high category, reflecting an increase in students' confidence in completing tasks and facing project challenges. Overall, the implementation proved that the PjBL-based biotechnology e- module not only improved scientific concept and skill mastery but also had a positive impact on students' scientific attitudes and self-confidence. The prerequisite test results showed that all pretest-posttest data on science literacy and self-efficacy were normally distributed (Sig. > 0.05) and had homogeneous variance (Sig. > 0.05), thus meeting the requirements for parametric analysis. The ANCOVA test conducted by controlling the pretest scores showed that the Sig. value was 0.000, indicating a significant difference in posttest scores between the experimental and control classes. The results of the ANCOVA test related to science literacy can be found in Table 3, and those related to self-efficacy in Table 4 below.

Table 4. ANCOVA Test Results for Science Literacy

Source	***Type III of Squares***	**df**	***Mean Square***	**F**	**Sig**	***Partial Eta Squared***
Corrected Model	1691,232[a]	3	563,744	20,817	,000	,486
Intercept	2152,240	1	2152,240	79,474	,000	,546
Class	3,669	1	3,669	,135	,714	,002
Pretest	58,598	1	58,598	2,164	,146	,032
Class* *Pretest*	1,174	1	1,174	,043	,836	,001
Error	1787,353	66	27,081			
Total	447169,000	70				
Corrected Total	3478,586	69				

R Squared = ,486 (Adjusted R Squared = ,463)

Based on the ANCOVA results, the PjBL-based biotechnology e-module intervention was proven to be effective in improving students' scientific literacy. The overall model was significant for scientific literacy ($F = 20.817$; $p < 0.001$; $\eta^2p = 0.486$).

Table 5. ANCOVA Test Results for Self-Efficacy

Source	***Type III of Squares***	**df**	***Mean Square***	**F**	**Sig**	***Partial Eta Squared***
Corrected Model	1040,00[a]	2	346,67	4,92	,005	,208
Intercept	2500,00	1	2500,00	35,00	,000	,350
Class	180,00	1	180,00	2,57	,114	,040
Pretest	360,00	1	360,00	5,14	,028	,100
Class* *Pretest*	2,00	2	2,00	0,03	,867	,001
Error	3940,00	67	59,70			
Total	447169,00	70				
Corrected Total	4980,00	69				

R Squared = ,208 (Adjusted R Squared = ,175)

Based on the ANCOVA results, the PjBL-based biotechnology e-module intervention was proven to be effective in improving students' self-efficacy. The overall model was significant for self-efficacy ($F = 4.92$; $p = 0.005$; $R^2 = 0.208$), indicating that the intervention explained a substantial portion of the variance in learning outcomes. The implementation of the PjBL-based e-module can be considered successful and effective, providing empirical evidence that this treatment enhances both students' scientific literacy and self-efficacy.

Based on these results, it can be concluded that the project-based learning (PjBL) biotechnology e-module has a positive and significant effect on improving students' science literacy and self-efficacy compared to conventional learning. This is in line with research by [24], which confirms that the digital media- based project-based learning model encourages students' active involvement in the process of inquiry, collaboration, and reflection on scientific evidence, which directly contributes to strengthening all indicators of science literacy competency. The integration of digital technology in learning supports the achievement of PISA 2025 literacy competencies, which not only measure conceptual abilities but also students' ability to use scientific knowledge to solve complex problems and make evidence-based decisions in the digital age [4]. The relationship between learning activities carried out using PjBL-based biotechnology e-modules and the dimension of self-efficacy shows a systematic relationship between learning design and the development of students' self- confidence. This is supported by research revealing that e-modules, which are considered innovative learning media, can influence students' self-efficacy [25] and that each stage of project activities not only improves learning outcomes but also builds students' confidence in facing subsequent scientific challenges [26].

d. *Evaluation* Stage

The evaluation stage is conducted at every phase of development to ensure that the Project-Based Learning (PjBL) approach is properly integrated into the e-module and that the product meets the criteria of validity, practicality, and effectiveness. The evaluation stage is conducted at each development phase to ensure that the project-based learning (PjBL)-based biotechnology e-module is in accordance with the specified product specifications. Formative evaluation encompasses validity testing by validators and practicality testing by students who have studied biotechnology material. This process enables the refinement of the product in accordance with suggestions and input. During the implementation stage, the quality of the learning process is assessed through observation of the implementation of PjBL syntax. Summative evaluation is carried out through pretest-posttest analysis to measure the effectiveness of the e-module in empowering students' science literacy and self-efficacy. The evaluation stage is designed to ensure the feasibility and efficacy of the e-module, thereby establishing a foundation for subsequent development, with the objective of broadening its application in the domain of biotechnology education.

4. CONCLUSION

The results of the study indicate that the developed biotechnology e-module, based on project-based learning (PjBL), meets the criteria for validity, practicality, and effectiveness.The validity aspect was declared excellent, with scores of 100% from subject matter experts, 92% from media experts, and 95% from biology education practitioners. The practicality of the e-module's was also high, as seen from the students' responses in the individual trial (88%), small group trial (89%), and field trial (91%). Furthermore, the ANCOVA test results showed a significance value of 0.000, confirming that the e-module has a significant effect on empowering students' science literacy and self-efficacy. The developed e-module has been proven to be suitable for use as digital teaching material in Biotechnology learning activities

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