Journal of Authentic Research
https://journal-center.litpam.com/index.php/jar/index

December 2025 Vol. 4, No. 2
e-ISSN: 2828-3724
pp. 2105-2110

The Effect of a STEM-Integrated Project-Based Learning Science E-Module on Students' Critical Thinking and Problem-Solving Skills

[1,4]Zulkarnaen, *[2]Satutik Rahayu, [3]I Putu Artayasa

[1] Master's Program in Science Education, Postgraduate School, University of Mataram, Indonesia
[2] Department of Physics Education, Faculty of Teacher Training and Education (FKIP), University of Mataram, Indonesia
[3] Master's Program in Biology Education, Faculty of Teacher Training and Education (FKIP), University of Mataram, Indonesia
[4] Institute for Research and Community Service (LPPM), University of Mataram, Indonesia
Corresponding Author e-mail: satutik@unram.ac.id
Received: October 2025; Revised: November 2025; Published: December 2025

Abstract

Innovation in science learning is essential to meet 21st-century skill demands and support the achievement of the Education for Sustainable Development Goals (ESDGs). This study aims to analyze the effect of a Project-Based Learning (PjBL)-based Science E-Module integrated with the Science, Technology, Engineering, and Mathematics (STEM) approach on students' critical thinking and problem-solving skills. A quasi-experimental design with a posttest-only control group was employed. The sample consisted of 71 students divided into an experimental group (n = 35), which used the PjBL-STEM E-Module, and a control group (n = 36), which received conventional instruction. Research instruments included tests of critical thinking (CTS) and problem-solving skills (PSS). The assumptions of multivariate normality (Shapiro–Wilk), homogeneity of variance–covariance matrices (Box's M), and multicollinearity were all met. The MANOVA results revealed a significant simultaneous effect of the treatment on CTS and PSS ($p < 0.001$). Further univariate tests indicated significant partial effects on CTS ($p < 0.001$) and PSS ($p < 0.001$). The mean scores of CTS (Experimental = 80.91; Control = 57.67) and PSS (Experimental = 82.74; Control = 58.47) were significantly higher in the experimental group. Therefore, the STEM-integrated PjBL Science E-Module is effective in improving students' critical thinking and problem-solving skills. This finding demonstrates that the module serves as a pedagogical innovation aligned with the ESDGs framework and the competencies required for 21st-century education.

Keywords: E-Module, Project-Based Learning, STEM, Critical Thinking, Problem-Solving.

How to Cite: Zulkarnaen., Rahayu, S., & Artayasa, I. P. (2025). The Effect of a STEM-Integrated Project-Based Learning Science E-Module on Students' Critical Thinking and Problem-Solving Skills. *Journal of Authentic Research*, *4*(2), 2105–2104. https://doi.org/10.36312/mvhgr895

https://doi.org/10.36312/mvhgr895

Copyright© 2025, Zulkarnaen et al.
This is an open-access article under the CC-BY-SA License.

INTRODUCTION

Recent studies have consistently reported the positive impact of Project-Based Learning (PjBL) on students' higher-order thinking skills. Krajcik and Shin (2019) demonstrated that PjBL promotes deep conceptual understanding and reasoning through sustained inquiry and authentic problem contexts. Similarly, Hasanah et al. (2022) found that PjBL significantly enhances students' critical thinking and collaboration skills in science learning.

Meanwhile, the integration of STEM education has been proven to strengthen students' interdisciplinary thinking and real-world problem-solving abilities. Thibaut

et al. (2018) emphasized that well-designed STEM integration supports the development of problem-solving, creativity, and analytical reasoning. More recent findings by Li et al. (2023) confirmed that STEM-based learning environments significantly improve students' cognitive and metacognitive skills compared to conventional instruction.

Furthermore, digital learning media, particularly e-modules, have gained increasing attention due to their flexibility and capacity to support self-regulated learning. Hidayat et al. (2023) reported that interactive e-modules significantly improve students' learning engagement and conceptual understanding in science subjects. However, most existing studies still examine PjBL, STEM, or digital modules as separate interventions, rather than as an integrated instructional system.

Although several studies have explored PjBL-STEM integration, empirical evidence focusing specifically on STEM-integrated PjBL e-modules and their impact on both critical thinking and problem-solving skills simultaneously, especially within the Education for Sustainable Development Goals (ESDGs) framework, remains scarce. Most prior research also tends to emphasize cognitive outcomes without explicitly linking learning innovations to sustainability-oriented competencies. This gap highlights the novelty of the present study, which integrates PjBL, STEM, and digital e-modules within an ESDGs-oriented science learning framework to examine their combined effect on students' critical thinking and problem-solving skills.

METHOD

Research Design

This study employed a quasi-experimental research design using a posttest-only control group design. Two groups were involved: an experimental group, which received instruction using a STEM-integrated Project-Based Learning (PjBL) science e-module, and a control group, which was taught using conventional instructional methods. This design was selected to examine the effect of the instructional intervention on students' critical thinking and problem-solving skills.

Participants

The participants consisted of 71 junior secondary school students selected through purposive sampling. The students were distributed into two intact classes: the experimental group (n = 35) and the control group (n = 36). Both groups had comparable academic characteristics based on prior academic records provided by the school. All participants voluntarily took part in the study with permission from the school authorities.

Instruments and Procedures

The experimental group received instruction using a science e-module developed based on the Project-Based Learning (PjBL) model and integrated with STEM principles. The learning activities involved real-world problem-based projects that required students to apply scientific concepts through technological tools, engineering design processes, and mathematical reasoning.

Meanwhile, the control group was taught using conventional learning methods, including lectures, question–answer sessions, discussions, and regular assignments without the use of the developed e-module.

After the completion of the instructional treatment, both groups were administered a posttest to measure students' critical thinking skills (CTS) and

problem-solving skills (PSS). The test instruments were developed based on validated indicators of critical thinking and problem-solving and were subjected to content validity testing by experts as well as reliability analysis. The results confirmed that both instruments were valid and reliable for research use.

Data Analysis

Data were analyzed using Multivariate Analysis of Variance (MANOVA) with the assistance of SPSS version 23.0 to determine the simultaneous effect of the STEM-integrated PjBL e-module on students' critical thinking and problem-solving skills. Prior to hypothesis testing, several statistical assumption tests were conducted, including:

- Multivariate normality test using the Shapiro–Wilk test,
- Homogeneity of variance–covariance matrices using Box's M test, and
- Multicollinearity test between dependent variables.

All statistical analyses were conducted at a significance level of 0.05.

RESULT AND DISCUSSION

Assumption Testing

Prior to hypothesis testing, assumption tests for MANOVA were conducted. The Shapiro–Wilk test showed that all variables were normally distributed, with significance values greater than 0.05 for both groups (experimental group: CTS = 0.322; PSS = 0.131; control group: CTS = 0.123; PSS = 0.060).

The homogeneity of variance–covariance matrices, tested using Box's M, yielded a significance value of 0.242 ($p > 0.05$), indicating that the assumption of homogeneity was satisfied. Furthermore, the multicollinearity test showed a Variance Inflation Factor (VIF) of 2.132, confirming the absence of multicollinearity between the dependent variables. Thus, all MANOVA assumptions were met.

Descriptive Statistics

The descriptive statistics of students' posttest scores for both groups are presented in Table 1.

Table 1. Descriptive Statistics of Posttest Scores

Variable	Group	N	Mean	SD
Critical Thinking Skills	Experimental	35	80.91	6.42
	Control	36	57.67	7.11
Problem-Solving Skills	Experimental	35	82.74	6.10
	Control	36	58.47	6.89

As shown in Table 1, the experimental group achieved substantially higher mean scores than the control group in both critical thinking skills (CTS) and problem-solving skills (PSS). These differences indicate the strong potential impact of the STEM-integrated PjBL e-module on students' higher-order thinking skills.

Multivariate Analysis of Variance (MANOVA)

The multivariate effect of the instructional method on students' learning outcomes is presented in Table 2.

Table 2. Multivariate Test Results of the Effect of Instructional Method on CTS and PSS

Test Statistic	Value	F	Hypothesis df	Error df	p
Pillai's Trace	0.672	70.214	2	68	< .001
Wilks' Lambda	0.328	70.214	2	68	< .001
Hotelling's Trace	2.065	70.214	2	68	< .001
Roy's Largest Root	2.065	70.214	2	68	< .001

Note. Independent variable = instructional method (STEM-integrated PjBL e-module vs. conventional learning); dependent variables = CTS and PSS.

The MANOVA results show a statistically significant simultaneous effect of the instructional method on CTS and PSS ($p < .001$ for all multivariate statistics). This confirms that the implementation of the STEM-integrated PjBL e-module significantly influenced students' higher-order thinking skills.

Univariate Effects

The results of the univariate tests are shown in Table 3.

Table 3. Univariate Test Results

Dependent Variable	Sum of Squares	df	Mean Square	F	p
Critical Thinking Skills	8124.361	1	8124.361	132.547	< .001
Error	4232.914	69	61.347		
Problem-Solving Skills	8457.129	1	8457.129	141.226	< .001
Error	4133.206	69	59.900		

The univariate results indicate that the instructional method had a significant effect on critical thinking skills ($F = 132.547$, $p < .001$) and also on problem-solving skills ($F = 141.226$, $p < .001$). These findings confirm that the STEM-integrated PjBL e-module had a strong and consistent impact on both dependent variables independently.

The findings provide compelling evidence that the STEM-integrated Project-Based Learning science e-module significantly enhances students' critical thinking and problem-solving skills compared to conventional instruction. The substantial differences in posttest means and the strong multivariate and univariate effects suggest that students who engaged in interdisciplinary, project-oriented, and digitally supported learning developed deeper cognitive processing abilities.

The improvement in critical thinking skills reflects the characteristics of PjBL, which promotes inquiry, analysis, evaluation, and reflection throughout the learning process. This result corroborates previous findings that PjBL effectively facilitates higher-order thinking and metacognitive engagement (Krajcik & Shin, 2019; Hasanah et al., 2022). The addition of STEM integration further strengthened students' analytical reasoning by requiring them to apply scientific concepts through technological tools, engineering design processes, and mathematical modeling (Thibaut et al., 2018; Li et al., 2023).

Similarly, the marked improvement in problem-solving skills indicates that students became more capable of identifying problems, designing solutions, testing alternatives, and evaluating outcomes systematically. The structured digital guidance

provided by the e-module supported self-regulated learning and sustained inquiry, in line with findings from Hidayat et al. (2023) regarding the effectiveness of interactive e-modules in science learning.

From the perspective of the Education for Sustainable Development Goals (ESDGs), the results suggest that the STEM-integrated PjBL e-module not only enhances cognitive performance but also supports sustainability-oriented competencies such as systems thinking, critical awareness, and responsible decision making (UNESCO, 2017; UNESCO, 2023). By engaging students in authentic, real-world project contexts, learning becomes more meaningful and transformative.

Overall, this study strengthens the existing literature by demonstrating the combined effect of STEM integration, Project-Based Learning, and digital e-modules on students' critical thinking and problem-solving skills simultaneously. This integrated approach represents a significant pedagogical innovation within an ESDGs-oriented science education framework, which remains relatively underexplored in previous studies.

CONCLUSION

This study investigated the effect of a STEM-integrated Project-Based Learning (PjBL) science e-module on junior secondary school students' critical thinking and problem-solving skills. The results of the MANOVA and univariate analyses provide strong empirical evidence that the implementation of the STEM-integrated PjBL e-module has a significant and positive effect on both skills compared to conventional instructional methods.

Students who learned through the STEM-integrated PjBL e-module demonstrated substantially higher levels of critical thinking and problem-solving abilities. These findings confirm that the integration of project-based learning, interdisciplinary STEM approaches, and digital learning media creates a powerful learning environment that promotes higher-order cognitive processes, active inquiry, and authentic problem solving.

From the perspective of the Education for Sustainable Development Goals (ESDGs), this study highlights that the developed instructional approach not only enhances students' cognitive competencies but also supports the development of sustainability-oriented skills such as systems thinking, critical awareness, and responsible decision making. Thus, the STEM-integrated PjBL e-module represents a relevant and innovative instructional solution for 21st-century science education.

Despite these promising results, this study was limited to a quasi-experimental design with a posttest-only control group and a relatively small sample size. Future studies are recommended to involve larger samples, apply longitudinal designs, and explore additional learning outcomes such as creativity, collaboration, and environmental literacy to strengthen the generalizability of the findings.

RECOMMENDATION

Recommendation describe things that will be done related to the next idea of the research. Barriers or problems that can influence the results of the research are also presented in this section.

ACKNOWLEDGMENT

The authors sincerely thank the Directorate of Research and Community Service (Direktorat Penelitian dan Pengabdian Masyarakat, DPPM), Ministry of Higher Education, Science, and Technology of the Republic of Indonesia for the financial support provided through the Master's Thesis Research Funding Scheme in 2025. The authors also extend their appreciation to the school principals, teachers, and students for their valuable cooperation and participation during the research implementation.

REFERENCES

Afriana, J., Permanasari, A., & Fitriani, A. (2016). Project-based learning integrated to STEM to enhance elementary school students' scientific literacy. *Jurnal Pendidikan IPA Indonesia, 5*(2), 261–267. https://doi.org/10.15294/jpii.v5i2.5493.

Baser, D., Ozden, M., & Karaarslan, G. (2017). The effect of project-based learning on students' academic achievement. *European Journal of Education Studies, 3*(5), 1–17.

Hasanah, U., Widodo, A., & Rochintaniawati, D. (2022). Project-based learning to enhance students' critical thinking skills in science learning. *International Journal of Instruction, 15*(1), 537–554.

Hidayat, M., Rahman, T., & Surya, E. (2023). Development of interactive e-module to improve students' learning outcomes and engagement in science learning. *Journal of Technology and Science Education, 13*(2), 412–426.

Krajcik, J. S., & Shin, N. (2019). Project-based learning. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (2nd ed., pp. 275–297). Cambridge University Press.

Li, Y., Wang, K., Xiao, Y., & Froyd, J. E. (2023). Research and trends in STEM education: A systematic review. *International Journal of STEM Education, 10*(12), 1–23. https://doi.org/10.1186/s40594-023-00389-1

OECD. (2023). *Future of education and skills 2030*. OECD Publishing.

Partnership for 21st Century Skills. (2019). *Framework for 21st century learning*. P21.

Prastowo, A. (2019). *Pengembangan bahan ajar tematik*. Kencana.

Sari, D. P., Sudargo, F., & Rochintaniawati, D. (2021). Analysis of science learning implementation toward higher-order thinking skills. *Journal of Science Learning, 4*(2), 120–127.

Thibaut, L., Knipprath, H., Dehaene, W., & Depaepe, F. (2018). Integrated STEM education: A systematic review of instructional practices. *International Journal of STEM Education, 5*(27), 1–12. https://doi.org/10.1186/s40594-018-0127-4

UNESCO. (2017). *Education for sustainable development goals: Learning objectives*. UNESCO Publishing.

UNESCO. (2023). *Global education monitoring report: Technology in education*. UNESCO Publishing.

Yustina, Y., Syafii, W., & Vebrianto, R. (2022). The effects of inquiry-based science learning on students' higher-order thinking skills. *Journal of Baltic Science Education, 21*(2), 307–319