RESEARCH ARTICLE

Project-based learning using a laboratory approach on learning outcomes and critical thinking in marine biology

Hasan Tuaputty [a,1,*], Saiful Alimudi [b,2], Ine Irene [a,3], L.N. Latuperissa [a,4], Anthony Kudjo Donkor [c,5]

[a] Department of Biology Education, Faculty of Teacher Training and Education, University of Pattimura, Jl. Ir. M. Putuhena, Ambon, Maluku 97233, Indonesia
[b] Faculty of Fisheries and Forestry, Universitas Muhammadiyah Maluku Utara, Jl. KH. Ahmad Dahlan No. 100, Ternate, North Maluku 97128, Indonesia
[c] Faculty of Education, University for Development Studies, P. O. Box TL1350, Tamale, Ghana

[1]tuaputtyhasan1@gmail.com*; [2] ipoelsan88@gmail.com; [3]arininr@gmail.com; [4]loveska11@gmail.com; [5]akudjod@yahoo.com

For correspondence:
tuaputtyhasan1@gmail.com

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Abstract: The learning process must actively involve students and provide opportunities for them to study and prove the theories they learn. This study determined the influence of the application of Project-Besad Learning (PjBL) using a laboratory approach on learning outcomes and critical thinking in marine biology. This study used a descriptive quantitative method, with the independent variable being the implementation of PjBL with a laboratory approach and involved 32 students in the sixth semester of Biology Education at Pattimura University Indonesia enrolled in marine biology courses. The dependent variables were students' learning outcomes and critical thinking, and the data were collected by tests (knowledge and critical thinking) and observations (attitude and skill). The analysis revealed that the integration of the PjBL with a laboratory approach had a weak effect on knowledge (0.003 <p 0.005), a moderate effect on attitude and skill (0.000 <p 0.005), and a strong effect on critical thinking. The regression analysis showed that there was a correlation between the independent variable and student knowledge (R2 = 0.257 or 25%), attitude (R2 = 0.471 or 47.1%), psychomotor/skill (R2 = 0.470 or 47%), and critical thinking (R2 = 0.934 or 93.4%). In conclusion, the implementation of PjBL using a laboratory approach can improve student learning outcomes and critical thinking in marine biology.

Keywords: critical thinking; laboratory approach; learning outcomes; marine biology; project-based learning

Introduction

Developing the potential of sixth-semester students in the Department of Biology Education, Faculty of Teacher Training and Education (FTTE), University of Pattimura, Indonesia, as prospective teachers in increasing knowledge, attitudes and skills as well as critical thinking skills, can be implemented through a learning process designed by the lecturers. A lecturer should be aware of the student's characteristics and potential and how to develop them according to the requirements of Law No.14 of 2005 to facilitate the development and actualize the students' potential, particularly optimizing learning outcomes, critical thinking skills, and creative thinking. In line with that, Koh (2017) state that learning process must provide meaningful experiences for students through active learning models. One active learning is project-based (Chowdhury, 2015; Derevenskaia, 2014; Raycheva et al., 2017; Sanchez-Muñoz et al., 2022). However, appropriate project-based learning for some topics needs to integrate with a relevant approach. Combining two approaches, methods, or learning models is expected to improve students' cognitive, affective, and psychomotor abilities towards the material being studied (Akgun, 2013; Baser et al., 2017; Herro & Quigley, 2017; Smyrnaiou et al., 2020). PjBL is complete learning and can be integrated with various approaches, methods and models, is sustainable and can promote students to actively seek information in completing project assignments. These student activities will eventually produce a product (Genc, 2015; Li et al., 2020; Soleh, 2021). Lecture innovations using Project-based Learning (PjBL) combined with a laboratory approach are unexplored and important in marine biology. PjBL implementation can be integrated with other approaches or strategies and does not eliminate tasks that are built on real activities in the form of a product. Learning innovations are key to student learning success as they can produce quality students through the integration of various approaches, methods and learning models (Binkley et al., 2014; Greenier, 2020; Sanchez-Muñoz et al., 2022). The lecturers must actively involve the students and provide opportunities for them to conduct studies on the concepts being studied, such as the integration of PjBL using a laboratory approach to learn marine biology.

The PjBL model uses projects which can be conducted through the use of laboratory media to explore, research, interpret, and synthesize to solve problems in marine biology concepts. Measurement and assessment of the students' mastery of the material or concepts can be measured by learning outcomes and critical thinking ability (Sutrisna et al., 2020). The implementation of learning with a laboratory approach allows students to apply the skills of researching, analyzing, making, and presenting (Dzikro & Dwiningsih, 2021; Fini et al., 2018; Li et al., 2020).

The application of PjBL using a laboratory approach can produce real products independently or in groups, according to students' skills (Eliyarti & Rahayu, 2021; Fini et al., 2018; Li et al., 2020; Raycheva et al., 2017; Von Dohlen et al., 2019). In addition, mastery of various laboratory equipment is very helpful for students in forming attitudes and intelligence skills or psychomotor and thinking intelligence (Eliyarti et al., 2020). The laboratory approach is used to prove the theory and provides opportunities for students to increase their understanding of knowledge, skills and attitudes (Li et al., 2020). The application of the PjBL syntax as innovative learning greatly affects learning outcomes, such as increasing knowledge (cognitive), increasing skills (psychomotor) and scientific attitudes, as well as increasing the students' thinking intelligence (Fadhil et al., 2021; Fini et al., 2018; Mora et al., 2020). Thus, the application of PjBL syntax is appropriate for proving the truth of theory in the form of projects to solve marine biological problems. Nonetheless, students need to understand and conduct the steps for implementing the integration of the PjBL using a laboratory approach correctly so that the students' potential, especially in critical thinking skills, can help them understand the marine biology concepts. The development of students' critical thinking skills in every teaching and learning process is very important because it can lead students to achieve optimum learning outcomes (Haseli & Rezaii, 2013; Karagöl & Bekmezci, 2015; Wan & Cheng, 2019).

Critical thinking skills can be developed by inviting students to identify various problems in the form of problem-solving and project-based learning. Students must be aware and believe by focusing their thoughts on a concept that is being studied (Reyk et al., 2022). Critical thinking is also useful for expressing ideas and plays an important role in assessing the benefits of new ideas, choosing the best ideas, and modifying them if necessary so that they are useful in doing jobs that require creativity (Mora et al., 2020; Sanchez-Muñoz et al., 2022). There are three conditions needed to think critically: (1) knowledge of methods for asking questions and expressing reasons logically (2), the skills to apply these methods, and (3) the attitude to use logical thinking to analyze a problem using experience and existing evidence. Implementation of PjBL using a laboratory approach can develop students' critical thinking skills to explore their thinking skills in understanding marine biology concepts, as well as improve learning outcomes and critical thinking. As a source of learning, the laboratory is useful in achieving three learning objectives, namely cognitive, affective and psychomotor skills, and can develop the intelligence of thinking of certain students. According to theoretical studies regarding the application of PjBL using a laboratory approach, there will be an increase in students' learning outcomes and critical thinking towards the concepts of marine biology courses. Therefore, this study aimed to determine and analyze linear regression or the effect of PjBL using a laboratory approach on learning outcomes and critical thinking about the concepts of marine biology of sixth semester students of the Biology Education Department at FTTE, University of Pattimura.

Method

This descriptive study of the integration of PjBL using a laboratory approach involved 32 students in the sixth semester of the marine biology course. To obtain valid and reliable research data, the following variables were assessed: (a) the independent variable is the application of PjBL syntax integrated with a laboratory approach of 32 students and (b) the dependent variables, including students' learning outcomes and critical thinking.

The implementation steps include: (1) *Starting With the Essential Question*, lecturers provide direction and assignments for students to compile fundamental questions related to the types of biotas and their habitats. (2) *Design a Plan for the Project*, the lecturer directs students to compile a project design, with a method of taking various types of marine life, according to habitat and tools and materials used in coastal waters. (3) *Create a Schedule*, asking students to make a schedule of project activities related to the timing of sampling marine life according to their habitat in the location of coastal waters. (4) *Monitor the Students and the Progress of the Project*, lecturers supervise several coastal water locations that are observed by groups of students to complete the projects. Monitoring is conducted by facilitating students in each process and conducting a rubric to record all student activities. (5) *Assessment of the Outcome* (testing project results), assessing student projects according to achievement standards, providing feedback related to learning outcomes in the form of assessments, namely knowledge, skills, and attitudes towards mastering projects related to the types of marine life and their habitats. (6) *Evaluation of Experience*, at the end of the course, lecturers and students reflect on the activities performed in the form of an assessment of knowledge, attitudes, skills, and critical thinking. This process is in the form of individuals, as well as student groups.

The assessment of free variables uses a syntax assessment instrument with a Likert scale according to the number of statements assessed against each syntax performed with the following scoring scores: Very Good = 4, Good = 3, Enough = 2, Poor = 1. The score of each individual or group of 32 students according to the Likert scale is assessed based on the number of scores obtained by students compared to the score set at times 100, as stated in the Formula 1.

$$\text{Learning outcome} = \frac{\text{Score obtained}}{\text{Total score}} \times 100 \quad (1)$$

Assessments of learning outcomes include: (1) Assessment of student knowledge of the types of marine life and their habitats, where the assessment instrument uses selected questions and the number of questions is adjusted to the types of marine life found by students. (2) Student attitudes are assessed based on the score of attitude statement results that are by the indicators assessed including diligent, polite, honest, doing well, thinking positively, and respecting opinions. The score obtained is compared to the score of the established attitude statement. Attitude assessment using the Likert scale is Very Good = 4, Good = 3, Enough = 2, Poor = 1. Attitude values are acquired using project-based learning syntax assessment formulas. (3) Student skills are assessed based on skill indicators, including using tools, taking measurements, making observations, identifying, using materials, using microscopes, and making preparations for marine biology with Very Good = 4, Good = 3, Enough = 2, Poor = 1. The skill value obtained is the same as the PjBL formula for syntactic value assessment with a laboratory approach. (4) To assess the level of critical thinking in students, the instrument used is a high-level essay or critical thinking question, as long as students conduct studies and possess knowledge about the concepts and theories of marine biology. The scores obtained from 32 students on free variables and bound variables were adjusted to the frequency or percentage of learning outcome achievement scores as stated in Table 1.

Table 1. Student achievement criteria

No.	Achievement Value	Achievement Criteria
1	90−100	Very Good
2	70−89	Good
3	50−69	Enough
4	0 <49	Poor

Linear regression analysis and ANOVA were performed in SPSS-20 using the achievement value on the free variable as the X value and the achievement value of the bound variable learning outcomes (knowledge, attitudes, skills, and critical thinking) of 32 students used as Y values.

Results and Discussion

The results of the assessment of 32 students of the Department of Biology Education at FTTE, University of Pattimura enrolled in marine biology courses are presented in Table 2.

Table 2. The results of the independent and dependent variable assessment of 32 students according to the achievement criteria scores

No.	Assessed Variables	Achievement Criteria (%)				∑
		Very Good	Good	Enough	Poor	
1	The integration syntax of PjBL using a laboratory approach	21.9	50.0	15.6	12.5	100
2	Student's knowledge of marine biology concepts	28.1	46.8	21.8	3.1	100
3	Student's attitude	31.3	46.9	18.8	3.1	100
4	Student's skills in completing project activities	31.3	34.4	31.1	3.1	100
5	Student's critical thinking skills in understanding the concepts of marine biology courses	28.1	40.6	25.0	6.3	100

According to Table 2, the independent variable is the mastery of the PjBL model syntax using a laboratory approach including very good and good criteria of 71.9%, enough criteria of 15.6% and poor criteria of 12.5%. The dependent variable is student knowledge related to marine biology concepts. This variable showed very good and good criteria of 75%, enough criteria of 21.8%, and poor criteria of 3.1%. The student's attitude according to the assessment score showed very good and good criteria of 78.1%, enough criteria of 18.8% and poor criteria of 3.1%. Student skills showed very good and good criteria 68.8%, enough criteria 28.1% and poor criteria of 3.1%. The results of students' critical thinking skills showed critical thinking skills with very good and good criteria of 68.8%, enough criteria of 25%, and poor criteria of 6.3%.

Students' Knowledge of Marine Biology

The ANOVA result to reveal the effect of project-based learning using a laboratory approach on students' knowledge of marine biology concepts is shown in Table 3.

Table 3. The ANOVA result of student's knowledge variable

	Sum of Squares	df	Mean Square	F	Sig.
Regression	1224.181	1	1224.181	10.398	.003
Residual	3532.038	30	117.735		
Total	4756.219	31			

The results in Table 3 indicate a weak effect of the PjBL using a laboratory approach to student knowledge. The results of the regression analysis of students' knowledge about the concepts of marine biology courses according to the statistical regression test are provided in Table 4.

Table 4. Linear regression analysis of PjBL using a laboratory approach on students' knowledge

R	R Square	Adjusted R Square	Std. Error of the Estimate
.507	.257	.233	10.851

The independent variable is knowledge.

Table 4 indicates that the regression level (relationship) is in the moderate category between the integration of the PjBL using a laboratory approach to student knowledge. The value of R2 = 0.257 indicates that there is a contribution of PjBL integration with the laboratory approach to student knowledge of 25.7%, and 74.3% which comes from other factors. The coefficient analysis of the regression equation between the integration of the PjBL using a laboratory approach to student knowledge can be explained based on the coefficients of the regression equation in Table 5.

Table 5. Results of the coefficient of regression equation integration of PjBL using a laboratory approach with students' knowledge

Coefficients					
	Unstandardised Coefficients		Standardised Coefficients		
	B	Std. Error	Beta	t	Sig.
1 / Knowledge	.4243.559	1200.915	-.542	-3.534	.001
(Constant)	.133.261	14.864		8.966	.000

Based on Table 5, the results of the correlation regression equation (Figure 1) between the integration of the PjBL model using a laboratory approach to student knowledge related to marine biology material concepts, namely a = 4243.559 and b = 133.261, then the regression equation Y = 4243.559 + 133 .261X, shows an understanding of the integration of the PjBL model of 0.4243.559 followed by student knowledge of 0.133.261.

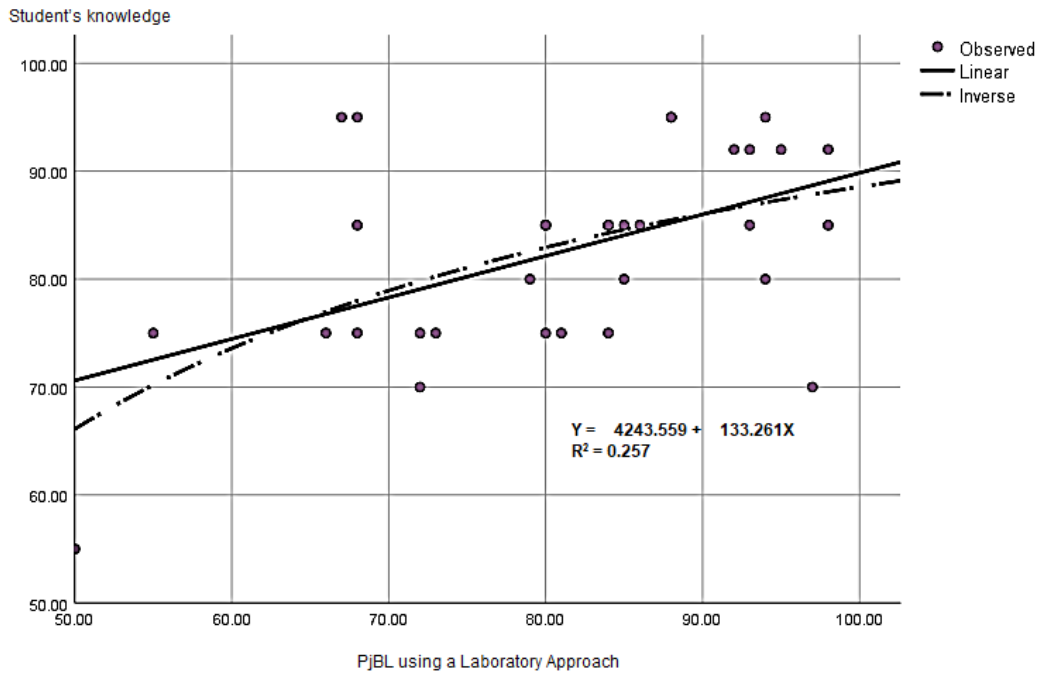

Figure 1. The regression equation of correlation between independent variable to student's knowledge

Figure 1 shows a moderate correlation between the PjBL using a laboratory approach to students' knowledge related to marine biology material concepts. According to the syntax stages of PjBL, there is a level of student understanding according to the line. This is evident in the ability of students to observe various types of marine life and the increased mastery of marine biology knowledge. According to Fini et al. (2018) the application of project-based learning according to its syntax commitment will create an active role for project-based students who are directly involved in real life as a solution to problem-solving, thereby more effectively increasing students' knowledge. Basic knowledge of students is needed when carrying out investigations to collect relevant information and use it as a basis for formulating hypotheses and analyzing data so that it directly impacts students' mastery of knowledge (DeWaters et al., 2014; Fini et al., 2018; Holmes & Hwang, 2016; Ubuz & Aydınyer, 2019). Furthermore, choosing a strategy for implementing a learning model by combining methods or models and approaches will improve students' cognitive, affective, and psychomotor abilities as well as their critical thinking skills (Akgun, 2013; Baser et al., 2017)

The application of lecture innovations by integrating PjBL using a laboratory approach is one solution to increase student activity and improve learning outcomes in understanding marine biology concepts. Fourth-semester students of the Department of Biology Education at FTTE, University of Pattimura were samples for marine biology courses. The correlation regression analysis showed a moderate effect on student knowledge and the contribution of this knowledge is obtained from the integration of PjBL. The integration of the PjBL with learning media increases students' understanding of the concepts and phenomena, providing them with opportunities to examine and think about the marine biology concepts being studied. The application of project-based learning may improve critical thinking processes in discovering and understanding the concepts being studied.

Students' Attitude of Marine Biology

There is an effect of integration of the PjBL using a laboratory approach to student attitudes during the marine biology course as shown in Table 6.

Table 6. The ANOVA result of student's attitude variable

	Sum of Squares	df	Mean Square	F	Sig.
Regression	2239.389	1	2239.389	26.693	.000
Residual	2516.830	30	83.894		
Total	4756.219	31			

The analysis revealed a strong correlation and effect between the integration of the PjBL using a laboratory approach on students' attitudes during the marine biology lecture process. The results of the regression test on student attitudes while participating in the marine biology lecture process according to the statistical regression test are shown in Table 7.

Table 7. Linear regression analysis of PjBL using a laboratory approach on students' attitude

R	R Square	Adjusted R Square	Std. Error of the Estimate
.686	.471	.453	9.159

The independent variable is attitude.

Based on Table 7, there is a strong correlation between the integration of the PjBL using a laboratory approach to student attitudes. The contribution of the integration of PjBL using a laboratory approach to student attitudes of 47.1%, and 52.9% which comes from other factors. To find out the form of regression between the integration of the PjBL using a laboratory approach to student knowledge is explained based on the coefficients of the regression equation in Table 8.

Table 8. Results of the coefficient of regression equation integration of PjBL using a laboratory approach with students' attitude

Coefficients					
	Unstandardised Coefficients		Standardised Coefficients		
	B	Std. Error	Beta	t	Sig.
1 / Attitude	.5129.033	992.743	-.686	-5.167	.000
(Constant)	.144.037	12.278		11.731	.000

According to Table 8, the regression results between the integration of the PjBL using a laboratory approach to student attitudes during the marine biology lectures gave values a = 5129.033 and b = 144.037, the regression equation Y = 5129.033 + 144.037X (Figure 2).

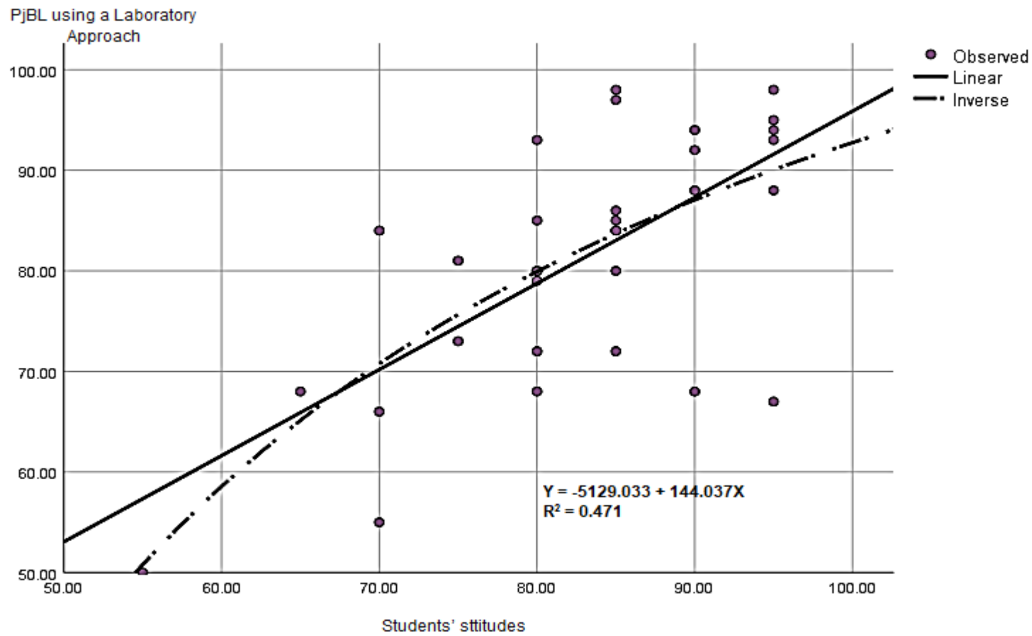

Figure 2. The regression equation of correlation between independent variable to student's attitude

If there is an attitude towards the integration of the PjBL using a laboratory approach of 5129.033, it will be followed by a change in student attitudes of 144.037. There is a strong correlation between the integration of the PjBL model using a laboratory approach to student attitudes during the marine biology lectures (Figure 2). The application of PjBL syntax influences student attitudes and the role of these attitudes is highly significant in motivating students to complete projects in groups. According to Agnafia (2021), a scientific attitude is closely related to the process of using the laboratory as a learning approach for students to understand concepts, such as marine biology and build intelligent thinking based on a scientific attitude. These results can be predicted by the relationship between scientific attitude and intelligence skills in utilizing the laboratory as a source of student learning. The PjBL using a laboratory approach can form students' attitudes and intelligence skills or psychomotor and thinking intelligence (Eliyarti et al., 2020). The laboratory approach proves the theory and provides opportunities for students to increase their understanding of knowledge, skills, and attitudes (Li et al., 2020).

Students' Skill of Marine Biology

The data analyses showed an effect of the PjBL using a laboratory approach on student skills in nature and the laboratory activities during the marine biology course (Table 9).

Table 9. The ANOVA result of student's skill variable

	Sum of Squares	df	Mean Square	F	Sig.
Regression	2234.793	1	2234.793	26.590	.000
Residual	2521.426	30	84.048		
Total	4756.219	31			

According to Table 9, the value of df = 1 and the value of F = 26,590 where the significant value was 0.000 ($p < 0.05$), indicating a strong effect between the PjBL model using a laboratory approach and student skills during the process of activities in nature and the laboratory during the marine biology course. The results of the regression analysis of students' skills during activities in nature and the laboratory during the marine biology course are shown in Table 10.

Table 10. Linear regression analysis of PjBL using a laboratory approach on students' skill

R	R Square	Adjusted R Square	Std. Error of the Estimate
.685	.470	.452	9.168

The independent variable is skill.

Table 10 shows the value of R = 0.685 with the regression level included in the moderate category between the integration of PjBL using a laboratory approach to student attitudes, while the value of R2 = 0.470, which means that there is a contribution of integration of the PjBL model using a laboratory approach to student skills of 47%, and 53% came from other factors. Based on the analysis, a regression equation was obtained between the integration of the PjBL model using a laboratory approach to student skills (Table 11). Table 11 reveal that the correlation equation between the PjBL using a laboratory approach to student skills during the marine biology course shows the values a = -4969.476 and b = 142.365, so the regression equation is Y = -4969.476 + 142.365X. Thus, if there is a relationship between PjBL using a laboratory approach and student's skill is -4969,476, it will be followed by a change in student skills of 144,037. This is in accordance with the linear regression equation in Figure 3.

Table 11. Results of the coefficient of regression equation integration of PjBL using a laboratory approach with students' skill

Coefficients					
	Unstandardised Coefficients		Standardised Coefficients		
	B	Std. Error	Beta	t	Sig.
1 / Skill	-4969.476	963.728	-.685	-5.157	.000
(Constant)	142.365	11.980		11.883	.000

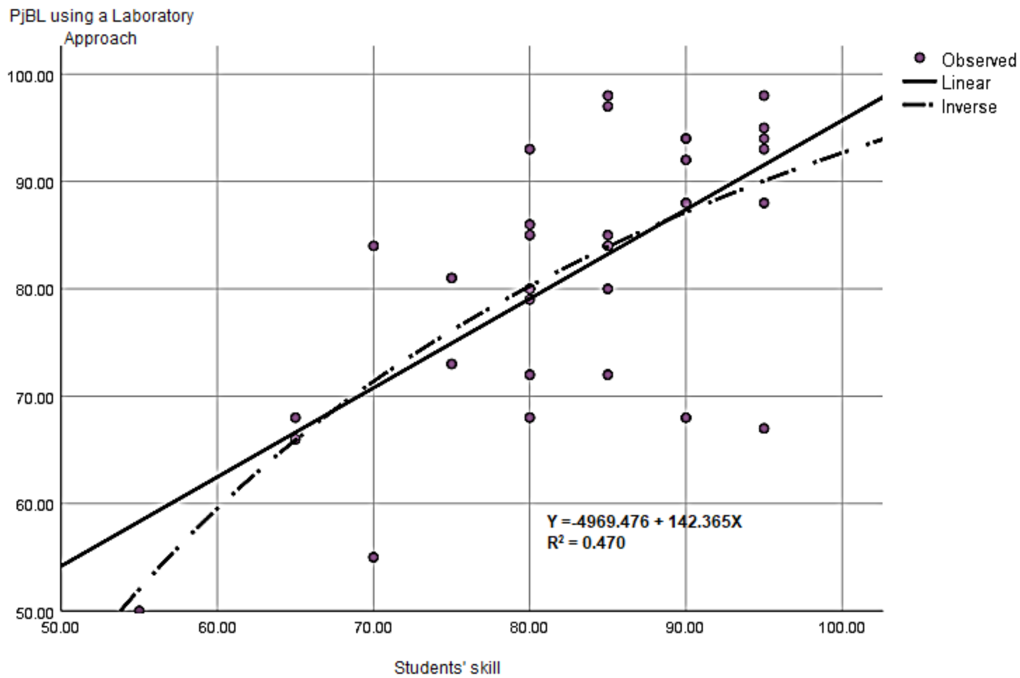

Figure 3. The regression equation of correlation between independent variable to student's skill

Figure 3 shows the moderate category between the integration of the PjBL using a laboratory approach to student skills related to understanding marine biology concepts (Fadhil et al., 2021). Project-based learning can help students develop critical thinking and creativity skills. The analysis explains the moderate correlation between the syntax of project-based learning integration and the laboratory approach and indicates that a small number of students lack the skills to use laboratory equipment. The skills of fourth-semester students of the Department of Biology Education at FTTE, University of Pattimura in implementing the integration syntax of the PjBL model using a laboratory approach showed a strong effect on skills and there is a regression correlation between skills and the implementation of project-based learning integration with a laboratory approach. This indicates that there is a contribution of integration of PjBL using a laboratory approach to student skills. Eliyarti and Rahayu (2021) state that students' skills in proving the truth both in nature and in the laboratory. Skills in using tools to measure environmental factors in coastal waters where there are marine biota and even skills in observing various types of morphology and anatomy of marine biota in the laboratory according to the student's critical thinking skills. Furthermore, Mega et al. (2022) revealed that critical thinking influences students to respond to various activities related to the mastery of the concepts being studied. Therefore, students must respond to changes quickly and effectively so they require flexible intellectual skills, the ability to analyses information and integrate PjBL using laboratory approaches that are oriented towards mastery of knowledge to solve various problems related to marine biology course concepts. The priority of students; critical thinking is to maximize their potential in seeing problems, solving problems, and creating innovations (Holmes & Hwang, 2016; Nunn & Braud, 2013). Thus, clear and rational critical thinking by students is needed to understand marine biology concepts.

Students' Critical Thinking of Marine Biology

The ANOVA result showed an effect of the PjBL using a laboratory approach to students' critical thinking during the marine biology course (Table 12).

Table 12. The ANOVA result of student's critical thinking variable

	Sum of Squares	Df	Mean Square	F	Sig.
Regression	4443.902	1	4443.902	426.865	.000
Residual	312.317	30	10.411		
Total	4756.219	31			

The value of df = 1 and the value of F = 426,865 (Table 12). The significant value is 0.000 ($p < 0.05$), indicating a strong effect between the PjBL using a laboratory approach to students' critical thinking in understanding the marine biology. The results of students' critical thinking on concepts of marine biology according to the statistical regression test are shown in Table 13.

Table 13. Linear regression analysis of PjBL using a laboratory approach on students' critical thinking

R	R Square	Adjusted R Square	Std. Error of the Estimate
.967	.934	.932	3.227

The independent variable is critical thinking.

Table 13 shows the value of R = 0.967 with a regression level which was included in the very strong category, while the value of R2 = 0.934, indicating that PjBL using a laboratory approach to students' critical thinking was 93.4%, and 6.6% came from other factors. The regression results between the integration of the PjBL model using a laboratory approach to students' critical thinking can be seen based on the coefficients of the regression equation in Table 14.

Table 14. Results of the coefficient of regression equation integration of PjBL using a laboratory approach with students' critical thinking

Coefficients					
	Unstandardised Coefficients		Standardised Coefficients		
	B	Std. Error	Beta	t	Sig.
1 / Critical thinking	-5049.393	244.396	-.967	-20.661	.000
(Constant)	145.627	3.172		45.908	.000

Table 14 shows the correlation between the PjBL using a laboratory approach to students' critical thinking during the marine biology course according to the value a = -5049.393 and b = 145.627, thus the regression equation Y = -5049.393 + 145.627X. Therefore, if the relationship between students' critical thinking and integration of the PjBL using a laboratory approach is -5049,393, it will be followed by a change in students' critical thinking of 145,627. The linear regression equation is shown in Figure 4. There is a strong correlation between the PjBL using a laboratory approach to students' critical thinking in understanding marine biology concepts. According to Miharja et al. (2019), there is a significant relationship between critical thinking or critical thinking skills and learning outcomes if the learning model corresponds to the material learned by the learner. The application of PjBL integration syntax through a laboratory approach shows conformity with concepts and materials in marine biology which is evident in the fact that there is a significant relationship between critical thinking and the application of PjBL syntax and laboratory approaches.

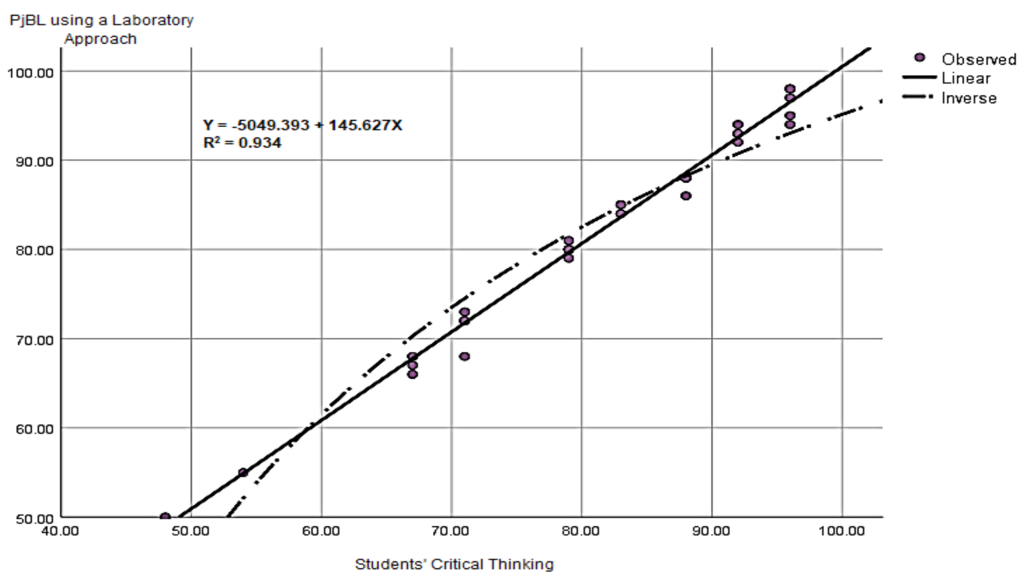

Figure 4. The regression equation of correlation between independent variable to student's critical thinking

Marine biology lectures emphasize critical thinking to optimize students' understanding of marine biology concepts. The level of regression (relationship) was very strong between the integration of the PjBL using a laboratory approach and students' critical thinking. According to Yamin et al. (2020), there is a relationship or effect on learning outcomes as the lectures are more student-centered when integrating PjBL using a laboratory approach. The integration of PjBL using a laboratory approach is closely related to mastering concepts, attitudes, and skills of students. The model allows students to develop critical and creative thinking skills through integration of learning models that are carried out by paying attention to indicators observing, questioning, trying, processing, reasoning, creating, and communicating, in a form of a project report (Holmes & Hwang, 2016; Martinez, 2022; Nunn & Braud, 2013).

The critical thinking skills possessed by sixth semester students of the Department of Biology Education, FTTE, University of Pattimura in identifying problems observing various types of marine biota as well as measuring aquatic physical-chemical factors and conducting studies on the relationship of aquatic environmental factors with the presence of marine biota in an aquatic ecosystem, anatomical observations and the physiology of marine biota in the laboratory through intelligent thinking and intelligence skills and even having a scientific attitude is evidence of the successful implementation of PjBL using a laboratory approach. (Reyk et al., 2022) state that critical thinking is thinking that makes sense and focused reflection to decide what should be believed or done. This means that thinking must be reasonable and focused on deciding what to do to understand the concept being studied. Maksum et al. (2022) explain that critical thinking is needed in creative investigations, which relate to the concepts being investigated to find solutions using critical and creative and innovative thinking stages in completing assignments. Furthermore, the use of learning models that are integrated through laboratories that are utilized to the fullest can affect the development of knowledge, scientific intelligence skills and students' critical thinking, which are necessary to understand the concepts being studied (Fini et al., 2018; Li et al., 2020; Von Dohlen et al., 2019). Permana et al. (2019) also reveal that students' critical thinking skills have a close relationship with students' understanding of concepts.

The use of project-based learning integration models has proven to improve students' learning outcomes and critical thinking related to understanding marine biology concepts using a laboratory approach. Learning is an ability acquired by individuals during the learning process with an appropriate model or approach and can increase intelligent thinking to improve behavior, knowledge, understanding, attitudes and skills.

Conclusion

In conclusion, the integration of the PjBL learning model in marine biology courses using a laboratory approach developed students' creative thinking skills. Therefore, it is recommended that PjBL learning is widely disseminated considering the significant benefits. The government as a policy maker should conduct training and outreach related to excellence and teaching using PjBL. Continuous research is urgently needed using other alternative approaches so that the advantages of PjBL interactions can be studied further.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author Contributions

H. Tuaputty: Methodology, Validation, Writing – original draft, Writing – review and editing. **S. Alimudi:** Analysis, Writing – original draft, Writing – review and editing. **I. Irene:** Analysis, Writing – original draft, Writing – review and editing. **L. N. Latuperissa:** Analysis, Writing – original draft, Writing – review and editing. **A. K. Donkor:** Writing – review and editing.

References

Agnafia, D. N. (2021). Profil sikap ilmiah mahasiswa pada mata kuliah Biologi Dasar II. *Jurnal Pendidikan Modern*, *07*(01), 26–32. https://doi.org/https://doi.org/10.37471/jpm.v7i1.361

Akgun, O. E. (2013). Technology in STEM project-based learning. *STEM Project-Based Learning an Integrated Science, Technology, Engineering, and Mathematics (STEM) Approach*, 65–75. https://doi.org/10.1007/978-94-6209-143-6_8

Baser, D., Ozden, M. Y., & Karaarslan, H. (2017). Collaborative project-based learning: An integrative science and technological education project. *Research in Science and Technological Education*, *35*(2), 131–148. https://doi.org/10.1080/02635143.2016.1274723

Binkley, M., Erstad, O., Herman, J., Raizen, S., Ripley, M., Miller-Ricci, M., & Rumble, M. (2014). Defining twenty-first century skills. In *Assessment and teaching of 21st century skills*. https://doi.org/10.1007/978-94-007-2324-5_2

Chowdhury, R. K. (2015). Learning and teaching style assessment for improving project-based learning of engineering students: A case of united Arab Emirates university. *Australasian Journal of Engineering Education*, *20*(1), 81–94. https://doi.org/10.7158/D13-014.2015.20.1

Derevenskaia, O. (2014). Active learning methods in environmental education of students. *Procedia - Social and Behavioral Sciences*, *131*, 101–104. https://doi.org/10.1016/j.sbspro.2014.04.086

DeWaters, J. E., Andersen, C., Calderwood, A., & Powers, S. E. (2014). Improving climate literacy with project-based modules rich in educational rigor and relevance. *Journal of Geoscience Education*, *62*(4), 469–484. https://doi.org/10.5408/13-056.1

Dzikro, A. Z. T., & Dwiningsih, K. (2021). Kelayakan media pembelajaran berbasis laboratorium virtual pada sub materi kimia unsur periode ketiga. *Chemistry Education Practice*, *4*(2), 160–170. https://doi.org/10.29303/cep.v4i2.2389

Eliyarti, E., & Rahayu, C. (2021). Deskripsi keterampilan dasar laboratorium mahasiswa teknik pada praktikum Kimia Dasar. *Jurnal Ilmiah Profesi Pendidikan*, *6*(1), 30–37. https://doi.org/10.29303/jipp.v6i1.143

Eliyarti, E., Rahayu, C., & Zakirman, Z. (2020). Tinjauan kontribusi Google Classroom dalam mendukung perkuliahan Kimia Dasar. *Jurnal Pendidikan Kimia Indonesia*, *4*(1), 32–39. https://doi.org/10.23887/jpk.v4i1.24299

Fadhil, M., Kasli, E., Halim, A., Evendi, Mursal, & Yusrizal. (2021). Impact of project based learning on creative thinking skills and student learning outcomes. *Journal of Physics: Conference Series*, *1940*(1), 0–8. https://doi.org/10.1088/1742-6596/1940/1/012114

Fini, E. H., Awadallah, F., Parast, M. M., & Abu-Lebdeh, T. (2018). The impact of project-based learning on improving student learning outcomes of sustainability concepts in transportation engineering courses. *European Journal of Engineering Education*, *43*(3), 473–488. https://doi.org/10.1080/03043797.2017.1393045

Genc, M. (2015). The project-based learning approach in environmental education. *International Research in Geographical and Environmental Education*, *24*(2), 105–117. https://doi.org/10.1080/10382046.2014.993169

Greenier, V. T. (2020). The 10Cs of project-based learning TESOL curriculum. *Innovation in Language Learning and Teaching*, *14*(1), 27–36. https://doi.org/10.1080/17501229.2018.1473405

Haseli, Z., & Rezaii, F. (2013). The effect of teaching critical thinking on educational achievement and test anxiety among junior high school students in Saveh. *European Online Journal of Natural and Social Sciences*, *2*(2), 168–175. http://european-science.com/eojnss/article/view/151/pdf

Herro, D., & Quigley, C. (2017). Exploring teachers' perceptions of STEAM teaching through professional development: implications for teacher educators. *Professional Development in Education*, *43*(3), 416–438. https://doi.org/10.1080/19415257.2016.1205507

Holmes, V. L., & Hwang, Y. (2016). Exploring the effects of project-based learning in secondary mathematics education. *Journal of Educational Research*, *109*(5), 449–463. https://doi.org/10.1080/00220671.2014.979911

Karagöl, İ., & Bekmezci, S. (2015). Investigating academic achievements and critical thinking dispositions of teacher candidates. *Journal of Education and Training Studies*, *3*(4), 86–92. https://doi.org/10.11114/jets.v3i4.834

Koh, J. H. L. (2017). Designing and integrating reusable learning objects for meaningful learning: Cases from a graduate programme. *Australasian Journal of Educational Technology*, *33*(5), 136–151. https://doi.org/10.14742/ajet.3072

Li, B., Jia, X., Chi, Y., Liu, X., & Jia, B. (2020). Project-based learning in a collaborative group can enhance student skill and ability in the biochemical laboratory: A case study. *Journal of Biological Education*, *54*(4), 404–418. https://doi.org/10.1080/00219266.2019.1600570

Maksum, H., Yuvenda, D., & Purwanto, W. (2022). Improvement of metacognitive and critical thinking skills through development of the a 'Teaching Factory Based on Troubleshooting' (TEFA-T) Model in automotive vocational learning. *Journal of Turkish Science Education*, *19*(3), 1015–1036. https://doi.org/10.36681/tused.2022.161

Martinez, C. (2022). Developing 21st century teaching skills: A case study of teaching and learning through project-based curriculum. *Cogent Education*, *9*(1). https://doi.org/10.1080/2331186X.2021.2024936

Mega, E., Festiyed, Yerimadesi, Eka, K., & Zulherman. (2022). Research trends in PjBL (Project-Based Learning) at Indonesian Journal of Biology Education. *Jurnal Iqra' : Kajian Ilmu Pendidikan*, *7*(2), 105–119. https://doi.org/10.25217/ji.v7i2.2464

Miharja, F. J., Hindun, I., & Fauzi, A. (2019). Critical thinking, metacognitive skills, and cognitive learning outcomes: a correlation study in genetic studies. *Biosfer*, *12*(2), 135–143. https://doi.org/10.21009/biosferjpb.v12n2.135-143

Mora, H., Signes-Pont, M. T., Fuster-Guilló, A., & Pertegal-Felices, M. L. (2020). A collaborative working model for enhancing the learning process of science & engineering students. *Computers in Human Behavior*, *103*, 140–150. https://doi.org/10.1016/j.chb.2019.09.008

Nunn, J. A., & Braud, J. (2013). A service-learning project on volcanoes to promote critical thinking and the Earth science literacy initiative. *Journal of Geoscience Education*, *61*(1), 28–36. https://doi.org/10.5408/11-271.1

Permana, T. I., Hindun, I., Rofi'ah, N. L., & Azizah, A. S. N. (2019). Critical thinking skills: The academic ability, mastering concepts and analytical skill of undergraduate students. *Jurnal Pendidikan Biologi Indonesia*, *5*(1), 1–8. https://doi.org/10.22219/jpbi.v5i1.7626

Raycheva, R. P., Angelova, D. I., & Vodenova, P. M. (2017). Project-based learning in engineering design in Bulgaria: Expectations, experiments and results. *European Journal of Engineering Education*, *42*(6), 944–961. https://doi.org/10.1080/03043797.2016.1235140

Reyk, J. V., Leasa, M., Talakua, M., & Batlolona, J. R. (2022). Research based learning: Added value in students' science critical thinking skills. *Jurnal Penelitian Pendidikan IPA*, *8*(1), 230–238. https://doi.org/10.29303/jppipa.v8i1.1121

Sanchez-Muñoz, R., Carrió, M., Rodríguez, G., Pérez, N., & Moyano, E. (2022). A hybrid strategy to develop real-life competences combining flipped classroom, jigsaw method and project-based learning. *Journal of Biological Education*, *56*(5), 540–551. https://doi.org/10.1080/00219266.2020.1858928

Smyrnaiou, Z., Georgakopoulou, E., & Sotiriou, S. (2020). Promoting a mixed-design model of scientific creativity through digital storytelling—the CCQ model for creativity. *International Journal of STEM Education*, *7*(1). https://doi.org/10.1186/S40594-020-00223-6

Soleh, D. (2021). Penggunaan model pembelajaran project based learning melalui Google Classroom dalam pembelajaran menulis teks prosedur. *Ideguru: Jurnal Karya Ilmiah Guru*, *6*(2), 137–143. https://doi.org/10.51169/ideguru.v6i2.239

Sutrisna, G. B. B., Sujana, I. W., & Ganing, N. N. (2020). Pengaruh model project based learning berlandaskan Tri Hita Karana terhadap kompetensi pengetahuan IPS. *Jurnal Adat dan Budaya Indonesia*, *1*(2), 84–93. https://doi.org/10.23887/jabi.v2i2.28898

Ubuz, B., & Aydınyer, Y. (2019). Project-based geometry learning: Knowledge and attitude of field-dependent/independent cognitive style students. *Journal of Educational Research*, *112*(3), 285–300. https://doi.org/10.1080/00220671.2018.1502138

Von Dohlen, H. B., Pinter, H. H., Winter, K. K., Ward, S., & Cody, C. (2019). Trauma-informed practices in a laboratory middle school. *Middle School Journal*, *50*(4), 6–15. https://doi.org/10.1080/00940771.2019.1650549

Wan, Z. H., & Cheng, M. H. M. (2019). Classroom learning environment, critical thinking and achievement in an interdisciplinary subject: a study of Hong Kong secondary school graduates. *Educational Studies*, *45*(3), 285–304. https://doi.org/10.1080/03055698.2018.1446331

Yamin, Y., Permanasari, A., Redjeki, S., & Sopandi, W. (2020). Implementing project-based learning to enhance creative thinking skills on water pollution topic. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *6*(2), 225–232. https://doi.org/10.22219/jpbi.v6i2.12202