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Research Article

Differences in Learning Outcomes and Students' Critical Thinking Skills using PjBL Integrated with Stem on Ecosystem Concept at High School 8 and 10 East Seram

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ABSTRACT

Project-Based Learning (PjBL) model integrated with STEM, as implemented in this study, represents a combination of two instructional approaches that enhance learning effectiveness, increase motivation, foster interest in understanding content, and cultivate innovative attitudes. This research aims to examine the differences in learning outcomes and critical thinking skills of students through the use PjBL integrated with STEM on concept of ecosystems at High School 8 and 10 East Seram. A quasi-experimental design was employed to investigate the differences in student achievement and critical thinking skills between groups taught with PjBL integrated with STEM and those taught conventionally. Data analysis involved prerequisite tests including normality and homogeneity, followed by t-tests. The findings indicate that there is a significant difference in learning outcomes when using PjBL integrated with STEM, with significance values of 0.004 at High School 8 and 0.002 at High School 10; there is a significant difference in critical thinking skills, with significance values of 0.003 at both schools; and there is a significant difference in both learning outcomes and critical thinking skills, with significance values of 0.000 at SMA High School 8 and 10 East Seram.

Keywords: critical thinking, learning outcomes, project-based learning, STEM

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INTRODUCTION

National education goals are not only aimed at ensuring that students acquire knowledge, but also at developing skills, attitudes, and learning experiences that encourage them to think logically, critically, and creatively. These abilities are expected to be applied in daily life (Ministry of Education and Culture, 2013). Science, Technology, Engineering, and Mathematics (STEM) is a learning approach that integrates multiple disciplines, including science, technology, engineering, and mathematics. By emphasizing these four core domains within the learning process, this approach is expected to enhance students' 4C skills — creativity, critical thinking, collaboration, and communication (Beers 2014). In addition, the STEM approach provides students with engineering experience and contributes to improved performance on final school examinations (Suwarma et al. 2013).

Project-Based Learning (PjBL) is one of the instructional models recommended in the 2013 Curriculum, which involves project activities and engineering processes as part of the learning experience. The implementation of

PjBL consists of six steps problem presentation, planning, scheduling, project supervision, assessment, and evaluation (Sani 2018).

The collaboration between PjBL model and STEM approach has been proven to increase learning effectiveness (Tseng et al. 2013). Moreover, this integrated approach can enhance students' learning motivation, foster interest in understanding content, and develop innovative attitudes (Afriana et al. 2016). PjBL integrated with STEM also has the potential to strengthen exploratory skills, design learning activities, engage collaboratively in projects, and produce mini products as learning outcomes (Lauhariyyah et al. 2017). One essential aspect of meaningful learning is critical thinking ability. This skill is vital for daily life, the workplace, and various social functions. Critical thinking is categorized as a complex cognitive process that helps students construct their understanding systems. From various expert perspectives, it can be concluded that critical thinking is a mental process used to objectively analyze or evaluate information. A sound understanding of information forms the basis for establishing belief in its validity or in a given argument.To achieve optimal learning outcomes, the learning process must equip students with relevant and applicable skills. Learning outcomes represent the abilities acquired by students after completing the learning process. According to Kunandar (2015), learning outcomes are associated with the achievement of specific skills aligned with predefined learning objectives.

Rosyid et al. (2018) further state that learning outcomes indicate the extent to which students understand the material after participating in learning activities. These outcomes reflect students' achievement, expressed through numerical scores, letter grades, or other symbols agreed upon by educational institutions. Furthermore, Purwanto (2011) emphasizes that learning outcomes are the achievements obtained after the completion of the learning process. Students' success can thus be observed through their academic performance, which reflects their learning results during the educational process.

The ecosystem concept is one of the essential topics in high school biology. To strengthen students' critical thinking and creativity, this topic should ideally be delivered through direct field observation. Experience-based learning allows students to better understand the ideas and interconnections among ecosystem components concretely. Through such observation activities, students not only gain clearer and deeper understanding of the ecosystem concept but also develop 21st-century skills such as problem-solving, collaboration, and communication. Therefore, PjBL integrated with STEM approach is highly suitable for teaching the ecosystem topic.

The PjBL integrated with STEM approach can be effectively implemented through the design of Student Worksheets that are contextual and challenging. Student Worksheets serves as an instructional tool that helps students learn independently through task completion, supported by work guidelines, observation sheets, and evaluation instruments. This aligns with Kunandar (2015), who states that the competencies developed in learning should correspond to specific goals established in the curriculum.

Accordingly, the development of PjBL integrated with STEM approach for the ecosystem topic not only supports the attainment of basic competencies but also acts as a strategic means of equipping students with skills relevant to modern challenges. Student Worksheets is a learning device containing a set of tasks that students must complete. The term Student Worksheets was adapted from the 2013 Curriculum terminology change from "students" to "learners." The purpose of using Student Worksheets is to assist students in understanding concepts, reinforcing comprehension, determining learning strategies, and providing guidance in practical activities (Latifah et al. 2016).

Student Worksheets integrated with the PjBL-STEM approach is expected to improve students' conceptual understanding through project-based activities. Furthermore, Student Worksheets functions as a learning guide that helps students develop both cognitive and other learning aspects through investigation and problem-solving activities. As a learning medium, Student Worksheets plays an important role in supporting independent, active, and efficient learning. By utilizing well-designed Student Worksheets, teachers can create more engaging, meaningful, and impactful learning experiences that contribute positively to students' academic quality.

A previous study by Selvianita and Hardeli (2023) as well as students' responses toward the use of the Student Worksheets. The study revealed that the use of PjBL-STEM improved students' learning outcomes and received positive responses. The research highlighted the importance of Student Worksheets in supporting both in-school and at-home learning, particularly in integrating the PjBL-STEM approaches. To strengthen the collaboration between STEM and PjBL, the availability of appropriate learning materials such as Student Worksheets is crucial. Student Worksheets not only aids comprehension but also trains students to think critically and solve problems contextually.

Based on observations conducted at High School 8 and 10 8 East Seram, it is found that both schools still rely primarily on government-issued textbooks based on the 2013 Curriculum, especially for Biology subjects. However, students experienced difficulties understanding the material presented in the textbooks, leading to suboptimal learning outcomes. Furthermore, it was observed that teachers had not yet developed Student Worksheets to support classroom instruction. Feedback from students also confirmed that textbook-based learning was not fully

effective in improving understanding. This indicates the need for developing more interactive and contextual learning materials, such as PJBL-based Student Worksheets integrated with STEM, to help students better comprehend biological concepts—particularly the ecosystem topic.

METHODS

This study is a quasi-experimental research that aims to examine the differences in students' learning outcomes and critical thinking skills through the use of PjBL-STEM based student worksheets among Grade X students at High School 8 East Seram and High School 10 East Seram, located in East Gorom, East Seram Regency.

Research instruments

1. Observation Sheet (Questionnaire): Used as a guideline for conducting observations to collect the necessary data.
2. Test Sheet (Essay): Designed to evaluate students' mastery of the material and their critical thinking skills, with the expectation of improving their learning outcomes.

Data collection methods

Data were collected through three main stages. First, a needs analysis was conducted by distributing questionnaires to science teachers and Grade X students to identify existing conditions and learning resource needs. Second, a product validity test was carried out by distributing questionnaires to three postgraduate instructors to evaluate the construct and content validity of the student worksheet. Third, a product effectiveness test was implemented using multiple-choice pretests and posttests, along with a critical thinking skills questionnaire, administered to both the control and experimental groups to assess the impact of the PjBL-STEM based student worksheet on students' learning outcomes and critical thinking skills.

Data analysis techniques

Data analysis was conducted through preliminary tests and hypothesis testing. The preliminary tests included a normality test using the Kolmogorov–Smirnov Test to ensure data distribution normality, and a homogeneity test to assess variance equality. Both tests used the criteria of Sig > 0.05 (normal/homogeneous) and Sig < 0.05 (non-normal/non-homogeneous). Subsequently, hypothesis testing was performed using the paired t-test, as the data were obtained from paired samples (before and after treatment). The results were determined by comparing the calculated t value (t_{count}) with the table t value (t_{table}), in order to examine the effect of using PjBL-STEM based student worksheet on students' critical thinking skills and learning outcomes.

RESULTS AND DISCUSSION

A. Learning outcomes (preetest and posttest)

Based on the research data, the students' initial and final test scores can be seen in Table 1 and Table 2.

Table 1. Qualification of achievement score of initial test and final test at High School 8 East Seram

X.A (PjBL-STEM)								X.B (Conventional)							
Pretest				Postest				Pretest				Postest			
C	F	%	C	K	F	%	C	K	F	%	K	K	F	%	C
> 70	5	23	Complete	> 70	22	100	Complete	> 70	3	14	Complete	> 70	22	100	Complete
< 70	17	77	Fail	< 70	-	-	Fail	< 70	19	86	Fail	< 70	-	-	Fail
T	22	100		T	22	100		T	22	100		T	22	100	

Note: C: minimum crtieria; F: frekuensi; %: percentage; K: completeness; T: total

Table 2. Qualification of achievement score of initial test and final test High School 10 East Seram

X.A (PjBL-STEM)								X.B (Conventional)							
Pretest				Postest				Pretest				Postest			
C	F	%	C	K	F	%	C	K	F	%	K	K	F	%	C
> 70	4	29	Complete	> 70	14	100	Complete	> 70	2	14	Complete	> 70	14	100	Complete
< 70	10	71	Fail	< 70	-	-	Fail	< 70	12	86	Fail	< 70	-	-	Fail
T	14	100		T	14	100		T	14	100		T	14	100	

Note: C: minimum crtieria; F: frekuensi; %: percentage; K: completeness; T: total

Based on the table above, it can be seen that at High School 8 East Seram, among students with a minimum mastery criterion > 70, there were 5 students who achieved mastery in Class X A and 3 students in Class X B.

Meanwhile, for students with mastery criteria < 70, there were 17 students who did not meet the criterion in Class X A and 19 students in Class X B. The average scores indicate that overall, the learning outcomes were below the mastery threshold. However, in the post-test, 100% of students showed improvement. The most significant improvement occurred in Class X A, with an average score of 80% for the PjBL-STEM based student worksheet group and 73% for the conventional group. At High School 10 East Seram, students with mastery criterion > 70 included 4 students who achieved mastery in Class X A and 2 students in Class X B, while those with mastery criterion < 70 included 10 students in Class X A and 12 students in Class X B. The average scores similarly indicated that the learning outcomes were below the mastery level. In the post-test, all students (100%) showed improvement, with the highest gains observed in Class X A, where the PjBL-STEM based student worksheet group achieved an average score of 75%, compared to 72% in the conventional group.

Students' affective abilities

Based on research data, the students' affective learning outcomes can be seen in Table 3.

Table 3. Qualification of student learning outcomes in the affective aspect at High School 8 and 10 East Seram

High School 8 East Seram								High School 10 East Seram							
X.A (PjBL-STEM)				X.B (Conventional)				X.A (PjBL-STEM)				X.B (Conventional)			
C	F	%	C	K	F	%	C	K	F	%	K	K	F	%	C
> 70	22	100	Complete	> 70	22	100	Complete	> 70	14	100	Complete	> 70	14	100	Complete
< 70	-	-	Fail	< 70	-	-	Fail	< 70	-	-	Fail	< 70	-	-	Fail
T	22	100		T	22	100		T	14	100		T	14	100	
		76				71				74				71	

Note: C: minimum crtieria; F: frekuensi; %: percentage; K: completeness; T: total

Based on Table 3, it can be seen that in terms of the affective aspect, at High School 8 East Seram, Class X A achieved 100% mastery with an average score of 76% (categorized as fairly good) after learning with the student worksheet, while Class X B achieved an average score of 71% with conventional learning (also fairly good). Similarly, at High School 10 East Seram, Class X A also showed 100% mastery with an average score of 74% using the student worksheet, whereas Class X B reached an average score of 71% through conventional instruction.

Students psychomotor abilities

Based on research data, students' psychomotor learning outcomes can be seen in Table 4 below.

Table 4. Qualification of student learning outcomes in psychomotor aspects at High School 8 and 10 East Seram

High School 8 East Seram								High School 10 East Seram							
X.A (PjBL-STEM)				X.B (Conventional)				X.A (PjBL-STEM)				X.B (Conventional)			
C	F	%	C	K	F	%	C	K	F	%	K	K	F	%	C
> 70	22	100	Complete	> 70	22	100	Complete	> 70	14	100	Complete	> 70	14	100	Complete
< 70	-	-	Fail	< 70	-	-	Fail	< 70	-	-	Fail	< 70	-	-	Fail
T	22	100		T	22	100		T	14	100		T	14	100	
		75				71				73				71	

Note: C: minimum crtieria; F: frekuensi; %: percentage; K: completeness; T: total

Based on Table 4, it can be observed that in terms of the psychomotor aspect, at High School 8 East Seram, Class X A achieved 100% mastery with an average score of 75% (categorized as fairly good) using the student worksheet, while Class X B obtained an average score of 71% with conventional learning (fairly good). Similarly, at High School 10 East Seram, Class X A also achieved 100% mastery with an average score of 73% (fairly good) through the use of student worksheet, whereas Class X B reached an average score of 71% using the conventional method (fairly good).

Final grade of student learning outcomes

The values of the cognitive, affective and psychomotor aspects are then calculated to find the final value which can be seen in Table 5 below.

Table 5. Qualification of student learning outcomes in final grades at High School 8 and 10 East Seram

High School 8 East Seram								High School 10 East Seram							
X.A (PjBL-STEM)				X.B (Conventional)				X.A (PjBL-STEM)				X.B (Conventional)			
C	F	%	C	K	F	%	C	K	F	%	K	K	F	%	C
> 70	22	100	Complete	> 70	22	100	Complete	> 70	14	100	Complete	> 70	14	100	Complete
< 70	-	-	Fail	< 70	-	-	Fail	< 70	-	-	Fail	< 70	-	-	Fail
T	22	100		T	22	100		T	14	100		T	14	100	
		78				72				74				71	

Note: C: minimum crtieria; F: frekuensi; %: percentage; K: completeness; T: total

Based on Table 5 above, the results of students' final learning achievement show that for scores above the Minimum Mastery Criterion > 70, there were 22 students (100%) who achieved mastery. When comparing the Mastery Criterion with the average final achievement scores, it can be concluded that the final learning outcomes of students at High School 8 East Seram were 78 for Class X A and 72 for Class X B. Meanwhile, at High School 10 East Seram, all students also achieved scores above the mastery criterion > 70, with 14 students categorized as having achieved mastery. Comparing the mastery criterion with the average final achievement scores, it can be stated that the final learning outcomes were 74 for Class X A and 71 for Class X B.

B. Critical thinking

Preetest and posttest

Critical thinking skills in class using the student worksheet learning model based on PjBL-STEM or with the conventional learning model (lecture) on ecosystem material are measured through an initial test (Pretest) and a final test (Protest) which are compiled based on critical thinking indicators (Table 6 and Table 7).

Table 6. Qualification of achievement score of initial test and final test High School 8 and East Seram

X.A (PjBL-STEM)								X.B (Conventional)							
Pretest				Postest				Pretest				Postest			
C	F	%	C	K	F	%	C	K	F	%	K	K	F	%	C
> 70	3	14	Complete	> 70	22	100	Complete	> 70	2	9	Complete	> 70	22	100	Complete
< 70	19	86	Fail	< 70	-	-	Fail	< 70	20	91	Fail	< 70	-	-	Fail
T	22	100		T	22	100		T	22	100		T	22	100	
						84									77

Note: C: minimum crtieria; F: frekuensi; %: percentage; K: completeness; T: total

Table 7. Qualification of achievement score of initial test and final test High School 10 and East Seram

X.A (PjBL-STEM)								X.B (Conventional)							
Pretest				Postest				Pretest				Postest			
C	F	%	C	K	F	%	C	K	F	%	K	K	F	%	C
> 70	2	14	Complete	> 70	14	100	Complete	> 70	2	14	Complete	> 70	14	100	Complete
< 70	12	86	Fail	< 70	-	-	Fail	< 70	12	86	Fail	< 70	-	-	Fail
T	22	100		T	14	100		T	22	100		T	14	100	
						78									77

Note: C: minimum crtieria; F: frekuensi; %: percentage; K: completeness; T: total

Based on Table 6, at High School 8 East Seram, prior to the learning intervention, only 3 students in Class X A and 2 students in Class X B had achieved mastery, while the majority had not yet reached the Minimum Mastery Criterion. After the learning process, all students (100%) achieved mastery, with the most significant improvement observed in Class X A, which obtained an average score of 84% using the PjBL-STEM, compared to 77% in the conventional class. Based on Table 7, at High School 10 East Seram, the initial condition showed that only 2 students in Class X A and 2 students in Class X B achieved mastery, while most students were below the Minimum Mastery Criterion. After the learning intervention, all students (100%) achieved mastery, with the greatest improvement seen in Class X A, which reached an average score of 78% using the PjBL-STEM, compared to 70% in the conventional class.

Data analysis needs

The results of the needs analysis for student worksheets based on PjBL-STEM can be seen in Table 8 and Table 9 below.

Table 8. Teacher response questionnaire on integrated PjBL-STEM student worksheets at High School 8 East Seram

	Assessment Aspects	Score each aspect	Minimum score	Percentage	Criteria
	Content Components	26	28	92	Very Worthy
	Presentation	11	12	91	Very Worthy
	Language	6	8	75	Worthy
	Graphics	6	8	75	Worthy
Total number			49		
Maximum score			56		
Percentage			87		
Criteria			Very Worthy		

Table 9. Teacher response questionnaire on integrated PjBL-STEM student worksheets at High School 10 East Seram

	Assessment Aspects	Score each aspect	Minimum score	Percentage	Criteria
	Content Components	26	28	92	Very Worthy
	Presentation	10	12	83	Very Worthy
	Language	7	8	87	Very Worthy
	Graphics	7	8	87	Very Worthy
Total number			50		
Maximum score			56		
Percentage			89		
Criteria			Very Worthy		

Validation data for integrated PjBL-STEM student worksheets

The results of the validation analysis of 3 validators on the PjBL-STEM based student worksheets can be seen in Table 10 below.

Table 10. Validation of PjBL-STEM based student worksheets

Material Expert Validation Results				
Aspect	**Score for each aspect**	**Maximum score**	**Percentage**	**Criteria**
Content suitability	32	36	88	Very Worthy
Suitability of questions	20	20	100	Very Worthy
Total number		52		
Maximum score		56		
Percentage		92		
Criteria		Very Worthy		
Linguist Expert Validation Results				
Aspect	**Score for each aspect**	**Maximum score**	**Percentage**	**Criteria**
Linguistic Components	21	28	75	Worthy
Total number		21		
Maximum score		28		
Percentage		75		

Criteria		Worthy		
Design Expert Validation Results				
Aspect	**Score for each aspect**	**Maximum score**	**Percentage**	**Criteria**
Graphic components	41	44	93	Very Worthy
Presentation components	21	24	87	Very Worthy
Total number		62		
Maximum score		68		
Percentage		91		
Criteria		Very Worthy		

Based on the Table above, it can be concluded that the use of PjBL based student worksheets integrated with STEM is very feasible to be implemented. It is known that the validation results from material experts and design experts show that the interpretation of the criteria is very feasible, while from language experts it shows that the interpretation of the criteria is feasible.

Student responses to student worksheet products

The assessment of the student response questionnaire instrument that has been taken is assumed to reflect the actual opinions of students because all factors that can cause subjective assessments have been minimized. The implementation of learning using Student Worksheets based on PjBL-STEM makes students more enthusiastic in following the learning process. Thus, the following results of student responses were obtained.

Table 11. Student responses to student worksheets at High School 8 and 10 East Seram

	Total respondens	**Percentage**
High School 8 East Seram	22	82
High School 10 East Seram	14	67

Based on Table 11, students' responses to the PjBL-STEM based student worksheet designed to enhance critical thinking skills and learning outcomes on the ecosystem topic at High School 8 East Seram showed a positive response of 82%, as reported by 22 students from Class X A (experimental class). Meanwhile, at High School 10 East Seram, students' responses to the same PjBL-STEM based student worksheet obtained from 14 students in Class X A (experimental class)—showed a positive response percentage of 67%, indicating that the use of this student worksheet was generally well-received and contributed to improving students' engagement, critical thinking, and learning outcomes.

C. Differences in learning models using student worksheets based on STEM-PjBL on cognitive learning outcomes and critical thinking of High School in East Seram

The results of the T-test (Sample T-test) can be seen in the Table 12 below.

Table 12. Test result T at High School 8 and 10 East Seram

No	**School**	**Variable**	**Class**	**Df**	**Mean**	**Sig**	**Information**
1	High School 8 East Seram	Learning outcomes	XA	22	77.18	.004	Real Difference
			XB	22	71.50	.004	Real Difference
		Critical thinking	XA	22	83.09	.002	Real Difference
			XB	22	75.77	.002	Real Difference
		Learning outcomes and critical thinking	XA	22	80.14	.000	Real Difference
			XB	22	73.64	.000	Real Difference
2	High School 10 East Seram	Learning outcomes	XA	14	74.00	.003	Real Difference
			XB	14	70.86	.003	Real Difference
		Critical thinking	XA	14	77.57	.004	Real Difference
			XB	14	71.07	.004	Real Difference
		Learning outcomes and critical thinking	XA	14	75.79	.000	Real Difference
			XB	14	70.96	.000	Real Difference

Based on the t-test output produced by the SPSS software above, the sig (2-tailed) value obtained is 0.000 < α = (0.05), so H0 is rejected and Ha is accepted. The evaluation of students' learning outcomes was conducted through a comparison of pretest and posttest scores between the experimental and control groups. The pretest was administered at the beginning of the learning process to assess students' baseline abilities prior to studying the ecosystem material (Wati and Zuhdi, 2017). This test served to determine students' readiness and their initial conceptual understanding, allowing for the identification of learning objectives that had already been achieved as well as those requiring further emphasis (Kadir 2015; Roestiya 2008). Subsequently, the posttest was administered after the learning process to evaluate the extent of students' mastery of the learning indicators covered (Yulianti et al. 2022). The analysis results indicated that the average posttest score of the class using PjBL-STEM based worksheets was higher than that of the conventional class. Descriptive data showed that although both classes exhibited an improvement from pretest to posttest, the experimental class demonstrated a more significant increase. This finding is consistent with Kahfi and Srirahayu (2021), who asserted that learning outcomes are influenced by facilities, infrastructure, and interactive learning media that encourage greater student engagement.

In addition to cognitive improvement, students' affective aspects also showed positive development. The affective assessment encompassed students' attitudes, values, and behaviors, such as active participation in group activities, willingness to answer questions, and ability to contribute ideas (Mu'in and Rahim, 2024). The findings revealed that the class utilizing STEM-integrated PjBL-based worksheets achieved higher affective scores than the conventional class. This indicates that students were more engaged, demonstrated effective interaction, and exhibited positive responses toward the learning process.

Students' psychomotor aspects also showed improvement. According to Larasati et al. (2023), the psychomotor domain can be assessed through observations of students' demonstrated skills, such as classifying data, organizing data into tables, and creating drawings. The research findings indicated that all students achieved mastery, both individually and collectively, with the experimental class attaining a higher average psychomotor score than the conventional class. Students' enthusiasm during practical activities demonstrated that the PjBL-STEM based worksheets effectively fostered tangible skills relevant to the ecosystem topic.

Overall, the final scores of students' learning outcomes demonstrated consistent success. All students achieved mastery, with the experimental class obtaining a higher average score than the conventional class. This indicates that students not only mastered the learning indicators but also exhibited strong motivation and determination to succeed. These findings reinforce that the implementation of PjBL-STEM based worksheets contributes to improving learning outcomes across cognitive, affective, and psychomotor domains.

All students achieved mastery, with the experimental class obtaining a higher average score than the conventional class. This indicates that students not only mastered the learning indicators but also demonstrated strong motivation and a strong desire to succeed. These findings reinforce that the implementation of PjBL-STEM based worksheets contributes to enhancing learning outcomes across cognitive, affective, and psychomotor domains.

Overall, the final scores of students' learning outcomes demonstrated consistent achievement. All students achieved mastery, with the experimental class obtaining a higher average score than the conventional class. This suggests that students not only mastered the learning indicators but also exhibited strong motivation and a genuine desire to succeed. These findings strengthen the evidence that the implementation of PjBL integrated STEM based worksheets contributes to improving learning outcomes across cognitive, affective, and psychomotor domains.

Critical thinking is a higher-order thinking skill that emphasizes students' active involvement in problem-solving processes based on the issues presented or encountered. Students are expected to be able to identify the causes of a problem and be guided to find alternative solutions or approaches in order to draw reflective and logical conclusions (Darwati and Purana, 2021). The critical thinking skill scores of students in this study were obtained from formative assessments, namely the pretest and posttest.

Based on the research findings (Table 5), the students' pretest scores in both the class using PjBL integrated STEM based worksheets and the conventional (lecture-based) class were low, whereas their posttest scores in both classes were high. This indicates an improvement in students' performance after participating in learning activities using both the PjBL integrated STEM based model and the conventional lecture model. In the learning process, the integration of these two models offers several advantages and has the potential to enhance students' critical thinking skills.The activities implemented in the PjBL-STEM learning process refer to the stages of project-based learning, which are also integrated with the principles of STEM. The stages include identifying essential questions, designing project plans, developing schedules, monitoring progress, assessing outcomes, and conducting evaluations. The initial step in STEM-integrated PjBL learning involves determining essential questions that assign students to complete projects aimed at solving problems and engaging in meaningful activities. The topics used should be relevant to real-world situations.

The development of students' critical thinking skills in the experimental class was influenced by the implementation of the PjBL integrated STEM learning model by the researcher. This finding is consistent with the study conducted by Fitriyah and Ramadani (2021), which demonstrated that the STEM-based PjBL learning model was 36% more effective in enhancing students' critical thinking skills compared to the conventional learning model. Similarly, Rahardhian (2022) reported that the application of the STEM-based PjBL model had a significant impact on students' critical thinking abilities, as learning through STEM projects helps students develop scientific skills, including critical thinking. Initially, students' participation was relatively low, as indicated by the small number of students who dared to ask questions or express opinions. This suggests that students tended to focus on the teacher without engaging in analysis, critique, or evaluation of the material presented. However, after the implementation of the PjBL integrated STEM learning model, students became more active in asking and answering questions, which reflected an improvement in their critical thinking skills. This is supported by the findings of Windasari et al. (2020), who showed that the STEM-based PjBL model encourages students to explore knowledge through product creation and solution-oriented activities, thereby fostering active participation throughout the learning process.

The research findings indicate that the alternative hypothesis (Ha) was accepted, meaning that there was a significant difference in learning outcomes and critical thinking skills between students taught using the PjBL integrated STEM based worksheets and those taught using conventional methods at High School 8 East Seram and High School 10 East Seram, with a significance value of $p < 0.05$. In this study, the researcher administered both a pretest and a posttest to the students. The pretest was conducted to assess students' prior understanding of the ecosystem topic and to determine their readiness before participating in the learning process (Kadir 2015). The posttest aimed to evaluate the level of success from both the teacher's and students' perspectives. It was administered after the learning process to measure whether students had fully mastered and achieved the learning objectives of the ecosystem topic by the end of the session.

Based on the final data analysis obtained from the pretest and posttest results, the findings indicate that the implementation of the PjBL integrated STEM based worksheet learning model at High School 8 East Seram resulted in higher average pretest and posttest scores, with an overall mean score of 77. This improvement can be attributed to several supporting factors that contributed to the increase in students' average scores, including: (1) Local environment,The students' surrounding environment can influence their learning mindset, such as positive parental attitudes, healthy peer interactions, and continuous motivation provided by teachers, (2) School discipline, The implementation of discipline at school fosters students' responsibility and consistency in learning, (3) Facilities and learning resources, Supporting facilities such as libraries help students easily access new information and expand their knowledge, (4) Learning motivation, Students with curiosity and intrinsic motivation are more likely to engage actively in learning, which positively impacts their academic achievement, (5) Students' talents and interests, When students possess a genuine interest and talent in learning, their academic performance and overall learning outcomes tend to improve.

In contrast, High School 10 East Seram showed lower average pretest and posttest scores, with an overall mean score of 71. This relatively lower performance can be attributed to several contributing factors, including: (1) Lack of parental support, One indicator of limited parental involvement in children's education is the lack of attention given to students' academic progress, (2) Low parental concern for attendance, Some parents show minimal concern regarding their children's school attendance, which affects students' learning consistency. (3) Limited learning independence, A lack of self-directed learning habits among students is suspected to be one of the main causes of their lower academic achievement, (4) Challenging environmental conditions, The difficult social and environmental circumstances faced by students may also hinder their academic development., (5) Inadequate learning facilities, Limited access to adequate learning resources and materials restricts students' ability to enhance their academic performance. (6) Shortage of qualified teachers, the limited number of educators in the school contributes to the lower quality of instruction and, consequently, students' academic outcomes, (7) Low learning motivation and work ethic – A weak learning ethos is a major factor contributing to students' low academic performance in the school.

The PjBL learning model has advantages in improving learning habits and motivating students to think creatively when solving everyday life problems. PjBL is able to improve students' critical thinking skills (Nita & Irwandi, 2021). Therefore, PjBL is very appropriate for achieving 21st-century educational goals because it is contextual, which can improve students' critical thinking skills (Hikmah et al. 2016).

The STEM approach in PjBL learning, teachers provide direction through observing, asking, trying, relating, and communicating natural phenomena that students commonly experience in everyday life. Furthermore, students can improve their critical thinking skills by determining possible alternative answers. Furthermore, students look for solutions to a problem, then students design a project according to the problems posed by the teacher. In the project design phase, students' thinking skills will emerge and be honed. At the end of the phase, the teacher guides students so they can model Priantari (2020) states that STEM-integrated project-based learning

focuses on students' critical thinking skills. Learning using the STEM approach can sharpen and improve students' learning skills such as formulating ideas and ideas. With this STEM approach, students appear to participate more and can express their ideas (Hidayani 2017).

The benefits obtained from the application of student worksheet in the learning process are very diverse. The use of student worksheet can provide opportunities for students to actively engage with the material being studied. The PjBL learning model integrated with STEM applied by this researcher is a combination of learning models and methods to help students deepen their understanding of systematic knowledge simultaneously and train their critical thinking skills. The PjBL learning model emphasizes the learning context through complex activities that allow students to freely explore, plan learning activities, collaborate on projects, and ultimately produce certain products. This learning model can also trigger activeness in study groups because the process of finding problem solutions obtained in this learning model makes students understand well about the ecosystem material taught using student worksheet teaching materials.

Thus, it can be concluded that there are differences in the learning outcomes and critical thinking skills of students taught using the STEM-integrated PjBL-based Student Worksheet learning model on ecosystems. Developing students' learning outcomes and critical thinking in a learning activity essentially means facilitating students' understanding of the relationship between the material being studied and themselves.

CONCLUSION

The results of the study indicate that the implementation of PjBLintegrated STEM based student worksheet has a significant effect on students' learning outcomes and critical thinking skills on ecosystem material. In High School 8, the average learning outcomes and critical thinking of class XA are higher (77 and 84) than class XB (71 and 77) with a significance value <0.05. Similar findings were also seen in High School 10, where class XA obtained an average learning outcome of 74 and critical thinking of 78, higher than class XB with values 71 and 70, and a significance value <0.05. Overall, this study proves that the PjBL-STEM-based student worksheet learning model is more effective than conventional methods. The application of this model not only improves learning outcomes, but also develops students' critical thinking skills, making it relevant for use in biology learning on ecosystem material to support 21st-century skills.

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