RESEARCH ARTICLE

The effect of project-based learning model on students' critical and creative thinking skills in the ecosystem concept

Fissilmi Khafah [a,1], Purwati Kuswarini Suprapto [a,2,*], Egi Nuryadin [a,3]

[a] Department of Biology Education, Faculty of Teacher Training and Education, Universitas Siliwangi, Jl. Siliwangi No.24 Tasikmalaya, West Java 46115, Indonesia

[1] fissilmifahrurojimaruf@gmail.com; [2] purwatikuswarini@unsil.ac.id*; [3] egi.nuryadin@unsil.ac.id

Abstract: Critical and creative thinking abilities are part of 21st century skills that have not been well utilized. One effort to improve these abilities can be through project-based learning (PjBL). This quantitative study aims to determine the effect of the PjBL model on students' critical thinking and creative thinking abilities on the ecosystem concept. This research used a quasi-experimental design with the matching posttest-only control group design and a population of all class The sample was determined using a purposive sampling technique with various considerations, selecting class X-1 as the experimental class and class X-2 as the control class. The research instrument used 15 questions for critical thinking skills and 12 questions for creative thinking. The collected data was then analyzed using the one-way ANOVA test. The results of the analysis show that the PjBL model has a significant effect on students' critical and creative thinking abilities on the ecosystem concept (P 0.000 < 0.05). Thus, the PjBL model can be used as an alternative learning to empower 21st century skills.

Keywords: Creative thinking; critical thinking; ecosystem concept; project-based learning

For correspondence:
purwatikuswarini@unsil.ac.id

Article history:
Received: 27 June 2023
Revised: 5 September 2023
Accepted: 14 September 2023
Published: 20 September 2023

10.22219/jpbi.v9i3.27461

p-ISSN: 2442-3750
e-ISSN: 2537-6204

How to cite:
Khafah, F., Suprapto, P. K., & Nuryadin, E. (2023). The effect of project-based learning model on students' critical and creative thinking skills in the ecosystem concept. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *9*(3), 244-255 https://doi.org/10.22219/jpbi.v9i3.27461

Introduction

The 21st century is notable for the rapid advancements in science and technology, which serve as the driving force behind innovations and have significantly impacted social, political, economic, and cultural systems (Issa, 2021; Perdana, 2020; Putri, 2023). Therefore, education in this century is experiencing a real change, which has contributed to highlighting the imperatives of this century for humanity to meet changing needs and expectations (Ellianawati, 2023; Silva, 2023). To address this issue, the Ministry of Education in Indonesia has introduced a new curriculum named Kurikulum Merdeka, which has come into effect this year, The new curriculum aims to equip students with the skills necessary for success in the 21st century (Yılmaz, 2021). These skills include critical and creative thinking, which are considered essential for higher-order cognitive thinking (Latorre-Cosculluela, 2020; Ludvik, 2023; Toheri, 2020). To achieve this, the Ministry has adopted effective teaching strategies that are designed to improve students' critical and creative thinking abilities. Education and curriculum that are centered on values and character, no longer only focus on mastering subject matter. All 21st century skills are not acquired from birth but are obtained from a process of practice, learning and experience (Álvarez-Huerta, 2022; Astutik, 2020; Ramdani, 2022).

Based on the results of the 2018 Program for International Student Assessment (PISA) released by the Organization for Economic Co-operation and Development (OECD), the science abilities of students in Indonesia have not experienced a significant increase from 2009 and are in the low performance quadrant. This shows that learning in Indonesia is not fully based on curriculum objectives. In addition, the weakness of students in Indonesia is their inability when faced with problems that require higher

order thinking skills (Arce-Saavedra, 2022; Astutik, 2020). Higher Order Thinking Skills are important to develop because they include critical and creative thinking, critical thinking is characterized as analytical, focused and objective thinking by optimizing the left brain. While creative thinking has the characteristics of creating, expanding, and subjectively by optimizing the right brain (Asmara, 2023; Bloom, 2020; Heong, 2020; Tharakan, 2020). In bloom's taxonomy revised the cognitive dimensions sequentially starting from remembering, understanding, applying, analyzing, evaluating, to creating (Krathwohl, 2021). Critical thinking is at the level of analyzing and evaluating, while creative thinking is at the level of creating. In line with Baruah (2023) critical and creative thinking are interrelated in a holistic view of human thinking skills. The ability to make decisions and solve problems requires critical thinking, the ability to combine a number of existing information and make something different for the purpose of solving new and unprecedented problems requires creative thinking. So to improve students' high-order thinking skills, fulfill 21st century skills and follow the demands of *Kurikulum Merdeka*, it will be effective if applied in a project-based learning (PjBL) process (Issa, 2021; Khoiri, 2023; Pramasdyahsari, 2023; Sangur, 2023).

The use of other learning models to improve critical and creative thinking skills such as problem-based learning (Hursen, 2021; Kardoyo, 2020). inquiry social complexity (ISC) (Perdana, 2020), Cooperative Learning Jigsaw and Group Investigation (Fallahi, 2023; Silva, 2023) can improve critical and creative thinking skills to the high category. These learning model is good, but to improve critical and creative thinking skills it is better to use the PjBL model (Issa, 2021; Santoso, 2021; Sumarni, 2020; Suradika, 2023). This is because the PjBL syntax requires students to make products that can answer essential problems or questions, making products is the highest level of bloom cognitive skills (Khoiri, 2023; Latifaj, 2023; Manikutty, 2022) and real implementation of creative thinking abilities (Wahyudi, 2021) because they are able to create something new from the results of their thinking even within the scope of the class. or school. Apart from that, PjBL has a syntax that has the most influence on critical thinking skills, namely at the first stage (start with the essential question) because at this stage students are guided to analyze the causes of problems and then design alternative solutions that can be implemented, then the syntax has the most influence on creative thinking skills, namely in the second stage (design a plan for the project) at this stage students need to express as many project ideas as possible after that determine a product that can be an alternative solution to the problem and answer essential questions (Latifaj, 2023; Sanchez-Muñoz, 2022). Apart from that, in the process the 5P approach (*Proyek Penguatan Profil Pelajar Pancasila*) is implemented with the aim of providing informal learning experiences to students with an interactive, flexible learning structure and enabling students to be directly involved in thinking about solutions to problems in the surrounding environment (Utama, 2022). In line with Issa (2021) recommended the necessity of adopting a PjBL.

According to Kardoyo (2020) PjBL can involve students directly in solving problems that are relevant to everyday life. Besides that, when making projects students usually have a sense of ownership so they will naturally be involved in solving problems, making decisions, or investigative activities, so that students have the opportunity to be independent in producing a realistic product and presentation. besides that the learning process with projects is innovative, creative and fun learning which is an alternative to 21st century learning (Nawangsari et al., 2022; Suradika, 2023; Tarling, 2023). Additionally, the George Lucas Educational Foundation (2005) explains the stages of this model include giving questions, designing projects, making schedules, monitoring the implementation of learning, conducting assessments, evaluations and reflections.

Based on the results of observations and interviews with one of the Biology subject teachers on September, 2022 at SMA Negeri 1 Tasikmalaya in class X, information was obtained that the previous learning process during Covid-19 carried out online was still teacher centered, learning methods lectures, the lack of interest of students to study teaching materials provided by the teacher, most students answer questions by looking at answers on the internet without delving deeper into how to solve these questions. In addition, the learning process only develops low-level cognitive, namely measuring cognitive aspects at the level of memory and understanding of an available concept, limited to preparation for answering exam questions, whereas according to Urry (2020) states that Biology is one of the subjects of science nature, which has concrete and abstract material concept, also a misconception often occurs when the students try to deal with those topics, not only remembers concepts but also understands these concepts through reasoning, solving problems and communicating ideas (Fitria, 2020; Ceylan, 2022).

Ecosystem material is considered difficult to understand because it has a lot of concrete and abstract understanding (Urry, 2020; Kovaliuk, 2021; Otto 2023) starting with observing ecosystem problems in the surrounding environment such as observing water, air, soil and other pollution in ecosystems (Grunewald, 2021; Zhang, 2023) then identifying interactions between ecosystem components and collaborate between students in order to be able to understand the flow of energy that occurs in it and be able to provide solutions to these problems (Tusznio, 2020; Ivars 2023; Wang 2022)

While the previous learning process was mostly through teaching materials in the form of videos or images only so that many students did not understand the concepts and terms in ecosystem material, this was certainly not effective and did not train critical and creative thinking skills which are important

for students to have. to solve a problem both in biology subjects and in everyday life.
Critical thinking is a mental process that involves cognitive activity (Nosari, 2023; Zhao, 2021) involving logical and analytical thinking skills aimed at solving problems and finding solutions, then producing a decision whereas creative thinking is thinking consistently and continuously producing something appropriate with the need to solve problems in a way that is unique, diverse and different from the others (Arjunaidi, 2022; Morales, 2021; Muskita, 2020; Paidi, 2023). According to Ennis (in Costa, 1985) there are five indicators of critical thinking, including: elementary clarification, basic support, inferring, advanced clarification, strategies and tactics. According to Torrance (in Munanadar, 2997) there are four indicators of creative thinking, including: fluency, flexibility, originality, and elaboration.
This research aims to determine the effect of the PjBL model on the critical and creative thinking abilities of students in class X of SMA Negeri 1 Tasikmalaya, Jawa Barat, Indonesia which uses the new curriculum, namely the Independent Curriculum. The independent curriculum states that in class X there is no science and social studies major, so students have the freedom to choose the subjects they will study. Apart from that, the 5P approach (*Proyek Penguatan Profil Pelajar Pancasila*) is implemented which aims to provide opportunities for students to learn from the surrounding environment, for example based on problems or phenomena that occur in the everyday environment such as ecosystem problems in the area where students live, because of this, of course the students' learning process is experiencing changes in the hope of improving critical and creative thinking skills to equip students for the 21st century. Apart from that, the benefit of this research is providing information on the influence of the PjBL process on students' critical and creative thinking abilities, so that students can be active in the learning process and able to solve a problem from the results of creating an idea or product by utilizing the existing environment.

Method

The research method used in this study was a quasi-experimental design with the research design being The Matching Posttest-Only Control Group Design. The research implementation is an even semester at SMAN 1 Tasikmalaya, West Java, Indonesia in the 2022/2023 academic year. The population of this study was all of class X which consisted of 12 classes with a total of 462 students with a research sample of class X-1 totaling 34 (14 male and 20 female) as the experimental class and class X-2 totaling 34 (13 male and 21 female) as the control class. The procedures in this study include: 1) the planning or preparation stage, 2) the implementation stage, at the implementation stage through learning activities: (a). Start with essential question, (b). Design project, (c). Create schedule, (d). Monitoring the students and progress of the project, (e). Assess the outcome, (f). Evaluation of the experience. 3) data collection stage. 4) data processing stage, 5). Data analysis stage, 6) conclusion stage.
The instrument used in this study was a test describing critical thinking skills based on five indicators of critical thinking, namely providing simple explanations, building basic skills, making inferences, providing further explanations, and setting strategies and tactics. Each indicator is represented by 3 essay questions so a total of 15 critical thinking skills questions. Meanwhile, the instrument used to measure creative thinking ability is based on four indicators of creative thinking, namely fluency, flexibility, originality and detailing. Each indicator is represented by 3 description questions so the total questions for creative thinking ability are 12 description questions. The two tests were carried out at the end of the lesson.
Data analysis techniques using descriptive statistical analysis, parametric statistics and non-parametric statistics. Descriptive statistical analysis was used to calculate posttest scores for students' critical and creative thinking skills, parametric tests for critical thinking abilities used the One-Way ANOVA hypothesis test and non-parametric tests for creative thinking skills used Kruskal Wallis. This can be done after previously carrying out prerequisite tests which include normality and homogeneity tests.

Results and Discussion

Based on the results of the calculation of the validity and reliability tests of the items on the ability to think critically and creatively using the Anates software version 4.0 for windows, 15 questions on the ability to think critically and 12 questions on the ability to think creatively are obtained. So, the number of questions used in this study is 27 items. Based on Table 1, the significant values in the experimental class and the control class have a significance value greater than 0.05.

Table 1. Normality test of critical and creative thinking

	Class	Kolmogorov – Smirnov		
		Statistic	Df	Sig.
Critical Thinking	Experimental Class	.102	34	.496
	Control Class	.117	34	.200
Creative Thinking	Experimental Class	.131	34	.148
	Control Class	.147	34	.062

On critical thinking in experimental class, it has a significance value of 0.496 and the control class has a significance value of 0.200. So, it can be stated that the data on the results of critical thinking skills in the experimental class and control class are normally distributed with Sig> α, namely 0.496 > 0.05 and 0.200 > 0.05. On creative thinking in experimental class, it has a significance value of 0.148 and the control class has a significance value of 0.062. So, it can be stated that the data on creative thinking skills in the experimental class are not normally distributed with Sig > α, namely 0.148 > 0.05, while the control class is normally distributed with Sig > α, namely 0.062 > 0.05.
Based on Table 2, the significant values in the critical and creative thinking have a significance value greater than 0.05. On critical thinking has a significance value of 0.870 and creative thinking has a significance value of 0.478.

Table 2. Homogeneity Test of Critical and Creative Thinking

	Levene's Test	Df1	Df2	Sig.
Critical Thinking	.000	1	66	.870
Creative Thinking	.000	1	66	.478

Based on Table 3, the results of the Partial One-Way ANOVA test analysis show that the critical thinking ability has a significance value of less than 0.05 (0.000 < 0.05) and the creative thinking ability has a significance value of less than 0.05 (0.001 < 0.05). This means rejecting Ho because sig. <0.05, it can be concluded that there is an effect of PjBL model on critical and creative thinking abilities. Then, to determine the overall effect of the PjBL model, a simultaneous test was carried out.

Table 3. Partial hypothesis test

		Sum of Squares	df	Mean Square	F	Sig.
Critical Thinking	Between Groups	260.132	1	260.132	14.743	.000
	Within Groups	1164.500	66	17.644		
	Total	1424.632	67			
Creative Thinking	Between Groups	465.941	1	465.941	12.644	.001
	Within Groups	2432.118	66	36.850		
	Total	2898.059	67			

Table 4 is the result of a simultaneous test of the effect PjBL model on students' critical and creative thinking abilities, obtained a sig. 0.000 < 0.05 with Fcount 10.504 > Ftable 3.138 This means that Ho is rejected or simultaneously there is an effect of PjBL model on students' critical and creative thinking skills in the ecosystem concept in class X SMA Negeri 1 Tasikmalaya, West Jawa, Indonesia in the 2022/2023 academic year.

Table 4. Simultaneous hypothesis test

	Model	Sum of Squares	df	Mean Square	F	Sig.
1	Regression	707.857	2	353.929	10.504	.000[b]
	Residual	2190.202	65	33.695		
	Total	2898.059	67			

The results of the One-Way ANOVA test, either partial or simultaneous, are in line with previous research which shows that the stages of the PjBL model have a positive effect on critical and creative thinking abilities. Sumarni (2020) indicated that continuous implementation of critical and creative thinking strategies could develop more meaningful concepts as well as high-level thinking skills. The

implementation of the PjBL has improved the students' abilities in thinking skills such as cause-effect thinking, predicting reasonable results, analyzing data through various points of view, evaluating, and creating. Those skills were developed through frequent opportunities to explore and express opinions and ideas in critical and creative thinking. Nawangsari (2022) shows that there is a relationship between making projects and critical and creative thinking skills. It is assumed that is a learning model using activities or projects to provide an understanding of one material. Through this model, students are expected to develop their knowledge more critically (Akpur, 2020; Raj, 2022) and involve students to complete a specific learning project by solving skills in working on a project to produce something (Bloom, 2020; Wahyudi, 2021), the following data shows effect of the PjBL model on critical and creative thinking abilities, seen from all indicators in the experimental class which is higher than in the control class.
Research conducted in the experimental class using the PjBL model has a posttest average score of the experimental class's critical thinking skills variable ($\bar{X}$ = 34.84) compared to the control class which has a posttest average score ($\bar{X}$ = 30.32) and the ability to think creatively in the experimental class was higher ($\bar{X}$ = 48.73) compared to the control class which had an average posttest score ($\bar{X}$ = 43.84). The following is a comparison diagram of the average posttest critical thinking in Figure 1 and creative in Figure 2.

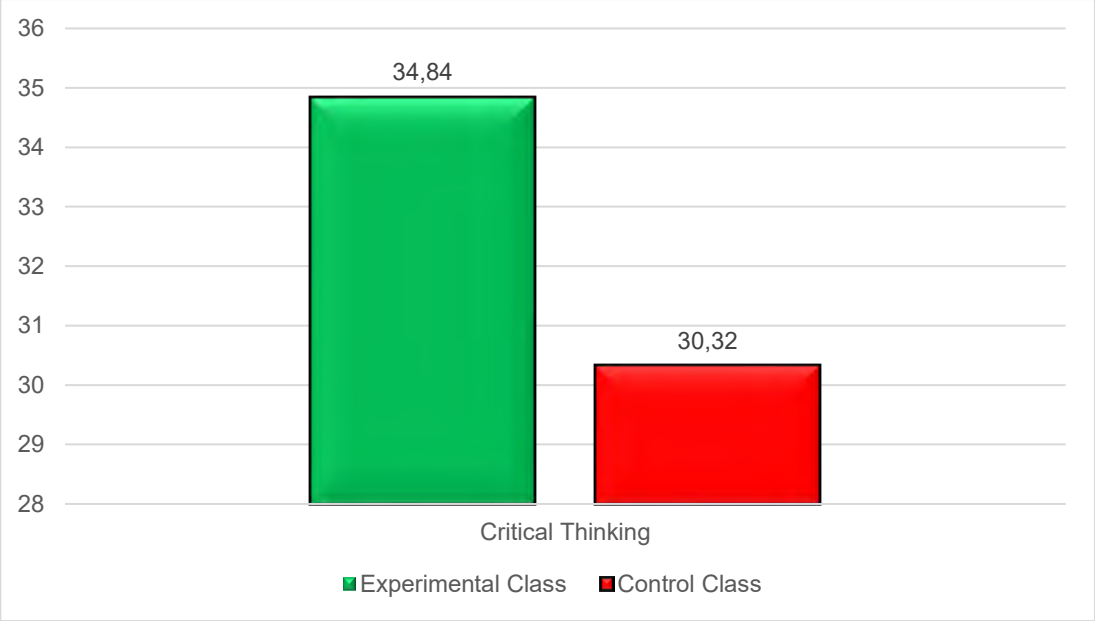

Figure 1. Comparison of the average critical thinking posttest scores

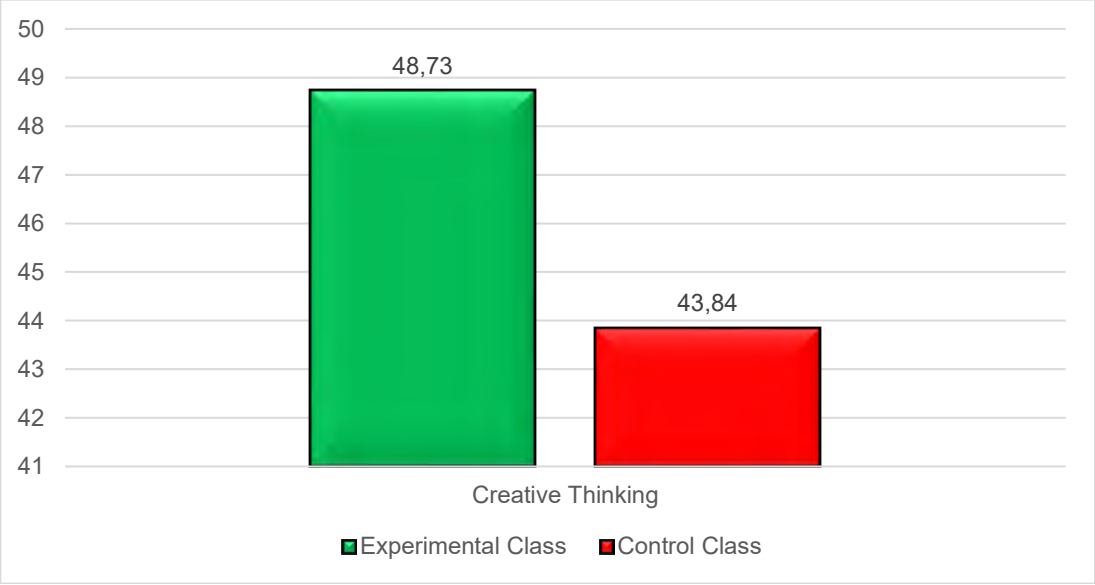

Figure 2. Comparison of the average critical thinking posttest scores

The difference in the posttest average scores for critical and creative thinking skills is due to the different treatment given in the learning between the experimental class and the control class. The experimental class uses the PjBL model which has a higher score than the control class which uses the discovery learning model.

This shows that the PjBL model can give a higher score on students' critical and creative thinking skills (Hamdani, 2020) in ecosystem material. The learning process includes three stages, namely opening, core activities and closing (Sankaran, 2020), the reason for the ability to think critically and creatively in the experimental class is higher than in the control class because the learning stages, more precisely, the core activities that take place are different (Santoso, 2021). The experimental class has six stages divided into two stages and unlimited monitoring time. Whereas in the control class there are several stages that must be completed at one time with a limited time. In the experimental class students are given worksheets (LKPD) which can provide opportunities for students to identify ecosystem problems in the surrounding environment, try to provide alternatives to these problems, construct assignments given by the teacher and finally produce works or products.

In line with (Ellianawati, 2023; Khoiri, 2023; Suradika, 2023) that PjBL syntax can highlight students' critical and creative thinking skills. The PjBL syntax that has the most influence on critical thinking skills is in the first stage (start with the essential question) at this stage students are guided to answer essential questions by identifying ecosystem problems in the surrounding environment, analyzing the causes of these problems and then designing alternative solutions to solve this problem (Anderson, 2016; Ceylan, 2022; Qiang, 2020) and PjBL syntax which has the most influence on creative thinking skills, namely in the second stage (design a plan for the project) at this stage students need to express as many project ideas as possible after that determine one product. which can be an alternative solution to problems and answer essential questions (Cooper, 2021; Freeman, 2021; Valentová, 2020).

Critical thinking on ecosystem concepts

The effect of increasing students' critical thinking skills is inseparable from the role of the PjBL model which makes students' critical thinking skills increase (Zhao, 2021). The PjBL model forms students to think critically, this model provides opportunities for students to build knowledge and develop **their** own skills (Harwati, 2021). This model also helps students to actively think about things in depth, ask questions, provide solutions to problems in everyday life and look for relevant information rather than passively waiting for information (Li, 2022; Supratman, 2021). Referring to Figure 2, students' scores can increase if there is a development in the learning process.

The research results obtained with the average value of students' critical thinking in the experimental class ($\bar{X}$ = 34.84) and the control class ($\bar{X}$ = 30.32). From these data it can be seen that the range of posttest scores obtained in the control class and the experimental class, where the average posttest score of the experimental class is greater than the posttest score of the control class with a difference in the average score of 4.52. This is in line with testing the hypothesis that there is an effect of the PjBL model on students' critical thinking. The percentage of achievement for each indicator of critical thinking ability in the experimental class and control class which is presented based on the critical thinking indicator according to Ennis (in Costa 1985) can be observed in Figure 3.

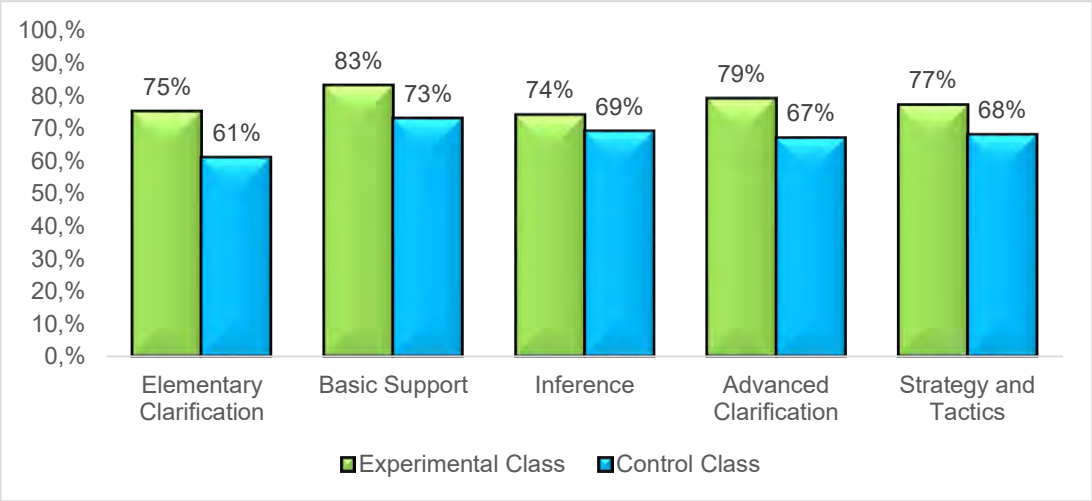

Figure 3. Percentage of achievement of each critical thinking ability indicator

Students' critical thinking skills are obtained through a description test conducted at the end of the learning meeting. It turned out that after the learning process was carried out in the experimental class, the results obtained for the average score of students who answered correctly were mostly found in the basic support indicator with an achievement percentage of 83% and the score that was the least answered correctly by students, namely the inference indicator with an achievement percentage 74%. Meanwhile, for the results of other indicators such as elementary clarification, advanced clarification and strategy and tactics, the respective percentages of achievement are (75%), (79%) and (77%).

Meanwhile, in the control class, the students answered correctly with the highest average score, namely the basic support indicator with an achievement percentage of 73% with a lower average frequency compared to the experimental class and the score that students answered at least correctly. namely the elementary clarification indicator with an achievement percentage of 61%. Meanwhile, for the results of other indicators such as inference, advanced clarification and strategy and tactics, the respective percentages of achievement are 69%, 67% and 68%. Figure 3 data shows that all indicators of critical thinking skills in the experimental class are higher than the control class.

In the elementary clarification indicator in the experimental class, students are better at focusing on questions that are being answered while the learning process is taking place, whereas in the control class, when learning is taking place, students are less focused on a question that is being answered, this is in line with Raj (2022) which states that subjects can go through elementary clarification indicators by focusing on questions and being able to maintain a good state of mind.

In the basic support indicator in the experimental class, students pay more attention to the alleged answers they are working on whether they are correct or not, whereas in the control class, students are less concerned with considering the answers they are working on, this is in line with Sangur (2023) which states that on the basic Support indicator the subject is able to analyze the problem by identifying relevant information and considering possible answers appropriately.

In the inference indicator in the experimental class during the learning process students were able to identify the main problems to be found a solution while in the control class students were still lacking in the process of identifying problems during the learning process, this was in line with Lira (2022) which stated that the inference indicator was the ability of students to identify the main issues then form answers that can be considered to draw the best conclusions.

On the advanced clarification indicator in the experimental class in the learning process students explore more understanding of the questions given by searching from several sources to convince themselves and find solutions to the questions given, whereas in the control class students find it easier to feel enough to answer a problem after finding one answer from one source, this is in line with Fitria (2020) which states that the advanced clarification indicator is a process of obtaining more detailed knowledge regarding a subject matter as an effort to be more self-assured.

In the Strategy and tactics indicator in the experimental class students are more critical in determining actions, the process of investigation and concluding final actions, while in the control class students are less critical in the investigation process and concluding final actions, this is in line with Aufa (2021) which states that the last indicator of critical thinking, namely Strategy and tactics, the subject concludes the results of suitable alternative answers as the final conclusion in the investigation process.

Creative thinking on ecosystem concepts

The effect of increasing students' creative thinking abilities cannot be separated from the role of the PjBL model which makes students' creative thinking increase (Ellianawati, 2023). The PjBL model also forms students to think at a higher level (HOTS) (Ardgondizza, 2022), able to analyze a problem (real world problem) (Wahyudi, 2021) and try to solve it by producing a structured product to construct higher knowledge and thinking (Utama, 2022). Referring to Figure 2, students' scores can increase if there is a development in the learning process.

The research results obtained with the average value of students' creative thinking in the experimental class ($\bar{X}$ = 48.73) and the control class ($\bar{X}$ = 43.84). From these data it can be seen that the range of posttest scores obtained in the control class and the experimental class, where the average posttest score in the experimental class is greater than the posttest score in the control class with a difference in the average score of 4.89. This is in line with testing the hypothesis that there is an effect of the PjBL model on students' creative thinking. The percentage of achievement for each indicator of the ability to think creatively in the experimental class and control class which is presented based on the indicators of creative thinking according to Torrance (in Munandar, 1997) can be observed in Figure 4.

.

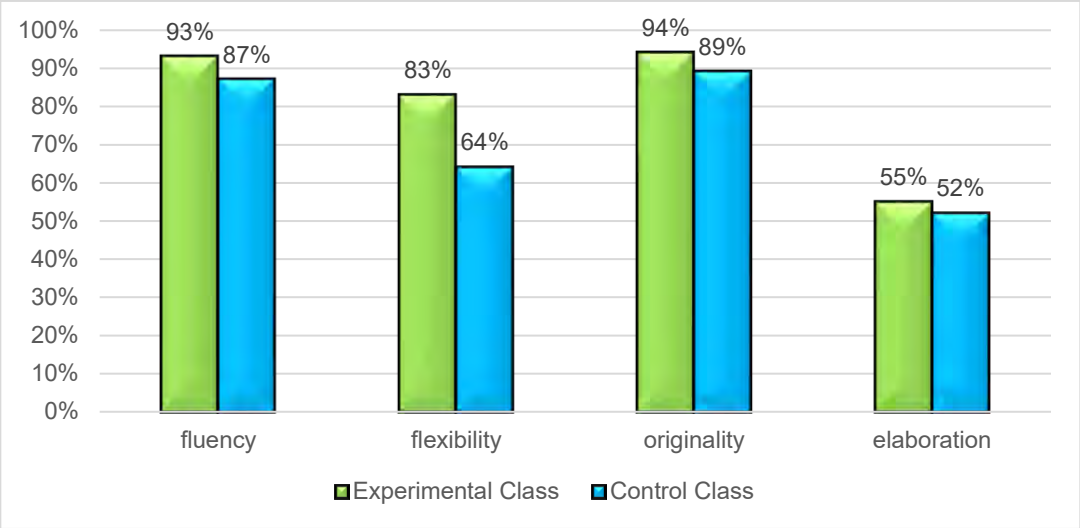

Figure 4. Percentage of achievement of each indicator of creative thinking ability

Students' creative thinking ability is obtained through a description test conducted at the end of the learning meeting. It turned out that after the learning process was carried out in the experimental class, the results obtained for the average score of students who answered correctly were mostly found on the originality indicator with an achievement percentage of 94% and the score that was the least answered correctly by students, namely on the elaboration indicator with an achievement percentage of 55 %. Meanwhile, for the results of other indicators such as fluency and flexibility, the respective percentages of achievement were 93% and 83%.

Meanwhile, in the control class, the students answered correctly with the highest average score, namely the originality indicator with an achievement percentage of 89% with a lower average frequency compared to the experimental class and the score that was the least answered correctly by students, namely on the elaboration indicator with an achievement percentage of 52%. Meanwhile, for the results of other indicators such as fluency and flexibility, the respective percentages of achievement were 87% and 64%. Figure 4.7 shows that all indicators of the ability to think creatively in the experimental class are higher than the control class.

Four indicators of creative thinking ability, first fluency when students provide good explanations, second flexibility where students are able to provide good solutions, third originality when students are able to provide creative ideas based on predetermined criteria, fourth elaboration where students are able to provide creative solutions based on specified criteria (Trisnayanti, 2020).

On the fluency indicator in the experimental class students think of more than three answers, when learning takes place students ask more questions, answer with a number of answers, think of many ideas and quickly see errors in objects or other people while in the control class students think more than one answer, not asking many questions and being less responsive when they see errors in other objects or people, this is in line with Mulyati (2021) which states that students who have fluency in thinking will ask lots of questions, answer with a number of answers, lots of ideas, work faster than other children, The ability to think fluently is essential for generating new ideas and creating valuable opportunities. Fluency is determined through the process of problem-solving, not just the end result and quickly seeing errors in objects or other people (Yanti, 2018).

The flexibility indicator in the experimental class produced more varied answers, saw problems from various views, changed ways of thinking and presented many alternative answers, while in the control class most students saw problems from one perspective and easily felt satisfied or satisfied when they had one. answer to answer a problem, this is in line with Handayani (2021) Flexibility involves being open to testing new ideas and possibilities. Those with flexible abilities can offer various interpretations of a problem, provide examples, and present multiple solutions. Students who are able to think flexibly will provide a variety of uses or that are unusual, various interpretations of an image or object, positions often conflict with the majority, are able to change spontaneous way of thinking (Puspitasari, 2019).

On the originality indicator in the experimental class students conveyed more unique expressions to understand the material, were able to develop new and unique answers, ideas or ideas to answer problems whereas in the control class during the learning process students were able to convey unique expressions for understanding the material but lacking in developing answers, ideas or ideas to answer the problems presented, this is in line with Munandar (2014) stating that students who have the ability to think originality have stepped from many the answer (fluency) to various answers (flexibility) is then able to face the challenge of developing new and unique answers (the answers can be new for the child

himself, most children of the same age or for the world in general) and originality is the ability to create unique combinations or offer rare definitions (Trisyanti, 2020).
In the elaboration indicator, students in the experimental class during the learning process provide more answers or solutions to a problem while detailing the details of the answers given. In addition, they are able to enrich and develop an idea or product, while in the control class, students are able to provide many answers but lack depth. adding or detailing the details of the answers given, this is in line with Mulyati (2021) which states that students are able to provide detailed answers while at the same time being able to enrich and develop these answers. Elaboration involves adding depth and detail to ideas, the last process of creative thinking is detailing or elaborating (develop, enrich) an idea (Handayani, 2021; Yanti, 2018).
Increasing students' critical and creative thinking abilities by using the PjBL model is due to the characteristics possessed by this model according to (Albar, 2021; Chen, 2022; Wahyuningsih, 2021) which states that the PjBL model is a learning model that uses projects to produce various alternative solutions that can solve problems in everyday. Students carry out exploration, assessment, interpretation, synthesis, and information to learn about critical, creative thinking and problem solving, as well as acquire essential knowledge and concepts from learning materials (Mursid, 2022; Santoso, 2021). Based on the description above, it can be concluded that the average posttest score for each indicator of critical and creative thinking skills obtained by students in the experimental class is higher than the average posttest score obtained by students in the control class.

Conclusion

Based on the research results, PjBL has an influence on students' critical and creative thinking abilities to the high category as seen from the posttest results. Critical and creative thinking abilities for each indicator in the experimental class are higher than in the control class, therefore, educators are expected to be able to implement PjBL with the 5P approach well. and designing learning effectively with appropriate time allocation, so that students can adapt to the independent curriculum and get used to thinking critically and creatively to prepare students for the 21st century. Furthermore, it is hoped that future research can investigate more deeply the influence of the PjBL model in empowering thinking skills others, both in biology learning and other learning.

Acknowledgement

The authors would like to thank the lecturers in the Department of Biology Education, Faculty of Teacher Training and Education, Universitas Siliwangi who have supported this research.

Conflicts of Interest

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

Author Contributions

F. Khafah: Methodology; Data analysis; Writing – original draft. **P. Kuswarini**: Writing – review and editing**. E. Nuryadin**: Writing – review and editing.

References

Akpur, U. (2020). Critical, reflective, creative thinking and their reflections on academic achievement. *Thinking Skills and Creativity*, *37*. https://doi.org/10.1016/j.tsc.2020.100683
Álvarez-Huerta, P. (2022). Disposition toward critical thinking and creative confidence beliefs in higher education students: The mediating role of openness to diversity and challenge. *Thinking Skills and Creativity*, *43*. https://doi.org/10.1016/j.tsc.2022.101003
Anderson, L. & Krathwohl, D. (2016). *Bloom's taxonomy revised understanding the new version of Bloom's taxonomy*.
Arce-Saavedra, B. J. (2022). Critical thinking, creativity, self-efficacy, and teaching practice in Peruvian teacher trainers. *Revista de Psicologia (Peru)*, *40*(1), 603–633. https://doi.org/10.18800/psico.202201.020
Arjunaidi, A. J. (2022). The Implementation of an inductive model on science students' critical thinking skills during online learning. *International Journal of Information and Education Technology*,

12(9), 858–865. https://doi.org/10.18178/ijiet.2022.12.9.1694
Asmara, R. (2023). Levels of Inquiry and Reading-Questioning-Answering (LoIRQA) to enhance high school students' critical and creative thinking. *International Journal of Instruction*, *16*(3), 325–342. https://doi.org/10.29333/iji.2023.16318a
Astutik, S. (2020). HOTS student worksheet to identification of scientific creativity skill, critical thinking skill and creative thinking skill in physics learning. In *Journal of Physics: Conference Series* (Vol. 1465, Issue 1). https://doi.org/10.1088/1742-6596/1465/1/012075
Aufa, M. N. (2021). Profile of students' critical thinking, creativity, and collaboration skills on environmental pollution material. In *Journal of Physics: Conference Series* (Vol. 1760, Issue 1). https://doi.org/10.1088/1742-6596/1760/1/012027
Baruah, J. (2023). Innovation in virtual teams: The critical role of anonymity across divergent and convergent thinking processes. *Journal of Creative Behavior*. https://doi.org/10.1002/jocb.603
Bloom, L. A. (2020). Using technology to foster creative and critical thinking in the classroom. In *Research Anthology on Developing Critical Thinking Skills in Students* (pp. 553–567). https://doi.org/10.4018/978-1-7998-3022-1.ch028
Buroidah, H., Zubaidah, S., Mahanal, S. (2023). Effects of project-based learning with project guide e-book on critical thinking and metacognitive skills: A case from undergraduate biology students in genetic 1 course. https://doi.org/10.33394/j-ps.v11i2.6727
Ceylan, Ö. (2022). The effect of the waste management themed summer program on gifted students' environmental attitude, creative thinking skills and critical thinking dispositions. *Journal of Adventure Education and Outdoor Learning*, *22*(1), 53–65. https://doi.org/10.1080/14729679.2020.1859393
Costa, Arthur L., (1985). *Developing minds a resource book for teaching thinking*
Cooper, A. A. (2021). Incorporating critical and creative thinking in a transitions course. *PRIMUS*, *31*(9), 995–1006. https://doi.org/10.1080/10511970.2020.1805659
Ellianawati, E. (2023). Development of critical and creative thinking skills for prospective physics teachers through mini-project-based learning during the COVID-19 pandemic. In *AIP Conference Proceedings* (Vol. 2614). https://doi.org/10.1063/5.0126053
Ennis, R. H. (2011). *The nature of critical thinking: an outline of critical thinking dispositions and abilities*. https://doi.org/10.5840/inquiryctnews20112613
Fallahi, N. (2023). The effectiveness of cognitive-behavioral psychodrama group therapy (CBPGT) on inadequate guardian male adolescents' creativity and critical thinking. *Thinking Skills and Creativity*, *47*. https://doi.org/10.1016/j.tsc.2022.101171
Fitria, R. (2020). Student's worksheet design for social arithmetic based on PBL to increase the critical thinking skills. *Universal Journal of Educational Research*, *8*(5), 2028–2046. https://doi.org/10.13189/ujer.2020.080541
Fraenkel, J. R., & Wallen, N. E. (2009). *How to design and evaluate research in education* (M. Ryan (ed.); Seventh Ed). Beth Mejia.
Freeman, K. J. (2021). The use of creative writing and staged readings to foster empathetic awareness and critical thinking. *Asia Pacific Scholar*, *6*(3), 75–82. https://doi.org/10.29060/TAPS.2021-6-3/OA2366
George Lucas Educational Foundation. (2005). Instructional module project based learning. [Online]. Diakses dari http://www.edutopia.org/modules/ pbl/project-based-learning
Guilford, J. P. (1950). *Characteristics of Creativity*. https://doi.org/10.1037/h0063487
Hamdani, Y. (2020). Preliminary analysis of physical module practicum modelling project based learning to improve scientific skills of high school students. In *Journal of Physics: Conference Series* (Vol. 1481, Issue 1). https://doi.org/10.1088/1742-6596/1481/1/012074
Harwati, K. (2021). Development of student worksheet to improve creative and critical thinking ability of students in causalitic-learning model. In *Journal of Physics: Conference Series* (Vol. 1816, Issue 1). https://doi.org/10.1088/1742-6596/1816/1/012038
Heong, Y. M. (2020). Development of integrated creative and critical thinking module in problem-based learning to solve problems. *International Journal of Scientific and Technology Research*, *9*(3), 6567–6571. https://api.elsevier.com/content/abstract/scopus_id/85082860936
Hursen, C. (2021). The effect of problem-based learning method supported by web 2.0 tools on academic achievement and critical thinking skills in teacher education. *Technology, Knowledge and Learning*, *26*(3), 515–533. https://doi.org/10.1007/s10758-020-09458-2
Issa, H. B. (2021). The effect of using project based learning on improving the critical thinking among upper basic students from teachers' perspectives. *Pegem Egitim ve Ogretim Dergisi*, *11*(2), 52–57. https://api.elsevier.com/content/abstract/scopus_id/85106580913
Kardoyo. (2020). Problem-based learning strategy: Its impact on students' critical and creative thinking skills. *European Journal of Educational Research*, *9*(3), 1141–1150. https://doi.org/10.12973/eu-jer.9.3.1141
Khoiri, N. (2023). Project-based learning via traditional game in physics learning: Its impact on critical thinking, creative thinking, and collaborative skills. *Jurnal Pendidikan IPA Indonesia*, *12*(2), 286–

292. https://doi.org/10.15294/jpii.v12i2.43198
Koes-H, S., & Putri, N. D. (2021). The effect of project-based learning in STEM on students' scientific reasoning. *Journal of Physics: Conference Series*, *1835*(1). https://doi.org/10.1088/1742-6596/1835/1/012006
Latifaj, D. (2023). Implementing project-based learning in english language classes — A case of kosovar lower secondary schools. *Baltic Journal of English Language, Literature and Culture*, *13*, 84–99. https://doi.org/10.22364/BJELLC.13.2023.06
Latorre-Cosculluela, C. (2020). Design thinking: Creativity and critical thinking in college. *Revista Electronica de Investigacion Educativa*, *22*, 1–13. https://doi.org/10.24320/redie.2020.22.e28.2917
Lewis, & Smith. (1993). *Defining higher order thinking. Theory Into Practice*. 131–137. https://doi.org/10.1080/00405849309543588
Li, Y. (2022). A seven-question based critical thinking framework for cultivating innovation talents in engineering research and its implementation perspectives. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *236*(9), 1157–1168. https://doi.org/10.1177/09544054221076232
Lira, L. A. N. (2022). Critical thinking as the foundation of pedagogical practice in university teachers. *Journal of Pharmaceutical Negative Results*, *13*, 22–31. https://doi.org/10.47750/pnr.2022.13.S05.04
Ludvik, M. J. B. (2023). The neuroscience of learning and development: Enhancing creativity, compassion, critical thinking, and peace in higher education. In *The Neuroscience of Learning and Development: Enhancing Creativity, Compassion, Critical Thinking, and Peace in Higher Education*. https://doi.org/10.4324/9781003447962
Manikutty, G. (2022). Driving innovation through project based learning: A pre-university STEAM for Social Good initiative. In *Proceedings - Frontiers in Education Conference, FIE* (Vol. 2022). https://doi.org/10.1109/FIE56618.2022.9962420
Morales, J. D. C. J. (2021). The philosophy for boys and girls (FpNN) methodology and the development of critical and creative thinking at school. *Revista de Filosofia (Venezuela)*, *38*(99), 461–471. 461-471. https://doi.org/10.5281/zenodo.5655790
Moss, C. M., & Brookhart, S. M. (2019). *Advancing Fromative Assessment In Every Classroom* (J. Connelly, Ed.; 2nd ed.). Library of COngress Cataloging In Publication Data. www.ascd.org/deskcopy
Muskita, M. (2020). Effects of worksheets base the levels of inquiry in improving critical and creative thinking. *International Journal of Instruction*, *13*(2), 519–532. https://doi.org/10.29333/iji.2020.13236a
Munandar, Utami. (2014). *Psikologi industri dan organisasi*. *Jakarta: Universitas Indonesia*.
Munandar. (1997). Mengembangkan inisiatif dan kreativitas anak. Jakarta: Universitas Indonesia. https://doi.org/10.20885/psikologika.vol2.iss2.art3
Nawangsari, N. S., Pujiastuti, P., & Gularso, D. (2022). *The effect of project-based learning model on PGSD s tudents ' critical thinking skill*. *10*(1), 19–27. https://doi.org/10.21831/jpe.v10i1.41565
Nosari, S. (2023). Creativity as a pedagogical premise of critical thinking and judgement. In *School Children as Agents of Change: Raising up Critical Thinking and Judgement in the Early Years* (pp. 17–25). https://doi.org/10.4324/9781003374282-4
Paidi. (2023). The effectiveness of free inquiry-based learning integrated with deep source usage on students' critical, creative thinking and self-directed learning skills. In *AIP Conference Proceedings* (Vol. 2614). https://doi.org/10.1063/5.0126638
Perdana, R. (2020). Inquiry social complexity (ISC): Design instructional to empowerment critical and creative thinking (CCT) skills in chemistry. In *Periodico Tche Quimica* (Vol. 17, Issue 34, pp. 727–735). https://doi.org/10.52571/PTQ.v17.n34.2020.751_P34_pgs_727_735
Pramasdyahsari, A. S. (2023). Fostering students' mathematical critical thinking skills on number patterns through digital book STEM PjBL. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(7). https://doi.org/10.29333/ejmste/13342
Putri, A. S. (2023). Effectiveness of STEAM-based blended learning on students' critical and creative thinking skills. *International Journal of Evaluation and Research in Education*, *12*(1), 44–52. https://doi.org/10.11591/ijere.v12i1.22506
Qiang, R. (2020). Critical thinking disposition and scientific creativity: the mediating role of creative self-efficacy. *Journal of Creative Behavior*, *54*(1), 90–99. https://doi.org/10.1002/jocb.347
Raj, T. (2022). Importance of critical thinking in the education. *World Journal of English Language*, *12*(3), 126–133. https://doi.org/10.5430/wjel.v12n3p126
Ramdani, D. (2022). The Effectiveness of collaborative learning on critical thinking, creative thinking, and metacognitive skill ability: Meta-analysis on biological learning. In *European Journal of Educational Research* (Vol. 11, Issue 3, pp. 1607–1628). https://doi.org/10.12973/eu-jer.11.3.1607
Sanchez-Muñoz, R. (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

Sangur, K. (2023). PjBL-HOTS: Integration of learning in improving critical thinking and digital literacy of biology education students. In *AIP Conference Proceedings* (Vol. 2642). https://doi.org/10.1063/5.0110304

Sankaran, S. (2020). Project-based learning-a novel approach to teach biosensors and transducers course for engineering students. *Journal of Engineering Education Transformations*, *34*(1), 61–69. https://doi.org/10.16920/jeet/2020/v34i1/151945

Santoso, A. M. (2021). The development of students' worksheets using project based learning (PjBL) in improving higher order thinking skills (HOTs) and time management skills of students. In *Journal of Physics: Conference Series* (Vol. 1806, Issue 1). https://doi.org/10.1088/1742-6596/1806/1/012173

Silva, A. M. G. N. D. A. (2023). Critical thinking development: Gender issues in the context of arts training in higher education. In *Convergencias: Revista de Investigacao e Ensino das Artes* (Vol. 16, Issue 31, pp. 85–96). https://doi.org/10.53681/c1514225187514391s.31.177

Silva, H. (2023). Fostering critical and creative thinking through the cooperative learning jigsaw and group investigation. *International Journal of Instruction*, *16*(3), 261–282. https://doi.org/10.29333/iji.2023.16315a

Sugiyono. (2019). *Metode PENELITIAN KUANTITATIF* (2nd ed.). Alfabeta.

Sumarni, W. (2020). Ethno-STEM project-based learning: Its impact to critical and creative thinking skills. *Jurnal Pendidikan IPA Indonesia*, *9*(1), 11–21. https://doi.org/10.15294/jpii.v9i1.21754

Supratman, Zubaidah, S., Corebima, A. D., & Ibrohim. (2021). *The effect size of different learning on critical and creative thinking skills of biology students*. *International Journal of Instruction*, *14*(3), 187–206.

Supratman. (2021). The effect size of different learning on critical and creative thinking skills of biology students. *International Journal of Instruction*, *14*(3), 187–206. https://doi.org/10.29333/iji.2021.14311a

Suradika, A. (2023). Project-based learning and problem-based learning models in critical and creative students. *Jurnal Pendidikan IPA Indonesia*, *12*(1), 153–167. https://doi.org/10.15294/jpii.v12i1.39713

Tarling, J. (2023). Trust, transgression and surrender: exploring teacher and send student perceptions of engagement with creative arts project-based learning (CAPBL) pedagogies. *Education Sciences*, *13*(8). https://doi.org/10.3390/educsci13080848

Tharakan, J. (2020). Using educational technology to enhance creative and critical thinking skills through open ended design projects. *Journal of Engineering Education Transformations*, *33*, 225–232. https://doi.org/10.16920/jeet/2020/v33i0/150150

Toheri. (2020). Where exactly for enhance critical and creative thinking: The use of problem posing or contextual learning. *European Journal of Educational Research*, *9*(2), 877–887. https://doi.org/10.12973/eu-jer.9.2.877

Urry, L. A., Cain, M. L., Minorsky, P. v, Wasserman, S. A., Orr, R. B., & Campbell, N. A. (2020). *Campbell Biology* (J. Dinsmore, Ed.; 12th ed.). Pearson Education.

Utama, I. D. (2022). Assessing critical thinking skills and creativity skills of higher education students by using ASSURE Models. *Journal of Higher Education Theory and Practice*, *22*(1), 54–65. https://doi.org/10.33423/jhetp.v22i1.4958

Valentová, M. (2020). Ways of critical and creative thinking development in practical training through video-study. *TEM Journal*, *9*(1), 327–334. https://doi.org/10.18421/TEM91-45

Wahyudi, W. (2021). Schemata and creative thinking ability in cool-critical-creative-meaningful (3CM) learning. *International Journal of Sustainability in Higher Education*, *22*(1), 1–28. https://doi.org/10.1108/IJSHE-06-2019-0198

Yılmaz, A. (2021). The effect of technology integration in education on prospective teachers' critical and creative thinking, multidimensional 21st century skills and academic achievements. *Participatory Educational Research*, *8*(2), 163–199. https://doi.org/10.17275/per.21.35.8.2

Zhang, Y. (2023). Intuition or rationality: Impact of critical thinking dispositions on the cognitive processing of creative information. *Thinking Skills and Creativity*, *48*. https://doi.org/10.1016/j.tsc.2023.101278

Zhao, H. (2021). Critical thinking of music educators as a factor in creative music pedagogy. In *Thinking Skills and Creativity* (Vol. 41). https://doi.org/10.1016/j.tsc.2021.100884