JPPIPA 11(1) (2025)

Jurnal Penelitian Pendidikan IPA

Journal of Research in Science Education

http://jppipa.unram.ac.id/index.php/jppipa/index

Integrated PjBL-STEAM Jigsaw on Critical Thinking and Creative Thinking of Students: A Biotechnology Study

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Received: November 04, 2024
Revised: December 24, 2024
Accepted: January 25, 2025
Published: January 31, 2025

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DOI: 10.29303/jppipa.v11i1.9632

Abstract: Critical and creative thinking are two different ways of thinking, but both are important in problem-solving and decision-making. The aim of this study is to determine: 1) The difference in students' critical thinking skills on biotechnology material after the implementation of integrated PjBL-STEAM Jigsaw; and 2) The difference in students' creative thinking skills in biotechnology after the implementation of integrated PjBL-STEAM Jigsaw. The results of statistical tests showed a difference in students' critical thinking skills after the application of integrated PjBL-STEAM Jigsaw, in both the control group and the experimental group. Post-hoc tests revealed a significant difference in critical thinking between Pertiwi High School and SMAK Rehoboth Ambon in the experimental group. The post-hoc tests also showed a significant difference in creative thinking for the control group, with a significant difference between SMAK Rehoboth and SMA Pertiwi Ambon. In the experimental group, no significant difference in creative thinking skills was found. Teachers need to develop learning models that enhance students' critical thinking skills, and provide questions that reflect students' critical thinking abilities, which can help students improve both their critical and creative thinking. Future research should investigate the factors affecting the low critical and creative thinking abilities of students.

Keywords: Biotechnology; Creative thinking; Critical thinking; Jigsaw; Project-based learning; STEAM.

Introduction

In the era of the Fourth Industrial Revolution in the 21st century, high technology dominates all human activities and changes the way we live. The education sector plays a crucial role in the development and progress of the nation's future generation. Adapting to changing times is essential to avoid being left behind by other countries. The challenges of the 21st century demand the development of high-quality human resources with a balance of knowledge and skills. Therefore, education is expected to be the main vehicle in preparing students to master various skills. The development of various skills is necessary to increase tolerance towards diversity, enhance critical thinking skills, and foster creativity in problem-solving by connecting theory with daily life (Thornhill-Miller et al., 2023).

Critical and creative thinking skills are at the core of the future of society, and students must possess these skills to overcome challenges in their learning environment (Kurniawan et al., 2021). Critical and creative thinking skills are essential to be learned, applied, and developed as they help students sharpen

How to Cite:
Salhuteru, C. P., Papilaya, P. M., & Muskita, M. (2025). Integrated PjBL-STEAM Jigsaw on Critical Thinking and Creative Thinking of Students: A Biotechnology Study. *Jurnal Penelitian Pendidikan IPA*, *11*(1), 910–922. https://doi.org/10.29303/jppipa.v11i1.9632

their cognitive abilities, interpret, analyze, evaluate information, and develop logical reasoning related to the problems they face (Rahayu & Alyani, 2020).

A study conducted by the Trends in International Mathematics and Science Study (TIMSS) to measure students' critical and creative thinking abilities through high-level cognitive questions shows that Indonesian students' critical thinking skills are still low (McComas, 2014). The PISA results indicate that the quality of education and the critical thinking abilities of Indonesian students are still relatively low. This is consistent with the results of the TIMSS and PISA surveys (Schleicher Andreas, 2018).

The weakness in students' critical and creative thinking abilities is caused by several factors, including: (1) Teacher-centered learning activities in the classroom, involving the delivery of information through lectures, making students passive in listening and copying; (2) Lack of encouragement for students to develop their thinking abilities during the learning process, leading to theoretical knowledge without practical application, which "freezes" critical thinking skills and makes them difficult to develop; and (3) The lack of variety in the teaching models used by teachers, which challenges students mainly to improve their memory, rather than focusing on critical thinking and using their reasoning to implement the concepts learned (Primadoniati, 2020; Mohamed Nor & Sihes, 2021; Putera et al., 2022).

The inability of students to think critically can be caused by an insufficient understanding of concepts. Students tend to memorize and solve problems without understanding the underlying concepts (Putera et al., 2022). To improve critical thinking, creative thinking, and conceptual understanding, several innovative teaching approaches have been implemented, including the development of interactive learning materials, student worksheets, and the application of innovative teaching models (Nulhakim et al., 2020).

Critical thinking, creative thinking, and conceptual understanding skills can be enhanced through the optimization of the PjBL-STEAM model. Therefore, this study proposes an integrated PjBL-STEAM Jigsaw model for biotechnology material, which consists of home groups and expert groups. The Jigsaw learning model is designed to help students take greater responsibility for their biotechnology learning. Students not only learn the given material but are also responsible for teaching and presenting the material to their group. This study aims to analyze the effect of the integrated PjBL-STEAM Jigsaw model on students' critical thinking skills, creative thinking skills, and conceptual understanding in science learning on biotechnology material. The objectives of this study are to determine: 1) The difference in students' critical thinking skills in biotechnology after the implementation of the integrated PjBL-STEAM Jigsaw model; and 2) The difference in students' creative thinking skills in biotechnology after the implementation of the integrated PjBL-STEAM Jigsaw model.

Method

The research method used in this study is explained as follows:

1. Quasi-experimental design method**,** which uses integrated PjBL-STEAM with JIGSAW design. This design includes a control group but does not fully control the external variables that may affect the experiment, because controlling variables is only done on one variable that is considered the most dominant.
2. This study involves two groups: an experimental group and a control group. The experimental group is taught using integrated PjBL-STEAM (Figure 1) with JIGSAW, while the control group is taught using conventional methods such as STAD, lectures, and question-and-answer sessions. Before being given the treatment, both groups are given a pretest to assess the students' understanding of the concepts that have been taught. After receiving different treatments, each group is then given a posttest in the form of a group activity using a student worksheet (LKPD)."

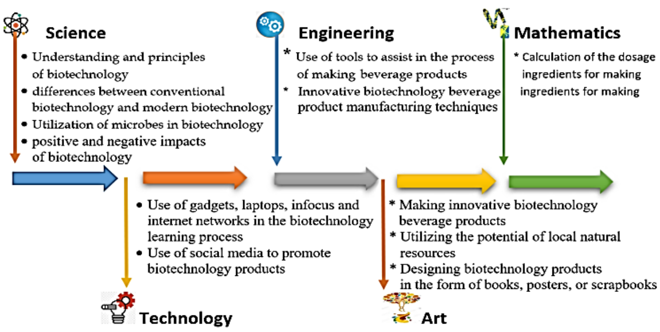

Figure 1. Integrated PjBL-STEAM Jigsaw

3. The research design used is a pretest-posttest control group design, as shown in Table 1.

Table 1. Research Design

Group	Pretest	Treatment	Posttest
Experimental	O_1	X_1	O_2
Control	O_3	X_2	O_4

Explanation

X_1 : The treatment given to the experimental group using integrated PjBL-STEAM JIGSAW
X_2 : The treatment given to the control group
O_1 : The pretest score of the experimental group
O_2 : The posttest score of the experimental group
O_3 : The pretest score oft he control group
O_4 : The posttest score oft he control group

4. The dependent variable is critical thinking, with the critical thinking skills indicators according to Sternberg (2016), which consist of five indicators: providing simple explanations (elementary clarification), building basic skills (basic support), drawing conclusions (inference), providing further explanations (advanced clarification), and arranging strategies and tactics (strategies and tactics). An assessment rubric is used to evaluate critical thinking. Another dependent variable is creative thinking skills, which are developed to enhance students' creative thinking. The object of this study is the application of the Jigsaw-integrated PjBL-STEAM model to critical thinking and creative thinking in Biotechnology material for high school students in Ambon City. A total of 108 students from Pertiwi High School Ambon, Kartika Ahmad Yani High School Ambon, and Rehoboth Christian High School Ambon participated, with each school having a control group and a treatment group.
5. A survey research was conducted to measure students' performance across several schools in Ambon city. The survey aimed to assess the extent of students' thinking abilities. It was given in the form of diagnostic questions consisting of 9 items, which measure four basic components: fluency, flexibility, originality, and elaboration. From students' responses, it can be identified which components students are struggling with and where conceptual improvements are needed for better learning outcomes.
6. The content material developed for the creative thinking instrument had been previously taught to the students, so they were expected to answer various questions related to creative thinking skills. The creative thinking skills test instrument consists of main material on Biotechnology. The instrument for measuring creative thinking skills contains 10 questions, representing the four indicators: fluency, flexibility, originality, and elaboration. These questions were validated by two experts in the field: one in creative learning and one in the content area of biological science. The questions were developed based on the indicators of creative thinking skills and oriented around biotechnology content.
7. The questions given to students were 10 diagnostic questions covering fluency, flexibility, originality, and elaboration. Each question provides several types of assessments based on students' answers. If students provide 3 or more alternative correct answers, they are categorized as "highly creative." If they give 2 correct alternatives, they are categorized as "creative." If they give 1 correct alternative, they are categorized as "somewhat creative," and if they provide only one answer with some correctness, they are categorized as "less creative." Data analysis was conducted experimentally. The results were calculated manually and analyzed using ANOVA at a significance level (α) of 0.05.

Result and Discussion

Student Responses to Critical Thinking Aspects

Critical thinking skills are not innate to humans from birth. These skills must be developed through the learning process. The aspects of critical thinking indicators are classified into five categories according to Ennis (2011), namely: 1) Providing simple explanations, which includes: focusing questions, analyzing arguments, asking and answering questions that require explanations or challenges; 2) Building basic skills, which includes: considering the credibility of sources and making observational judgments; 3) Drawing conclusions, which includes: formulating and considering deductions, formulating and considering inductions, formulating decisions and considering their outcomes; 4) Providing further explanations, which includes: identifying terms and considering definitions, identifying assumptions; and 5) Organizing strategies and tactics, which includes: determining actions and interacting with others.

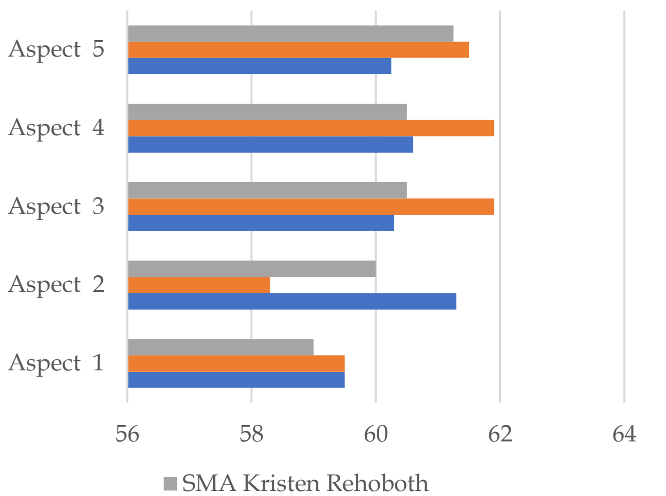

Figure 2. Critical Thinking Skills Graph for the Control Class
Note: a score interval of 81–100 is categorized as very high; a score interval of 61–80 is categorized as high; a score interval of 41–60 is categorized as medium; a score interval of 11–40 is categorized as low; a score of 20 is categorized as very low.

Overall, the research results show that students' critical thinking skills improved across all aspects from 1 to 5. However, in the third aspect, drawing conclusions, there is still a need for improvement. According to Bolisani & Bratianu (2018), the ability to make conclusions is a skill that stems from human reasoning, which involves knowledge gained from discoveries made. Through the ability to draw conclusions, students are expected to be able to derive results from what they have discovered based on their ideas and thoughts about events and scientific knowledge in their environment or issues that have been observed (Wibowo et al., 2024).

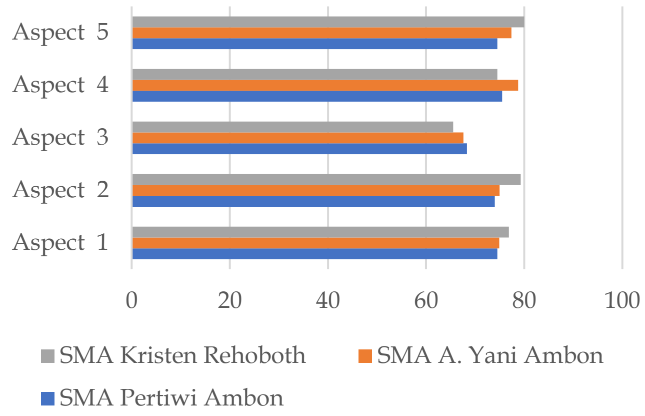

Figure 3. Critical Thinking Skills Graph for the Treatment Class

Aspects: 1) Providing simple explanations, 2) Building basic skills, 3) Drawing conclusions, 4) Providing further explanations, 5) Organizing strategies and tactics

The study also found that in order for students to make conclusions, they must first understand the definition of a conclusion itself. 2) The factors that influence students' ability to make conclusions are quite diverse. However, the most dominant factor affecting their ability to draw conclusions is their understanding of the material or reading used as a reference for conducting an experiment. Critical thinking skills are essential in the learning process of the Fourth Industrial Revolution because they play a role in solving everyday problems (Azmi et al., 2022). In addition, critical thinking skills also contribute to other skills such as communication and information skills, as well as the ability to examine, analyze, interpret, and evaluate evidence. Therefore, critical thinking skills are necessary for all areas of learning, including biology education (Fuadiyah et al., 2022).

Student Responses to Creative Thinking Based on the Aspects of Fluency, Flexibility, Originality, and Elaboration

The analysis of students' creative thinking skills in biotechnology was adjusted according to the indicators of fluency, originality, flexibility, and elaboration. From the 108 students who took the test, the percentage of answers containing all four creative thinking indicators in biotechnology was obtained. The average percentage of the four indicators of creative thinking skills is shown in Table 2. This study analyzes five indicators of creative thinking skills. Figures 4 and 5 illustrate the improvement in students' creative thinking skills across the three schools involved in the research. In the treatment class, the following observations were made: (1) Fluency, students were able to achieve an average score of 78.92, which falls under the creative category. Students were able to generate many ideas, methods, suggestions, questions, concepts, or alternative answers quickly and fluently within a certain time frame, with a focus on quality; (2) Flexibility**, s**tudents achieved an average score of 78.93, also in the creative category. This indicator involves the ability to generate varied ideas, answers, or questions from different perspectives, by changing the approach or thinking process; (3) Originality**, s**tudents achieved an average score of 79.15, categorized as creative**.** This indicator relates to the ability to express ideas, concepts, or solutions in an unconventional, unique, and new way—ideas that had not occurred to others; (4) Elaboration, students achieved an average score of 77.58, which is also categorized as creative**.** This involves the ability to enrich, develop, expand, elaborate on, or provide detailed explanations of an object or concept.

Based on the results achieved by the students in this study, it was found that the PjBL-STEAM (Project-based Learning STEAM) approach had a positive impact on the development of students' creative thinking skills, as well as on their skills and attitudes. In STEAM learning, students are not only taught theoretical knowledge but also engaged in practical activities. As a result, students experience the learning process firsthand, making their knowledge more extensive and meaningful (Marta et al., 2022). The STEAM learning approach (Science, Technology, Engineering, Arts, and Mathematics) is an integrated approach that combines five fields of knowledge: science, technology, engineering, arts, and mathematics. PjBL-STEAM is a contextual learning method, where students understand real-world events around them. PjBL-STEAM teaches students to solve problems, which helps them develop creative thinking skills and deepen the knowledge they already possess. Effective learning activities occur when students actively engage in the learning process and develop concepts through hands-on experimentation (Indahwati et al., 2023). Thus, integrating PjBL-STEAM can be an alternative method to help improve students' creative thinking skills. The integration of PjBL-STEAM positively affects students' creative thinking abilities by enabling them to think at a higher level, actively collaborate, and solve everyday problems. It also encourages students to identify, formulate, and address problems, as well as think about how to incorporate technology into processing the information they receive (Pramashela et al., 2023).

Table 2. Student Responses to Creative Thinking Questions Based on Fluency, Flexibility, Originality, and Elaboration

Question		Student Answers	Domain of Creativity
Fermentation time has a significant impact on total acidity, pH, viscosity/consistency, and the total number of lactic acid bacteria. How can we design the best categories based on starter concentration and the effect of fermentation time on the characteristics of yogurt! 	S63:	Yogurt is made using the same starter concentration and bacteria, but with different fermentation times: 6 hours, 8 hours, and 10 hours. The fermentation time significantly affects the total acidity, pH, viscosity/consistency, and total lactic acid bacteria.	Very creative
	S17:	The longer the fermentation process, the higher the concentration of acetic acid.	Creative
	S98	A fermentation process that is too fast results in lower alcohol production.	Quite creative
	S21:	Fermentation is typically carried out over 2-3 days.	Less creative
Yogurt is made by adding *Lactobacillus bulgaricus* and *Streptococcus thermophillus* bacteria at different concentrations into cow's milk. In the first container (P1), 3% starter is added; in the second container (P2), 5% starter is added; and in the third container (P3), 7% starter is added. How can the effect of starter concentration be designed to determine the best concentration for high-quality yogurt characteristics! 	S3	Yogurt should have a thick to semi-solid consistency, a characteristic odor, a sour taste, and a uniform texture.	Very creative
	S26:	Starter culture is an essential aspect in fermentation technology. A starter is a microorganism in the right quantity and physiological condition, ready to be inoculated into the fermentation medium.	Creative
	S43:	The yogurt must have a thick to semi-solid appearance, a distinctive smell, a sour taste, and a homogeneous consistency.	Quite creative
	S27	Single-use yogurt starter cultures: one packet produces one batch of yogurt.	Less creative
Look at the picture of the gandaria fruit above! Come up with an interesting idea for processing the gandaria into a food product using a fermentation process! 	S14	The Gandaria fruit can be processed naturally using yeast and bacteria that convert carbohydrates into alcohol and organic amino acids in anaerobic conditions during wine production.	Very craetive
	S72	Gandaria fruit can be used to make wine because the fruit contains acids.	Creative
	S69	Gandaria can be turned into an alcoholic fermented beverage without the addition of sugar.	Quite creative
	S58	Gandaria fruit can be made into a refreshing drink or pickled, with some recipes using yeast and others not.	Less creative

The results of the Creativity Test answered by 108 biology students, based on a ranking system of student creativity levels, aim to show the level of creativity among learners on biotechnology material, as shown in the control and treatment classes in Tables 3 and 4.

Table 3. Creativity Levels in the Control Class

Creativity Levels	Domain Kreativitas (Frekuensi dan Persentase)			
	Fluency	Flexibility	Originality	Elaboration
Very Creative (High Level): **(68 – 100)**	5 (0.09%)	3 (3.40%)	7 (4.54%)	5 (5.68%)
Moderately Creative (Medium Level): **(34 – 67)**	37 (0.68%)	42 (57.95%)	42 (45.45%)	39 (65.9%)
Less Creative (Low Level): **(0 – 33)**	12 (0.22%)	9 (40.47%)	5 (50%)	10 (19.2%)
Number of Students				54 people
Average Score / Median Score	62.56	33.36	25.36	28.40
Creativity Level	Creative Medium	Less Creative	Less Creative	Less Creative

The creative thinking skills shown in Tables 4 and 5 indicate an improvement in the treatment class, where the average level is very creative. Creative thinking skills are part of the learning process that helps students become successful learners, confident individuals, and responsible citizens. Therefore, it is important to develop these skills in various subjects to help students develop their creativity and solve problems creatively (Naibaho, 2022). Creativity is a crucial skill for problem-solving and generating new ideas (Ola W. A. Gafour & Walid A. S. Gafour, May 2020), producing new ideas by combining, changing, or adding to existing ideas (Ritter & Mostert, 2017), using various ideas, improving, analyzing, and evaluating ideas to enhance and maximize creative efforts.

Table 4. Creativity Levels in the Treatment Class

Creativity Levels	Domain Kreativitas (Frekuensi dan Persentase)			
	Fluency	Flexibility	Originality	Elaboration
Very Creative (High Level): **(68 – 100)**	5 (0.09%)	3 (3.40%)	7 (4.54%)	5 (5.68%)
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Less Creative (Low Level): **(0 – 33)**	12 (0.22%)	9 (40.47%)	5 (50%)	10 (19.2%)
Number of Students				54 people
Average Score / Median Score	76.78	79.26	64.84	80.26
Creativity Level	Very creative	Very creative	Very creative	Very creative

Group Dynamics in Jigsaw

Group dynamics refers to the social interaction process that occurs among group members. This process involves various factors such as communication, conflict, trust, and cooperation (Zen et al., 2023). Managing group dynamics is crucial to ensure that students can work effectively together in completing tasks and developing their social skills.

The Jigsaw cooperative learning model is an approach in which students actively collaborate in small origin groups and expert groups to achieve shared learning goals. The fundamental concept of this model includes several important aspects that provide a foundation for collaborative teaching. One key element is positive interdependence, which teaches students that individual success within a group is closely related to the overall success of the group. In this context, students learn that they depend on one another, which fosters cooperation

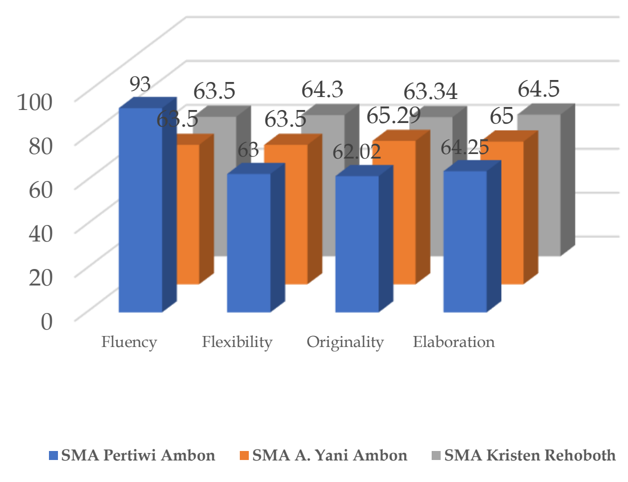

Figure 4. Creative Thinking Skills in the Control Class

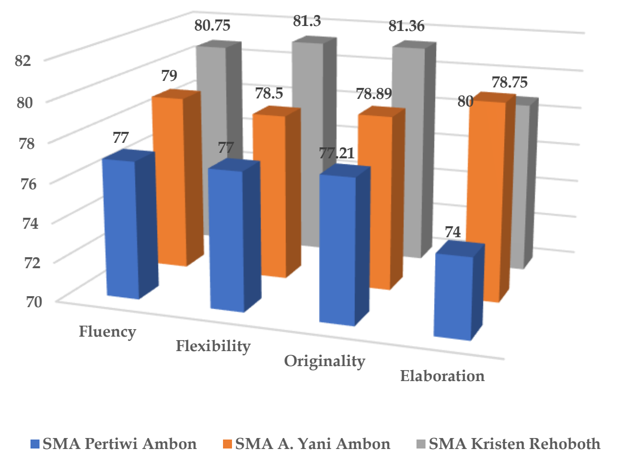

Figure 5. Creative Thinking Skills in the Treatment Class

The Jigsaw group consists of five STEAM expert groups: Science, Technology, Engineering, Art, and Mathematics. From Figure 6, it can be observed that the indicator with the highest percentage of students' creative thinking skills is originality, which reached 70.9%. The lowest indicator was elaboration, with a percentage of 50%. This study also shows that most students were able to offer two different approaches to solving the problems: elimination and substitution. One student successfully solved the problem using both methods correctly. However, most students lacked precision and carefulness when performing calculations, even though they demonstrated the correct process. Meanwhile, the remaining students either left their calculations unfinished or did not answer the question at all.

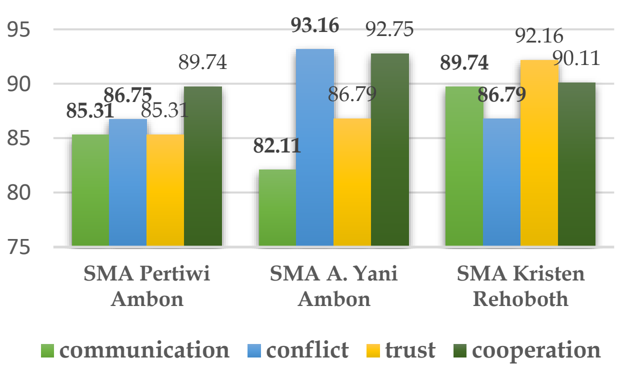

Figure 6. Jigsaw Group Dynamics Chart

Based on the data analysis, the results for the creative thinking skill Originality showed that students from SMA Kristen Rehoboth Ambon achieved the highest average score of 81.36, which falls under the "creative" category. This indicator reflects the ability to express ideas, concepts, or solutions to problems by creating unconventional, unique, and novel combinations of biotechnology elements that others may not have thought of. On average, high school students in the study schools were able to solve biotechnology problems using the Jigsaw cooperative model, falling into the "creative" category. This is because the Jigsaw cooperative model encourages students to be more creative in sharing ideas with their peers in groups (Nasution et al., 2020).

The Jigsaw cooperative model stages can serve as a factor in enhancing creative thinking skills. The process begins with dividing students into 4-6 groups, where each group is assigned a specific topic according to STEAM. Once the groups have discussed their topics, they spread out into other groups to present their discussion results. The final step is to return to their original groups and discuss the outcomes of the presentation. This process enables students to develop creativity by analyzing data in their initial groups and presenting their findings.

The biotechnology problem-solving tasks given in the study allowed for an assessment of students' creative thinking abilities. This is because solving biotechnology problems can enhance creative thinking skills (Pambudi et al., 2024). This study aimed to observe and describe students' creative thinking abilities in solving biotechnology problems using the Jigsaw approach, and the results fell within the "creative" category.

In general, the implementation of the Jigsaw model proceeded as expected. However, some challenges were encountered during the study. First, students still required a great deal of assistance from the teacher when discussing biotechnology topics, which, in turn, guided students toward the correct answers. Another challenge was the application of the Jigsaw model itself, which left students somewhat confused at the start of the learning process, requiring more time to organize the flow of the lesson. Additionally, students faced difficulties solving biotechnology problems within the time frame provided by the teacher in the final session. These challenges could serve as suggestions for future researchers to improve the implementation of this model.

The research findings indicate that students, working in groups, were largely able to offer three different ways to solve biotechnology problems, using several methods, including:

Practical Work

Students engage in biotechnology practical work to better understand the material. The practical activities can be done in school, but there are also assignments that can be done at home, such as asking others, searching for information in books, or online. Practical work is an essential aspect of biology learning to make the learning process more effective. The implementation of practical work serves as a method for proving theories proposed by experts. During practical activities, students carry out a series of experiments aimed at honing their scientific skills and deepening their understanding of the principles or concepts they are studying. Furthermore, practical work provides direct experiences by involving interactions between students and the learning objects, thus offering meaningful learning for students (Salinas-Navarro et al., 2024).

Image Assistance

Students who are at the learning assistance level and face conflicts can be supported through the presentation of material in the form of images. Biotechnology is a topic in biology that discusses the use of scientific principles involving living organisms to produce products and services that benefit human life. In biotechnology learning, students may face challenges during the learning process.

The selection of appropriate image media is crucial in all subjects, including biotechnology learning. This is because biotechnology often deals with tangible or real-life phenomena that are visual in nature. Therefore, using images makes it easier for students to absorb and understand what they are learning, resulting in positive outcomes in achieving the desired learning objectives (Qalbina & Ahda, 2019). Through image literacy activities, experiments, and discussions, students can identify the application of conventional biotechnology in meeting daily food needs.

Project-Based Learning (PjBL) Work

Students are actively engaged in learning activities, participate in discussions, think critically, and collaborate on projects. They create presentation materials in the form of posters, videos, or PowerPoint slides. However, there are some challenges in the implementation, particularly related to the time needed to complete the projects. Time limitations in the project learning schedule can become an obstacle, especially when the projects are not finished. Therefore, the consistent application of this learning model is important to encourage active student participation in the learning process, particularly in biotechnology topics. Despite these challenges, particularly time constraints, it is crucial to consistently apply this learning model to foster student involvement in biotechnology learning (Aisa et al., 2023).

Students' Project Results

In biology lessons, the teacher encourages students to study biotechnology using Project-Based Learning (PjBL). This method emphasizes student involvement in real-world and meaningful projects. Using this PBL method, the students in grade 10 directly practice analyzing conventional/traditional biotechnology by making a simple fermented drink, such as local Maluku fruit yogurt. In this biology lesson, students are divided into groups, and each group decides on a product to create. Figure 7 shows students making a drink related to conventional biotechnology topics, and Figure 8 shows students creating a video to be presented in front of the class and published on social media. The students are enthusiastic and excited about the learning process. The goal of this lesson is to teach students the technique of improving the value of products with the help of microorganisms.

Figure 7. Students Making a Drink from Local Natural Resources Related to Conventional Biotechnology Material

The application of Project-Based Learning by the teacher brings about changes and innovations in the learning process. With the introduction of these innovations in teaching, the learning experience becomes more engaging and enjoyable. Engaging learning will motivate students to be more enthusiastic and excited about their studies.

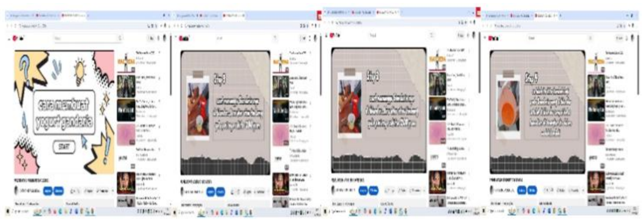

Figure 8. Creating a Video and Publishing It on Social Media

As educators, it is essential to constantly innovate teaching methods to ensure professional teaching. It is important not to make learning monotonous by relying solely on lectures and repetitive material (Wuntu et al., 2022).

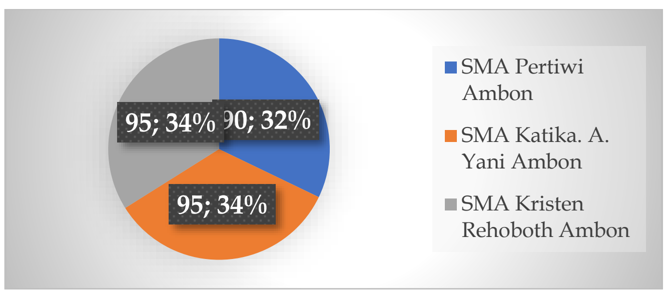

Figure 9. Project Assessment Results of Students

The assessment results of the beverage product using the PjBL-STEAM biotechnology concept in Figure 9 show that the average student performance was excellent. SMA Pertiwi scored 90.32%, SMA Kartika A. Yani scored 95.34%, and SMA Kristen Rehoboth Ambon scored 93.34%. These results indicate that students were able to express their product work through creative thinking, specifically fluency (the ability to generate relevant ideas and concepts), and flexibility (the ability to create diverse and creative ideas, renew approaches, and view things from different perspectives) (Sellars et al., 2018). Teachers monitored the entire process step by step, following each choice before students began their projects and until the final outcome. Many aspects of PjBL naturally involved students creating answers that were unconventional, different from the usual, and ideas that most people had not considered. They were able to make interesting combinations and produce innovative outcomes (Bereczki & Kárpáti, 2021).

Project-Based Learning (PjBL) is a recent development in the educational world. The pedagogical context students encounter is often very different from their previous experiences, making it challenging to adapt to the changes. Participation and perseverance are key factors in successful learning, as highlighted by many researchers. PjBL involves real-world challenges focused on actual issues or problems, not simulations or artificial scenarios, where the solutions have the potential for real-world application (Lavado-Anguera et al., 2024).

Statistical Analysis of Critical Thinking Skills of Students Using Integrated PjBL-STEAM Jigsaw

The analysis of the ANACOVA test revealed a significant difference in students' critical thinking skills after the implementation of the integrated PjBL-STEAM Jigsaw method. The p-value was 0.002, indicating a significant difference between the control and treatment groups. Further Post Hoc analysis showed significant differences in critical thinking skills between students from SMA Pertiwi Ambon, SMA Kartika A Yani Ambon, and SMAK Rehoboth, with a p-value of 0.004.

The differences in critical thinking skills among students indicate that students' ability to think critically when providing solutions to problems, and their ability to generate something new or different, varies among them (Suryawan et al., 2024). Critical thinking skills involve analyzing problems systematically and concretely, distinguishing issues carefully and thoroughly, and identifying and examining information to plan solutions. This is a cognitive process for students (Aswanti & Isnaeni, 2023). As described above, critical thinking skills are fundamental for problem-solving. Therefore, critical thinking skills are crucial for developing cognitive abilities and effectively retaining information (Khasawneh, 2024).

Critical thinking skills can be applied for the success of learning. Critical thinking not only involves participation in the process but also demands that students possess skills such as prediction, analysis, synthesis, evaluation, and reasoning. One of the learning models that can support and teach students critical thinking is the application of Project-Based Learning (PjBL) (Amhar et al., 2022). Project-Based Learning (PjBL) is an innovative learning model that encourages students to think creatively, critically, and interactively, and to draw conclusions through projects to create artifacts. This can be achieved through the PjBL learning model with a STEAM approach, which emphasizes 21st-century critical thinking skills.

The STEAM approach with the PjBL learning method can be applied to biology education because it is relevant. PjBL aims to focus students on real-world problems, thereby motivating them to study knowledge principles and concepts directly. PjBL has the potential to enhance critical and creative thinking skills because it involves students directly in problem-solving related to everyday life (Panigrahi & Hanum, 2024).

An integrated STEAM approach can develop students' critical thinking skills to solve problems based on STEAM components and can improve group-based problem-solving collaboration. Moreover, the integration of PjBL-STEAM, where students are asked to complete projects, can sharpen students' creativity (Saefullah et al., 2021). Through the integration of STEAM and PjBL, the work produced by students will differ in each group. Within these groups, there will be collaboration to form understanding of the material, and each group will be given the freedom to plan learning activities, carry out the project, and produce a presentation.

Teachers' ability to implement PjBL learning modified with Jigsaw significantly supports effective learning for students. The Jigsaw learning model is a technique that emphasizes cooperative learning within groups, where students are responsible for working together to achieve common goals. In the PjBL learning model, students are asked to study cooperatively to master the material by carefully reviewing the content and discussing it with peers from diverse backgrounds and abilities.

Statistical Analysis of Differences in Students' Creative Thinking Skills Using Integrated PJBL-STEAM and Jigsaw

The results of the ANACOVA test showed significant differences in students' creative thinking skills between the control group and the experimental group, with a p-value of 0.001. Similarly, there were significant differences in creative thinking skills among students from different schools, with a p-value of 0.003. Further post-hoc testing with LSD revealed significant differences in the control group between SMAK Rehoboth and SMA Pertiwi Ambon, with a p-value of 0.001. In the experimental group, no significant differences in creative thinking skills were found.

Based on observations, the differences in students' creative thinking skills are partially due to the fact that teachers rarely apply interactive learning methods in the classroom. During the learning process, teachers tend to focus on explaining the learning material, with students mainly listening to the explanations, which results in passive student participation. Ridha et al. (2023) explain that teacher-centered learning patterns make students unaccustomed to expressing their ideas and thoughts, which hinders the development of their creativity and leads to a lack of creativity.

Additionally, the use of methods with low cognitive demands also affects the differences in students' creative thinking skills. Taat et al. (2020) state that the lecture method in teaching does not foster students' creative thinking skills because the learning process focuses solely on students' ability to memorize information. Khaeruddin et al. (2023) argue that students should be encouraged to develop their thinking skills, not just memorize the material given, but also be able to analyze, synthesize, and create.

Therefore, improving creative thinking skills is essential. As part of 21st-century skills, creative thinking is crucial in various fields such as economics, citizenship, and globalization, which are closely interconnected. To enhance students' creative thinking skills, it is necessary to improve their understanding of problems, fluency, flexibility, and innovation in problem-solving (Putri et al., 2023).

The integrated PJBL-STEAM with Jigsaw approach requires collaboration, communication among peers, problem-solving skills, and self-management. The implementation of PJBL-STEAM shows that students have developed critical and creative thinking, problem-solving abilities, collaboration, argumentation skills, and responsibility (Hayyun & Setiowati, 2023). The Jigsaw model is a cooperative learning model where students work in small groups, collaborating and relying on one another positively and responsibly. In the Jigsaw model, students have numerous opportunities to explain ideas and process information, which can enhance their interaction skills. Each participant is responsible for the success of the group and completing the topic they are assigned, as well as explaining it to their group members.

Creative thinking has often received little attention in science education. However, when students focus on the learning process, creativity enhances their understanding and encourages cognitive development (Permana Sari et al., 2024). Students need to tap into their creative potential to address various contextual problems, which require reasoning, argumentation, and creative thinking abilities. Both critical and creative thinking skills are crucial for achieving science learning goals. These skills need to be nurtured and developed. Meaningful science education allows students to ask questions and express their ideas, facilitating their cognitive growth.

Conclusion

Based on the results of the research and discussion in this thesis, it can be concluded that there is a difference in students' critical thinking skills after the implementation of the Jigsaw-integrated PjBL-STEAM approach. The control and treatment groups showed a significant value of 0.002 following the implementation of the Jigsaw-integrated PjBL-STEAM approach. There is a difference in critical thinking, as shown by the ANOVA test, which indicates a difference between school groups with a significance value of 0.06 after the implementation of the Jigsaw-integrated PjBL-STEAM approach. Further tests revealed that in the treatment group, there was a significant difference in critical thinking between SMA Pertiwi and SMAK Rehoboth Ambon, with a mean difference of 4.01974*. In the control group, however, no significant differences were found among the three schools. Additionally, there was a difference in students' creative thinking skills between the control and treatment groups, with a significance value of 0.001, indicating a significant improvement after the implementation of the Jigsaw-integrated PjBL-STEAM approach ($p < 0.05$). A difference in creative thinking skills between school groups was also found, with a significance value of 0.003. Further tests revealed a significant difference in creative thinking in the control group between SMAK Rehoboth and SMA Pertiwi Ambon. In the treatment group, however, no significant difference in creative thinking skills was found.

Acknowledgments

We would like to express our gratitude to all parties who have supported the completion of this research. We hope that this study will be useful for further developments in education.

Author Contributions

All authors have made significant contributions to the development of this scholarly work. The first author was responsible for conducting the research and preparing the manuscript. The second and third authors provided guidance, direction, and suggestions throughout the research and manuscript preparation process. The authors collaborated with each other at every stage of the research process, following the established procedures.

Funding
This research received no external funding

Conflicts of Interest
The authors declare no conflict of interest.

References

Aisa, R., Kusnadi, K., & Solihat, R. (2023). Application of Problem-Based Learning in Biotechnology Learning Contains Local Potential Jruek Drien Aceh to Improve Problem-Solving and Self-Directed Learning Skills of High School Students. *Jurnal Penelitian Pendidikan IPA*, *9*(11), 10128–10137. https://doi.org/10.29303/jppipa.v9i11.5047

Amhar, A., Sabrina, R., Sulasmi, E., & Saragih, M. (2022). Student critical thinking skills and student writing ability: The role of teachers' intellectual skills and student learning. *Cypriot Journal of Educational Sciences*, *17*(7), 2493–2510. https://doi.org/10.18844/cjes.v17i7.7683

Aswanti, N. H., & Isnaeni, W. (2023). Analysis of critical thinking skills, cognitive learning outcomes, and student activities in learning the human excretory system using an interactive flipbook. *REID (Research and Evaluation in Education)*, *9*(1), 37–48. https://doi.org/10.21831/reid.v9i1.53126

Azmi, Z. L., Marlina, L., Fathurohman, A., Putri, R., Zulkardi, Z., Sari, D., Gustiningsih, T., Rawani, D., Lisnani, L., Sari, A., & Septimiranti, D. (2022). Study of Critical Thinking Skills for Junior High School Students In the Era Industial Revolution 4.0. *JIPFRI (Jurnal Inovasi Pendidikan Fisika Dan Riset Ilmiah)*, *6*(1), 19–23. https://doi.org/10.30599/jipfri.v6i1.1255

Bereczki, E. O., & Kárpáti, A. (2021). Technology-enhanced creativity: A multiple case study of digital technology-integration expert teachers' beliefs and practices. *Thinking Skills and Creativity*, *39*(November 2020). https://doi.org/10.1016/j.tsc.2021.100791

Bolisani, E., & Bratianu, C. (2018). The Emergence of Knowledge Management. In *Knowledge Management and Organizational Learning* (Vol. 4, Issue December 2017). https://doi.org/10.1007/978-3-319-60657-6_2

Busyairi, A., Zuhdi, M., & Makhrus, M. (2022). The Analysis of Concept Mastering and Creative Thinking Skills of Prospective Physics Teachers Post-Online Learning During the Covid-19 Pandemic. *Jurnal Ilmiah Profesi Pendidikan*, *7*(4b). https://doi.org/10.29303/jipp.v7i4b.958

Diani, R., Latifah, S., Jamaluddin, W., Pramesti, A., Susilowati, N. E., & Diansah, I. (2020). Improving Students' Science Process Skills and Critical Thinking Skills in Physics Learning through FERA Learning Model with SAVIR Approach. *Journal of Physics: Conference Series*, *1467*(1). https://doi.org/10.1088/1742-6596/1467/1/012045

Dywan, A. A., & Airlanda, G. S. (2020). Efektivitas Model Pembelajaran Project Based Learning Berbasis STEM dan Tidak Berbasis STEM terhadap Kemampuan Berpikir Kritis Siswa. *Jurnal Basicedu*, *4*(2), 344–354. https://doi.org/10.31004/basicedu.v4i2.353

Fuadiyah, M., Norra, B. I., & Astutik, F. (2022). Biology learning model to improve critical thinking skills of ten grade students: A meta-analysis. *Assimilation: Indonesian Journal of Biology Education*, *5*(2), 101–112. https://doi.org/10.17509/aijbe.v5i2.46084

Hayyun, M., & Setiowati, G. D. (2023). Implementation of the Steam-Based Project Based Learning Model in Improving Elementary School Students'Science Problem …. *Proceeding of International Seminar and …*, *May*, 134–145. https://jurnal.umj.ac.id/index.php/ISJR/article/view/18077

Indahwati, S. D., Rachmadiarti, F., & Hariyono, E. (2023). Integration of PJBL, STEAM, and Learning Tool Development in Improving Students' Critical Thinking Skills. *IJORER : International Journal of Recent Educational Research*, *4*(6), 808–818. https://doi.org/10.46245/ijorer.v4i6.434

Khaeruddin, K., Indarwati, S., Sukmawati, S., Hasriana, H., & Afifah, F. (2023). An Analysis of Students' Higher Order Thinking Skills Through the Project-Based Learning Model on Science Subject. *Jurnal Pendidikan Fisika Indonesia*, *19*(1), 47–54. https://doi.org/10.15294/jpfi.v19i1.34259

Khasawneh, M. A. S. (2024). The Challenges Facing Vocational Education Online from the Teachers' Perspectives. *Journal of Curriculum and Teaching*, *13*(2), 180–196. https://doi.org/10.5430/jct.v13n2p180

Kurniawan, R., Kurniawan, A. W., & Wijaya, D. (2021). Students' interest in physical education learning: Analysis of internal and external factors. *Journal Sport Area*, *6*(3), 385–393. https://doi.org/10.25299/sportarea.2021.vol6(3).7402

Lavado-Anguera, S., Velasco-Quintana, P. J., & Terrón-López, M. J. (2024). Project-Based Learning (PBL) as an Experiential Pedagogical Methodology in Engineering Education: A Review of the Literature. *Education Sciences*, *14*(6). https://doi.org/10.3390/educsci14060617

Marta, N., Djunaidi, & Santosa, F. H. (2022). The Steam Approach: Theory and Its Implementation in History Learning. *Proceeding The 2nd ICHELSS*, 831–

839. http://journal.unj.ac.id/unj/index.php/hispisi/article/download/30963/13769

McComas, W. F. (2014). Trends in International Mathematics and Science Study (TIMSS). *The Language of Science Education*, 108–108. https://doi.org/10.1007/978-94-6209-497-0_97

Mohamed Nor, H., & Sihes, A. J. (2021). Critical Thinking Skills in Education: A Systematic Literature Review. *International Journal of Academic Research in Business and Social Sciences*, *11*(11). https://doi.org/10.6007/ijarbss/v11-i11/11529

Mubah, S. (2024). *Developing Critical Thinking and Cybersecurity Literacy Skills Ahead of the 2024 Election for Students At Vocational*. *8*(3), 357–365.

Naibaho, L. (2022). Pre-Service Efl Teachers' Creative Thinking. *Indonesian Journal of Learning and Instruction*, *5*(2). https://doi.org/10.25134/ijli.v5i2.6841

Najaah, L. S. (2021). Analisis Keterampilan Berpikir Kritis Dan Kolaborasi Peserta Didik Sekolah Menengah Pertama (Smp). *Jurnal Jaringan Penelitian Pengembangan Penerapan Inovasi Pendidikan (Jarlitbang)*, 115–122. https://doi.org/10.59344/jarlitbang.v7i2.64

Nasution, T. A., Purba, A., & Afrinda, V. (2020). The Influence of Jigsaw Cooperative Model toward Writing Exposition Text Ability of Class X At SMK Negeri 1 Pematang Siantar. *Budapest International Research and Critics Institute (BIRCI-Journal): Humanities and Social Sciences*, *3*(3), 2349–2356. https://doi.org/10.33258/birci.v3i3.1183

Nulhakim, L., Setiawan, F. R., & Saefullah, A. (2020). Improving Students' Creative Thinking Skills Using Problem-Based Learning (PBL) Models Assisted by Interactive Multimedia. *Jurnal Penelitian & Pengembangan Pendidikan Fisika*, *6*(1), 9–16. https://doi.org/10.21009/1.06102

O'Reilly, C., Devitt, A., & Hayes, N. (2022). Critical thinking in the preschool classroom - A systematic literature review. *Thinking Skills and Creativity*, *46*(August). https://doi.org/10.1016/j.tsc.2022.101110

Ola W. A. Gafour, & Walid A. S. Gafour May. (2020). Creative Thinking skills – A Review article. *Journal of Education and E-Learning*, *May 2020*, 1–21.

Pambudi, E. S., Parno, Marsuki, M. F., Fardhani, I., Fitriyah, I. J., & Silfiyah, E. (2024). *Improving Creative Thinking Skill on Biotechnology Material Through The Effectiveness of Project Based Learning-STEM E-Module Provided with Formative Assessment*. Atlantis Press SARL. https://doi.org/10.2991/978-2-38476-245-3_36

Panigrahi, R. R., & Hanum, E. (2024). *Project-Based Learning on STEAM-Based Student ' s Worksheet with Ecoprint Technique : Effects on Student Scientific Reasoning and Creativity*. *10*(2), 222–236.

Permana Sari, R., Putri, H., & Setiawaty, S. (2024). and Disaster Management Implementation of Project Based Learning Model Integrated STEAM Approach to Improve Students Critical Thinking. *Technology, Mathematics, and Disaster Management*, *1*(1), 1–13. http://dx.doi.org/10.62864/jestmdm.v1i1.5

Pramashela, A. D., Suwono, H., Sulisetijono, S., & Wulanningsih, U. A. (2023). The Influence of Project-based Learning Integrated STEAM on the Creative Thinking Skills. *Bioedukasi*, *21*(2), 138. https://doi.org/10.19184/bioedu.v21i2.39737

Primadoniati, A. (2020). Pengaruh Metode Pembelajaran Problem Based Learning terhadap Peningkatan Hasil Belajar PAI Di SMPN 2 Ulaweng Kabupaten Bone. *Jurnal Al-Qayyimah*, *2*(2), 40–55. https://doi.org/10.30863/aqym.v2i2.650

Putera, A. R., Purwanto, N. A., Mulyadi, M., & Jannah, R. (2022). Hayula: Indonesian Journal of Multidisciplinary Islamic Studies Vol.6, No.1, January 2022. *Hayula: Indonesian Journal of Multidisciplinary Islamic Studies*, *6*(1), 59–80.

Putri, Z. A., Insyasiska, D., & Wahyono, P. (2023). Problem Based Learning to Improve Creative Thinking Skills and Technological Literacy on Virus Material. *Jurnal Eksakta Pendidikan (Jep)*, *7*(2), 185–196. https://doi.org/10.24036/jep/vol7-iss2/767

Qalbina, P., & Ahda, Y. (2019). Characteristics of biotechnology learning materials generally used by biology education students in Padang City. *Journal of Physics: Conference Series*, *1185*(1). https://doi.org/10.1088/1742-6596/1185/1/012154

Rahayu, N., & Alyani, F. (2020). Kemampuan Berpikir Kritis Matematis Ditinjau Dari Adversity Quotient. *Prima: Jurnal Pendidikan Matematika*, *4*(2), 121. https://doi.org/10.31000/prima.v4i2.2668

Ridha, R., Rahma, A., & Rusdi, M. (2023). The Role of Teachers in Increasing Student s ' Creativity and Learning Activeness in Civic Education Subject Subject Subject of Class X MIPA 2 SMAN 16 Bone Learning. *Jurnal Pendidikan Mandala*, *8*(4), 1101–1106.

Ritter, S. M., & Mostert, N. (2017). Enhancement of Creative Thinking Skills Using a Cognitive-Based Creativity Training. *Journal of Cognitive Enhancement*, *1*(3), 243–253. https://doi.org/10.1007/s41465-016-0002-3

Saefullah, A., Suherman, A., Utami, R. T., Antarnusa, G., Rostikawati, D. A., & Zidny, R. (2021). Implementation of PjBL-STEM to Improve Students' Creative Thinking Skills On Static Fluid Topic. *JIPF (Jurnal Ilmu Pendidikan Fisika)*, *6*(2), 149.

https://doi.org/10.26737/jipf.v6i2.1805
Salinas-Navarro, D. E., Vilalta-Perdomo, E., Michel-Villarreal, R., & Montesinos, L. (2024). Designing experiential learning activities with generative artificial intelligence tools for authentic assessment. *Interactive Technology and Smart Education*, *May*. https://doi.org/10.1108/ITSE-12-2023-0236
Schleicher Andreas. (2018). The Future of Education and Skills: Education 2030. *OECD Education Working Papers*, 23. http://www.oecd.org/education/2030/E2030 Position Paper (05.04.2018).pdf
Sellars, M., Fakirmohammad, R., Bui, L., Fishetti, J., Niyozov, S., Reynolds, R., Thapliyal, N., Liu-Smith, Y. L., & Ali, N. (2018). Conversations on critical thinking: Can critical thinking find its way forward as the skill set and mindset of the century? *Education Sciences*, *8*(4). https://doi.org/10.3390/educsci8040205
Shahroom, A. A., & Hussin, N. (2018). Industrial Revolution 4.0 and Education. *International Journal of Academic Research in Business and Social Sciences*, *8*(9), 314–319. https://doi.org/10.6007/ijarbss/v8-i9/4593
Sidabutar, N., & Mercuriani, I. S. (2024). Analysis of Critical Thinking Ability of High School Students in Sleman Regency on Virus Material. *Jurnal Penelitian Pendidikan IPA*, *10*(3), 1213–1219. https://doi.org/10.29303/jppipa.v10i3.5320
Sternberg. (2016). Critical thinking: Its nature, measurement, and improvement. *National Inst. Of Education*, *11*(1), 217–232. https://pdfs.semanticscholar.org/80a7/c7d4a9898 7590751df4b1bd9adf747fd7aaa.pdf
Suryawan, I. P. P., Sudiarta, I. G. P., Suharta, I. G. P., & Pujawan, I. G. N. (2024). Students' Critical Thinking Ability in Solving Controversial Mathematical Problems Seen from Computational Thinking. *International Journal of Religion*, *5*(11), 3038–3051. https://doi.org/10.61707/dd3d5t59
Taat, M. S., Abdulbaki, K., & Al-Saqqaf, A. (2020). The Impact of Lecture and Interactive Methods onStudent's English Competency. *International Journal of Emerging Technologies in Learning*, *15*(20), 255–266. https://doi.org/10.3991/ijet.v15i20.16683
Thornhill-Miller, B., Camarda, A., Mercier, M., Burkhardt, J. M., Morisseau, T., Bourgeois-Bougrine, S., Vinchon, F., El Hayek, S., Augereau-Landais, M., Mourey, F., Feybesse, C., Sundquist, D., & Lubart, T. (2023). Creativity, Critical Thinking, Communication, and Collaboration: Assessment, Certification, and Promotion of 21st Century Skills for the Future of Work and Education. *Journal of Intelligence*, *11*(3). https://doi.org/10.3390/jintelligence11030054
van Laar, E., van Deursen, A. J. A. M., van Dijk, J. A. G. M., & de Haan, J. (2020). Determinants of 21st-Century Skills and 21st-Century Digital Skills for Workers: A Systematic Literature Review. *SAGE Open*, *10*(1). https://doi.org/10.1177/2158244019900176
Wibowo, A. M., Utaya, S., Wahjoedi, W., Zubaidah, S., Amin, S., & Prasad, R. R. (2024). Critical Thinking and Collaboration Skills on Environmental Awareness in Project-Based Science Learning. *Jurnal Pendidikan IPA Indonesia*, *13*(1), 103–115. https://doi.org/10.15294/jpii.v13i1.48561
Wuntu, C. N., Singal, Y., & Rorintulus, O. A. (2022). IJEAL (International Journal of English and Applied Linguistics) The Implementation Of Project Based Learning (Pbl) In Improving Students' Speaking Skill At Sma Yadika Kopandakan II. *IJEAL (International Journal of English and Applied Linguistic*, *2*(3), 387–398.
Zen, D. S., Iskandar, D., Nirwana, H., & Suharyati, H. (2023). The Role of Group Dynamics in Resolving Conflict. *Pedagonal : Jurnal Ilmiah Pendidikan*, *7*(2), 145–152. https://doi.org/10.55215/pedagonal.v7i2.8429