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Evaluation of Implementation of the PjBL-Based STEAM Approach Affect on Critical Thinking Skills and Creativity

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Abstract

A scientific approach with a problem-based model is presently employed to enhance students' critical thinking abilities and creativity at. Nevertheless, students are not frequently afforded the chance to construct their own knowledge or learning experiences by creating products that incorporate Scientific, Technological, Engineering, Artistic, and Mathematical aspects (STEAM). As a result, the researchers will endeavor to develop a project-based STEAM approach to engage students in technology integration. Environmental Pollution, which applies biology and technology principles in everyday life, is a suitable Biology topic to be integrated with the STEAM approach. This quasi-experimental study aimed to enhance students' critical thinking and creativity skills by implementing an online STEAM-based project learning approach. The research design employed in this study was the Pretest-Posttest Control Group Design. A purposive sample of 20 students was divided into experimental and control groups, and data were collected through critical thinking skills tests, questionnaires, observation, and documentation. Descriptive analysis and average difference tests were used for data analysis. The study found a significant difference in critical thinking skills between the experimental and control groups after implementing the STEAM approach. Furthermore, the experimental group demonstrated high levels of creativity, achieving 82.5% fluency, 90% flexibility, 90% originality, and 86.88% elaboration, with an overall average score in the very good category.

Keywords:*STEAM, Project based learning, creativity, critical thinking skills*

1. Introduction

A method in the field of education that is designed to address the requirements of modern-day learning is STEAM-based learning, which stands for Science, Technology, Engineering, Arts, and Mathematics(Yakman, 2008).In Indonesia, STEAM learning is regarded as a significant advancement in education that aims to cultivate individuals capable of building a science and technology-driven economy. STEAM education is an approach that combines science and technology with engineering and the arts, and incorporates mathematical concepts, which serve as the foundation of science.(Aguilera & Ortiz-Revilla, 2021).

One that supports critical thinking skills is creativity. According to Kristin (2016) creativity is a person's ability to give results to something new both from ideas, the ideas they have will produce something that has use or usability.(Walia, 2019)It is these new ideas or ideas that will be able to help students to develop creativity. In this case, the teacher takes an active role in facilitating students' creative development during the learning process.(Li et al., 2022)The teacher's encouragement in developing student creativity will make students more motivated to convey ideas in the process of developing their creativity.(Hidayat et al., 2023)

The results of initial observations at SMA Negeri 1 Kuningan, the Biology teacher at the school had not implemented and related the learning process that required students to be creative and innovative. In the learning process, the teacher prefers to apply the learning process with the lecture method assisted by discussion activities, because the teacher does not need to prepare tools or materials to carry out practical activities. The teacher only explains the concepts contained in textbooks or other reference learning resources. This situation makes students feel bored and bored so that a learning process must be applied that links the environment with science. Teachers also have not implemented this learning because they do not understand how to implement integration between technology, art which contains elements of mathematics in science in biology subjects. Teachers find it difficult to apply it because of constraints with limited time allocation in linking theory with practicum.

The implementation of biology learning should be directed more towards activities that encourage students to learn pro-actively and psychologically by associating the material to be studied by integrating technology with science.(Haleem et al., 2022)In addition, in the revised 2013 curriculum that uses a scientific approach, it is explained that there are 4 (four) models suggested in this learning, namely discovery, inquiry, problem based learning, and project based learning models.(Sani, Ridwan et al., 2015)

At SMA Negeri 1 Kuningan, a scientific approach with a problem-based model is presently employed to enhance students' critical thinking abilities and creativity. Nevertheless, students are not frequently afforded the chance to construct their own knowledge or learning experiences by creating products that incorporate scientific, technological, engineering, artistic, and mathematical aspects (STEAM). As a result, the researchers will endeavor to develop a project-based STEAM approach to engage students in technology integration. Environmental Pollution, which applies biology and technology principles in everyday life, is a suitable Biology topic to be integrated with the STEAM approach.

The outbreak of the Covid-19 caused by the Corona Virus Disease has resulted in distinctive challenges for educational institutions, particularly in higher education. It has affected over 200 countries globally,(Office, n.d.)and to prevent the spread of the virus, the government has implemented several measures like isolation, physical distancing, and PSBB. As a consequence, individuals are obliged to work, worship, and study remotely from their homes. Therefore, educational institutions must adopt innovative teaching approaches.(Singh & Steele, 2021)One such approach is online or network-based learning, as recommended by (Keiler, 2018). In this context, the teacher plays a vital role in guiding students through the online learning process and facilitating their learning.(Gustiani, 2020)

E-learning or online learning systems employ technology to aid in the process of teaching and learning. This method enables teachers to provide materials and engage in discussions at any time, utilizing the internet network(Nyawo, 2022). Incorporating online learning alongside traditional systems can offer numerous advantages, such as enhancing competencies and streamlining teaching and learning activities.(Yassin & Abasha, 2022)Proper guidance and training for both teachers and students in implementing online learning systems are essential(Mukarromah & Wijayanti, 2021). To facilitate online lectures, the Google Meet application is utilized in conjunction with a selected Google form to assist both students and lecturers/teachers(Aswir et al., 2021)

Drawing on the previously described background, this study aims to address the following questions: (1) What measures can be taken to enhance the critical thinking abilities of students who are taught using the STEAM approach based on the online PjBL model compared to those who are not taught using this approach in Environmental Pollution Materials for Class X SMA? (2) To what extent does implementing the STEAM approach based on the online PjBL model increase student creativity in Environmental Pollution Materials for Class X SMA? (3) How do students perceive the implementation of the online PjBL model-based STEAM approach in Environmental Pollution Materials in Class X SMA, in terms of enhancing their critical thinking abilities and creativity?

2. Theoretical Framework

2.1 STEAM Approach

STEAM-based learning (Scientific, Technological, Engineering, Artistic, and Mathematical aspects) has a significant urgency in the context of modern education. This approach integrates multiple disciplines and skills, essentially reflecting how the real world operates. Here are some of the urgency of STEAM-based learning:

Development of Multidisciplinary Skills: STEAM encourages students to develop understanding and skills in multiple disciplines, such as science, technology, engineering, arts, and mathematics. This helps students build holistic insight and better adaptability in a changing world(Lestari et al., 2023).The STEAM approach promotes integration between different disciplines, similar to how real-world problems are actually solved. This helps students see the relationship between different concepts and understand how knowledge can be applied in practical contexts(Pasani & Amelia, 2021).

Problem-Solving Ability Development: STEAM learning teaches students to design, plan, and evaluate solutions to complex challenges. They develop deep and systematic problem solving abilities.The STEAM approach encourages students to take an active role in the learning process. They are invited to ask questions, seek answers, and undertake in-depth projects, allowing them to take control of their own education(Anggraeni & Suratno, 2021).

In the digital era, technological literacy is very important. STEAM learning helps students understand the basics of technology and adapt to new technological developments(Wahyuningsih et al., 2020).STEAM's interactive and project-based approaches are generally more appealing to students(Rahmawati et al., 2021). This can increase their interest and motivation in learning, help reduce dropout rates and improve academic results.

STEAM learning involves evidence-based problem solving and data analysis. Students learn to collect and critically analyze information, thereby developing strong analytical thinking skills.Through the artistic component of the STEAM approach, students are encouraged to think creatively and encourage innovation. They learn to see problems from multiple points of view and develop unique and out-of-the-box solutions(Kristanto & Dharma, 2023).

In order to respond to the demands of a complex and changing modern world, STEAM-based learning can provide a solid foundation for students to develop the understanding, skills, and insights needed to succeed in various fields.

2.2 Project Based Learning

Project-based learning (PBL) is a learning approach that involves students in carrying out real projects or project-oriented assignments as a major part of the learning process. In this model, students do not only receive knowledge passively, but they are actively involved in planning, designing, implementing, and evaluating projects that have relevance to the content of lessons and real life(Jumaat et al., 2017). The main goal of PBL is to encourage deep understanding, problem solving, collaboration, creativity, and the practical application of knowledge.The main functions of learning with the Project Based Learning model are:

1) Development of Deep Comprehension: Through substantive and contextual projects, students have the opportunity to understand lesson concepts more deeply. They not only memorize facts, but also understand how those concepts interact in real-world situations. Students face challenges that are relevant to real life, which enable them to apply the knowledge and skills of the lesson in practical contexts. This helps clarify the link between the lesson and the real world(Arif, 2018).

2) Improved Problem Solving Ability: Students are presented with concrete challenges and problems that they must solve within the context of a project. It teaches them the ability to design problem-solving strategies, collect data, analyze information, and evaluate solution options(Yu et al., 2015).

3) Collaboration and Communication: In PBL, students often work in groups or teams to complete projects. It develops collaboration skills, effective communication, and working together in teamwork(Sirait & Amnie, 2023).

4) Creativity and Innovation: Projects in PBL often allow students to think creatively and seek innovative solutions. They are given the freedom to develop new approaches to solving problems.

5) Independent Learning: PBL encourages students to take an active role in the learning process. They learn to manage time, manage resources, and overcome challenges on their own, which develops independence and responsibility.

6) High Motivation and Engagement: Projects that are interesting and relevant to students' lives can increase intrinsic motivation and engagement in learning. Students tend to be more motivated because they see the meaning of what they are learning.

7) Development of Technology Skills and Information Literacy: Many projects in PBL involve using technology and understanding how to search, analyze, and use information effectively.

2.3 Critical Thinking Skill

Critical thinking skills that are expected from the implementation of project-based learning models include:

Students are expected to be able to analyze complex information in projects, identify important components, and understand the relationships between these elements. Students are invited to evaluate the information, ideas or solutions generated in the project by considering their reliability, relevance and validity(Markula & Aksela, 2022).Students are given the opportunity to build strong arguments based on relevant data and evidence, as well as communicate their opinions logically and persuasively.Students are invited to reflect on the results of their project, analyze what worked and why, and identify areas that need improvement in the future(John Butterworth & Thwaites, 2013).

Through a project-based model, students can develop the ability to identify complex problems, devise problem-solving strategies, and implement effective solutions(Jalinus & Nabawi, 2018). Students are able to look at an issue from multiple points of view, consider multiple perspectives, and respond in an informed and open way(Murawski, 2022).

Through project-based learning, students can develop the ability to ask in-depth questions, encourage further exploration, and dig deeper into information(Miller & Krajcik, 2019).Students can integrate knowledge from different disciplines or sources, creating a more comprehensive understanding.In project-based learning, students need to take responsibility for developing their own projects, take initiative to understand necessary concepts, and overcome obstacles independently(Wiyanarti, 2018).

It is hoped that these skills will develop along with the application of project-based learning models, giving students the ability to think more critically, analytically, and be ready to face real-world challenges.

2.4 Creativity

Several indicators of creativity that are expected to emerge from the application of the Project Based Learning (PBL) model include:

Development of Innovative Solutions: Students are able to design innovative and unconventional solutions to problems or challenges presented in projects. Students are able to take different or extraordinary approaches in designing, executing, or communicating their projects(Singh & Steele, 2021).Students can generate new ideas that have never been considered before, both in the context of a given problem and in presenting solutions.

Flexibility of Thinking: Students can adjust and change their ideas easily according to changing situations or project needs.Students can combine concepts or ideas from different disciplines or sources to create more comprehensive solutions(Tong et al., 2022).Students are able to express themselves creatively through various media, including pictures, writing, presentations, and other visual elements(Raiyn, 2016).

Making Original Products: Students produce products or works that have elements of uniqueness and originality that reflect their creative thinking(Wijayati et al., 2019).Students dare to explore alternatives and variations in their solutions, without being afraid to try new things.Students are able to find unusual or non-traditional solutions to the problems at hand.Students continually reconsider, revise, and improve their ideas and solutions to achieve better results(Hamidah et al., 2020).

Associative Thinking: Students can make unusual connections between seemingly not directly related concepts.Students are able to ask odd or different questions to encourage further thinking and deeper exploration(Facione, 2015). Students can find creative ways to overcome obstacles or obstacles that may arise in a project.Students are willing to take risks in experimenting with new ideas and approaches, even if the results are not always certain(Cintang et al., 2018).

These indicators reflect the potential for creativity that can be developed and measured through the application of the Project

3. Method

3.1 Research Sites

The study described in this passage was conducted at SMA Negeri 1 Kuningan Regency, which is situated on Jl. Siliwangi, within the Kelurahan Kuningan, Kecamatan Kuningan, Kabupaten Kuningan. The research spanned a duration of two months, from June to July 2020, aligning with the curriculum schedule for the biology subject in both Class X IPA 1 and X IPA 2 at SMA Negeri 1 Kuningan.

3.2 Research Design

The chosen research design for this study was the Pretest-Posttest Control Group Design, as documented in an undisclosed source(Creswell, 2015). This design was implemented to discern variations in creativity and critical thinking abilities.

3.3 Population and Sample

During the research, the experimental class was exposed to the STEAM (Scientific, Technological, Engineering, Artistic, and Mathematical) approach utilizing the Project-based Learning (PjBL) model. In contrast, the control class employed the Problem-based Learning (PBL) model. The study population encompassed all Class X IPA students at SMA Negeri 1 Kuningan, comprising a total of 250 students distributed across 7 classes, with an average of 36 students in each class. To ensure a more representative sample, a non-probability sampling method with a purposive technique was utilized, following certain criteria. This ensured the data collected was indicative of the larger student body(Etikan et al., 2017)

3.4 Data Collection

Data collection methodologies consisted of direct observation, administration of questionnaires, and examination of relevant documentation. The assessment consists of 20 multiple-choice questions and a survey that uncovers the signs of the research factors, specifically gauging critical thinking and creativity skills. The execution of teaching and evaluation of student output is conducted using observation sheets administered by observers

3.5 Data Analysis

The validation and reliability of the research instruments were assessed through statistical tests, including the biserial correlation test and the KR-20 test. For data analysis, a combination of descriptive analysis and inferential statistics, specifically the average difference test, were applied(Yellapu, 2019).

4. Results

4.1 Critical Thinking Skills

The description of the data on students' critical thinking test results is presented as follows:

Table 1. Overview of Pretest Critical Thinking Test Results

Descriptive Statistics	InterventionGroup	Control Group
Mean	54,00	54,75

Standart Deviation	5,76	14,64
Maximum	65,00	75,00
Minimum	45,00	15,00

The data presented in Table 1 reveals that the experimental class had an average score of 54 for their critical thinking skills pretest, with a standard deviation of 5.76. The highest score obtained was 65, while the lowest was 45. However, the control class had an average score of 54.75 for their critical thinking skills pretest, with a higher standard deviation of 14.64. The highest score in the control class was 76, while the lowest score was 15. A breakdown of the pretest results for critical thinking skills for each indicator is provided in the subsequent table.

Table 2. Data Description of Critical Thinking Skills Per Pre-test Indicator

Group	**Critical Thinking Indicator**	**Score**
Control	Interpretation	56,80
	Analysis	48,80
	Evaluation	55,00
Intervention	Interpretation	58,70
	Analysis	60,00
	Evaluation	46,00

Table 2 shows the results of the research on critical thinking skills per pretest indicator which shows that critical thinking skills in the experimental group are highest on the analysis indicator, while in the control class critical thinking skills are highest on the interpretation indicator.

Table 3. General Description of Post-test Critical Thinking Test Results

DescriptiveStatistics	Intervention Group	Control Group
Mean	77,50	65,50
Standard Deviation	8,81	13,95
Maximum	100,00	85,00
Minimum	70,00	35,00

Table 3 displays the results of the final test for the critical thinking skills of the treatmentand control group. The average score of the intervention group is 77.5, with a standard deviation of 13.95. The highest score achieved is 100, and the lowest is 70. On the other hand, the control group has an average score of 65.5, with a standard deviation of 13.95. The highest score obtained is 85, and the lowest is 35. The post-test results for critical thinking skills for each indicator can be seen in the table below

Table 4. Description of Critical Thinking Skills Data Per Indicator post-test

Group	**Critical Thinking Indicator**	**Score**
Control	Interpretation	69,10
	Analysis	67,50

	Evaluation	72,00
Intervention	Interpretation	77,30
	Analysis	85,00
	Evaluation	72,00

In Table 4, the study's post-test results on critical thinking skills per indicator indicate that the intervention group demonstrated the highest critical thinking skills in the analysis indicator, while the participants in the control group presented the highest skills in the interpretation indicator. The study's pretest and posttest outcomes of critical thinking skills were used to compute the normalized average gain (<g>) to determine the progress in critical thinking skills among Class X high school students in environmental pollution after applying the STEAM approach.

The presentation of the results of the normalized average gain on students' critical thinking skills in the experimental and control classes on the Environmental Pollution Theme can be seen in table 5 below:

Table 5. Gain Index for Critical Thinking in Intervention and Control Group

Group	**Pretest Mean**	**Post-test Mean**	**<g>**	**Criteria**
Intervention	54,00	77,50	0,49	Medium
Control	54,75	65,50	0,20	Low

Table 5 displays the comparison of the improvement in critical thinking skills between the experimental and control groups. Despite the control group having higher average critical thinking skills at the beginning, the improvement values were significantly different. The intervention group showed a notable increase in their average pretest score from 54 to 77.50, with a normalized gain value of 0.49, which is classified as moderate. In contrast, the control class only achieved an average post-test value of 65.50, with a normalized gain value of 0.20, which is categorized as low.

The mean value of the post-test results for the intervention group meets the minimum completeness criteria (KKM), while the control group is still below the KKM of 75. To determine the significance of the difference in the average critical thinking skills between the intervention and control groups, a two-sample mean test was conducted after satisfying the normality and homogeneity test prerequisites. SPSS 19 for Windows was utilized to perform a statistical test and compare the critical thinking skills final test (post-test) results between the intervention and control groups. Inferential statistical tests were executed to test the hypothesis, and prior tests of normality and homogeneity of data variances were conducted.

Table 6. Data Normality Test Results of Pre-test Critical Thinking Test

Group	Sig.	Criteria
Pretest Intervention	0,618	Normal distributed data
PretestControl	0,143	Normal distributed data

The statistical analysis of the pretest critical thinking skills test for both the intervention and control groups indicates that their significance values exceed 0.05, indicating that both sets of data are normally distributed. The results of the data variance homogeneity test for the pretest critical thinking skills between the experimental and control groups are presented in Table 7

Table 7. Posttest Data Normality Test Results Critical Thinking Post-test

Group	Sig.	Criteria

Post-testIntervention	0,129	Normal distributed data
Post-test Control	0,256	Normal distributed data

Upon conducting statistical calculations on the post-test critical thinking ability data for both the intervention and control groups, it was observed that the significant values for both groups are greater than 0.05, indicating the normal distribution of data. This observation was further confirmed by the normality assumption test, which was performed for both groups separately. According to Prabawati (2010: 53), the data can be considered normally distributed if the Asymp.Sig (2-tailed) value is ≥ 0.05. Therefore, it can be concluded that the critical thinking skills values for both groups satisfy the normality test, allowing for the homogeneity test to be performed. Table 8 shows the results of the homogeneity test conducted for the pre-test critical thinking ability data between the intervention and control groups.

Table 8.Homogeneity Test Results of Data Variants of the Pretest Critical Thinking Test

Group	Variance	F_{count}	Sig.	Criteria
Intervention	0,58	1,083	0,786	Homogeneous data variance
Control	0,97			

The computation results reveal that the F-count is 1.083, which is lower than the F table, and the significant value is 0.786, which is greater than 0.05. As a result, it can be deduced that the data variance in both groups is uniform, indicating that they have the same variance. The outcomes of the variance homogeneity test calculation of posttest critical thinking ability data between the experimental and control classes are demonstrated in Table 9

Table 9.Homogeneity Test Results of Critical Thinking Post test

Group	Variance	F_{count}	*Sig.*	Criteria
Intervention	0,30	0,24	0,140	Homogeneous data variance
Control	1,35			

The results of the calculations indicate that both groups have homogeneous data variance, as the Fcount is lower than the F table, and the significant value is higher than 0.05. Prabawati (2010) states that data variance is considered homogeneous if the Sig. Levene Statistic test is greater than or equal to 0.05. The normality and variance homogeneity assumption tests confirm that the data is normally distributed and that the data variance is homogeneous. Consequently, inferential statistical testing using parametric non-statistical tests, particularly the Independent Sample T-Test, was used.

To investigate whether there was a significant difference in the average critical thinking skills between the interventiongroup, which received the STEAM approach based on the PjBL model, and the control group, which did not receive the treatment or use the PBL model, an Independent Sample T-Test was conducted using SPSS 19 for Windows. Prabawati (2010) notes that the test criteria are t-count > t-table or Sig. value <0.05. If the criteria are met, Ho is rejected, and H1 is accepted. The test outcomes for the average differences in critical thinking skills on pre-test data between the interventiongroup and the control group are presented in Table 10.

Table 10. Results of the Mean Difference Test of Pretest Critical Thinking Data

Compare		**T**	Df	***Sig. (2-tailed)***	**Meaning**
Pair 1	PretestK –PretestE	**0,195**	19	**0,847**	Ho is accepted, Ha is rejected

Table 10 presents that there is no significant difference in the average critical thinking ability between the interventiongroup and the control group based on the pretest data. This is confirmed by the t-value of 0.195, which is less than the t-table value of 2.02, and a significant value (p-value) of 0.847, which is greater than 0.05. The t-test statistical analysis revealed that there was no significant difference between the critical thinking skills of the intervention group and the control group. Table 11 displays the results of the computation of the difference in critical thinking skills between the intervention group and the control group based on the post-test data.

Table 11.Results of the Mean Difference Test of Critical Thinking Data Post test

Compare		**T**	Df	***Sig. (2-tailed)***	**M**eaning
Pair 1	Postes-K - Postes-E	**2,671**	19	**0,015**	Ho is rejected, Ha is accepted

According to Table 11, there is a variation in the mean critical thinking abilities after the experiment between the intervention and control groups. This is validated by the t-value of 2.671, which is higher than the t-table value of 2.02, and a significant p-value of 0.015, which is less than 0.05. The t-test findings reveal a significant difference in the post-test critical thinking abilities of the intervention group when compared to the control group.

4.2 Increasing Student Creativity Through the Implementation of the PjBL Model-Based STEAM Approach

The research centers on enhancing students' creativity by utilizing the PjBL model-driven STEAM method, while utilizing product performance information as the primary research data. Table 12 offers a summary of the creative product performance outcomes for studentsin both the treatment and control classifications.

Table 12. Description of Creativity Data

No	**Statistics**	**Control Group**	**Intervention Group**
1	**Mean**	76,25	86,88
2	Standarddeviation	3,27	6,05
3	Maximum	81,25	93,75
4	Minimum	68,75	75

Table 12 presents the mean outcomes of innovative product performance for both the intervention and control categories. Within the intervention cohort, students attained an average score of 86.88. Notably, the highest and lowest scores stood at 93.75 and 75 respectively. In contrast, the control cohort posted an average score of 76.25. The range of scores in this group spanned from 81.25 as the highest to 68.75 as the lowest. Moreover, the research outcomes incorporated observational data concerning student creativity in the experimental group, which can be graphically depicted for each parameter.

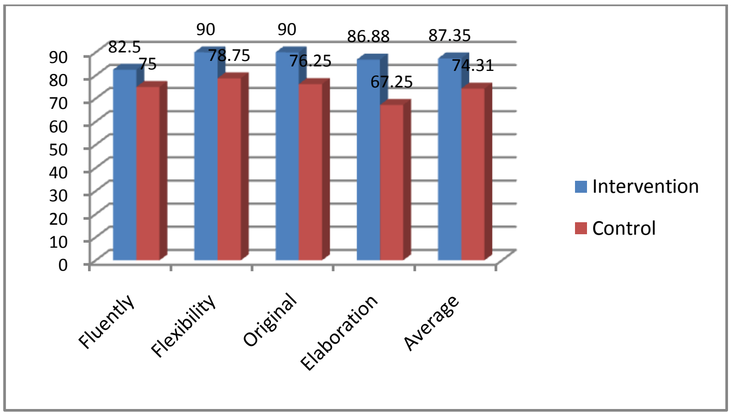

Figure 1 Observation Results of Creativity

Referring to the Figure 1 provided above, it illustrates the post-implementation student creativity under the online STEAM approach founded on the PjBL model, centered around the theme of environmental pollution, specifically within the experimental class. Across various indicators, the fluency reached a rate of 82.5%, flexibility stood at 90%, originality reached 90%, and elaboration achieved 86.88. In contrast, the control class showcased creativity percentages of 75 in fluency, 76.25 in flexibility, 76.25 in originality, and 67.25 in elaboration.

In conclusion, the experimental group showcased praiseworthy creativity, attaining an average score of 86.88, whereas the control group demonstrated satisfactory creativity, achieving an average score of 76.25. Graph 1 visually portrays that students in the experimental group demonstrated heightened creativity across all parameters, excelling notably in flexibility and originality. Conversely, students in the control cohort exhibited notable creativity primarily in the flexibility metric. The subsequent diagram provides a visual depiction of the contrast in creativity between the intervention and control cohorts.

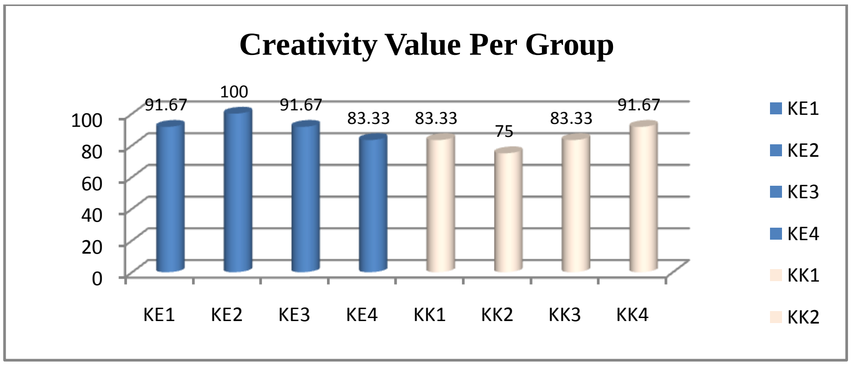

Figure 2.Comparison of Creativity between Control (KK) and Experimental (KE) Groups

Figure 2 displays a comparative chart that illustrates the assessment of student creativity across the two groups. In the intervention group, Group 1 achieved a score of 91.67, Group 2 obtained a perfect score of 100, Group 3 received a score of 91.67, and Group 4 secured a score of 83.33. On the other hand, the evaluation of creativity in the control group resulted in scores of 83.33 for Group 1, 75 for Group 2, 83.33 for Group 3, and 91.67 for Group 4. This data emphasizes that the highest creativity assessment was recorded in Group 2 of the intervention cohort (EG2), while in the control group, the highest rating was observed in Group 4 (CG4). By considering the assessment outcomes from both groups, it can be inferred that the levels of creativity within the intervention group surpass those found in the control group.

4.3 Student Response

Student response questionnaires were made to find out student responses after implementing learning using the STEAM approach. Description of student response data is presented in table 13 below

Table 13 Description of Student Response Data to the STEAM Approach

Statistics	Score	ScoreInterval	Category	Frequency	Percentage (%)
Mean	66,13	68 – 75	Strongly agree	7	46,67
Max	75,00	60 – 67	Agree	6	40,00
Min	47,00	52 – 59	Disagree	1	6,67
Range	28,00	44 – 51	Strongly disagree	1	6,67
Interval	7,00	Total		15	100,00

Table 13 presents the results of the descriptive analysis of student responses, which shows an average value of 66.13, with the highest score being 75 and the lowest value being 47. The range is 28 and the score interval is 7. The analysis indicates that 7 respondents (46.67%) were in the strongly agree category, 6 respondents (40%) were in the agree category, 1 respondent (6.67%) was in the disagree category, and 1 respondent (6.67%) fell into the strongly disagree category. From the descriptive analysis, it can be concluded that the student responses to the STEAM approach based on the PjBL model are in the very agree category, indicating that the approach is highly effective and should be used in other learning processes.

4. Discussion

4.1 Implementation of the STEAM approach with the Project Based Learning model

There were no problems with the implementation of the STEAM approach based on the PjBL model by the teacher during the three meetings, because all the learning phases were carried out very well. In the first stage, namely the determination of fundamental questions (start with essential questions), students' initial knowledge is explored so that students can develop the ideas they already have at a later stage.(Technology, 2017)This is because at the stage of determining basic questions (start with essential questions) students' initial knowledge has not been perfectly facilitated so that the development of their ideas is also not optimal. Before entering the second stage, namely compiling a project plan (design project), at this stage, the teacher then asks students to work in groups, each group consisting of 5 students who have been previously formed and provide LKS (student worksheets) in the form of a file link. So that students are motivated and get hands-on experience, the teacher previously instructed students to do literacy about environmental pollution from various relevant sources and observe environmental pollution that occurs around the residence so that they can be directed according to the learning material, then the observed data is written on LKS (Student Worksheet) that has been provided via the file link and printed out by students.(Retnowati et al., 2022)

In the second stage, namely compiling a project plan (design project), students design a project. In project planning the teacher determines that the project topics created must relate to the real world and relate to the Science, Technology, Engineering, Art and Mathematics (STEAM) approach. Through online learning using the Google Meet application the teacher guides students to design projects that will be made such as making design drawings and determining the tools and materials to be used. At this stage, the implementation of project planning (design project) of students' prior knowledge and the development of student ideas has been maximized.

The third stage is preparing a schedule (create schedule). At this stage students collaboratively with their groups arrange activity schedules in completing projects and the teacher guides students through online learning using the Google Meet application to determine important steps in preparing projects and students determine the time limit given in completing their project tasks (activities). starting from the beginning of the implementation time (timeline) to the deadline for implementation (deadline). The time schedule for the project plan is made by filling in the LKS that the teacher has provided. At this stage, the implementation of creating a student schedule is still going well even though it is not optimal.

At the end of the lesson the teacher reminded the student groups to prepare tools and materials to be used to make products at the next meeting. During the preparation of tools and materials, students can ask questions directly to the teacher via Whatsapp. At the second meeting, continuing the next PjBL stage in the fourth stage, namely monitoring or implementing the project (Monitor the Students and the Progress of the Project) in accordance with the plans that have been made. Each group carries out a project with offline learning carried out at school. Activities at this stage begin with preparing tools and materials and then students create STEAM-based drawing designs with attention to fluency, flexibility, originality and elaboration in accordance with the planning stage, then the next step is to create products in collaboration between group members monitored by the teacher directly . This activity is carried out outside of class hours in accordance with the agreed time. Students also convey any obstacles faced by the group. The teacher responds, facilitates and provides input on the obstacles encountered so that all groups are expected to complete the project on time.

In the fifth stage, namely Testing the Results (Asssess the Outcome) or evaluating project results. In this activity to test the results of the project, each group was asked to present product results which included the tools and materials used, the design drawings made and the steps for making products online through the Google Meet application and other groups responded. The aim is to determine the group's mastery and understanding of the implementation of projects and products made.

Once students have presented their project results, the teacher evaluates their achievements in terms of knowledge, skills, and attitudes related to the topic. The purpose of this activity is to develop critical thinking skills, specifically in evaluating the strengths and weaknesses of the products.

During the final phase called "Evaluating the Experience," the teacher engages in self-reflection, while also allowing students to reflect on all the activities they have engaged in during their learning journey using the Science, Technology, Engineering, Art, and Mathematics (STEAM) approach. The objective of this phase is to evaluate the strengths and weaknesses of the learning process to identify areas for improvement in future learning endeavors.(Plomp & Nieveen, 2010)

According on the results of observations during the learning process, in the preliminary stage a score of 5 was obtained out of a total score of 5 (100%). At the core activity stage of implementing the learning process, a score of 8 was obtained out of a total score of 8 (100%). And in the final stage of learning implementation, a score of 4 is obtained from a maximum score of 4 (100%). Overall it shows that the implementation of learning reaches 100% which is included in the very good category.

The results of this study are in accordance with the opinion of Kosasih (2014) Project Based Learning is a learning model that uses a project or activity as its goal. Learning is focused on solving problems which is the main goal of the learning process so that it can provide more meaningful learning because learning does not only understand what is learned but makes students know what the benefits of learning are for the surrounding environment.

4.2 Differences in Increasing Critical Thinking Skills in the Experiment Group and the Control Group

The enhancement in critical thinking abilities can be observed through the normalized gain derived from the evaluation of the pre-test and post-test using 20 multiple-choice questions that encompass three factors, namely interpretation, analysis, and evaluation. The dissimilarity in the level of students' critical thinking abilities between the experimental and control groups is due to the fact that the STEAM approach, based on the PjBL learning model, was implemented in the experimental group by creating products whose stages encourage critical thinking skills activities, particularly interpretation. The study's findings reveal that the achievement of critical thinking skills is more impacted by the interpretation indicators.

This Interpretation aspect is like working on a project, students can collaborate and carry out investigations in collaborative groups. The skills needed and developed by students in teams are planning, organizing, negotiating, and making consensus about the tasks to be done, who is doing it, and how to gather the information needed in an investigation. The skills students need and will develop are essential skills as a foundation for the success of their projects. The skills developed through collaboration in teams lead to active learning, where each individual has varying skills so that each individual tries to show the skills they have in their teamwork. Whereas in the control class students used group discussion and question and answer methods by following the LKS instructions provided by the teacher. Students carry out group discussions, then present the results of the discussions and conduct question and answer between groups and finally the teacher provides reinforcement of the results of group discussions.

The findings of this research are consistent with Sukiawati study (2021), which revealed that PjBL has a positive impact on academic achievement(Reyes, 2023), students' positive attitudes(Nurfaidah & Training, 2021), work skills(Pratiwi et al., 2020), and problem-solving awareness(Learning et al., 2020). The study aimed to evaluate the enhancement of critical thinking skills among high school students in class X who were learning about environmental pollution, after the implementation of the STEAM approach. The difference in the critical thinking skills of the intervention and control groups was measured by calculating the normalized average gain value (<g>) obtained from the pre-test and post-test results.

The results of the analysis demonstrated that the intervention group that received instruction through the STEAM approach based on the PjBL model exhibited better performance in critical thinking skills, as PjBL incorporates stages that facilitate these skills. PjBL learning commences with essential questions that prompt students to reflect on environmental pollution issues around their living environment and encourage them to explore potential solutions to these problems, which helps students establish their learning objectives. In the next stage, students formulate a project implementation plan and schedule. This step teaches students how to determine themes, objectives, gather relevant information, identify necessary tools and materials, define experimental procedures, and divide tasks among group members. The subsequent phase involves project implementation, testing of outcomes, and evaluation. The PjBL learning model, which is based on the STEAM approach, enhances critical thinking skills, particularly with respect to the analytical indicators.(Rizki et al., 2022)

The control class conducts online learning using the PBL learning model through a question-and-answer discussion method to solve problems contained in environmental pollution LKS, then the teacher supervises and guides online. At the time the presentation was not going well. So this does not facilitate the development of critical thinking skills in finding and solving environmental pollution problems.

The results of research on critical thinking skills in the intervention group, obtained data that analyzing is the highest indicator. This can be explained because by carrying out project assignments students can observe more details on a thing or object in the project they are working on by outlining its constituent components or assembling these components for further study so that a product is produced that is beneficial to society in accordance with the STEAM aspect. While the lowest critical thinking skills are on the evaluation indicator, this is possible because the evaluation factor is a more difficult factor after remembering, understanding, applying, and analyzing in the realm of cognitive learning outcomes according to Bloom's revised theory(Language & Mulia, 2018). The results of this study are in accordance with the results of research by Gonzales &Quenzy (2012) who found that learning with a project-based model is not only to increase students' awareness and understanding of the need for clean water, but also to improve students' critical thinking skills in their daily lives.(Anazifa, 2017)

4.3 The Effect of the STEAM Approach on Student Creativity

The results of this study indicate that students' creativity increases higher on the indicators of flexibility and originality. This is a natural thing because in the process of implementing a project students think, arrange schedules, design products, and work to carry out project tasks that require flexibility in thinking, require mathematical abilities in designing and measuring, as well as artistic values (taste, beauty/aesthetics), so that the resulting product is fit for sale. Based on the products produced, on average each group is able to make products made from STEAM-based plastic waste. The products produced are two flower vases, a piggy bank and eco-bricks. Of the four groups, there was one group that paid little attention to the STEAM element, namely the process of making chairs from ecobricks. They pay less attention to cleanliness and beauty (art), the method of making and using tools and materials is still lacking (technology).

The findings of this study demonstrate that the application of the STEAM approach has led to an increase in student creativity. This aligns with the conclusions of prior research by (Ergül & Keskin, 2014), who argued that the STEAM approach centers on real-world issues that pique students' curiosity and stimulate deep thinking, as learners must obtain and utilize new knowledge in the context of solving open-ended problems.

Moreover, the present study employed a project-based learning model that involves tackling an open-ended project to acquire in-depth, subject-specific skills. This is consistent with Requires et al's (2018) findings, which indicate that project-based learning enables students to take ownership of their own learning and therefore promotes the development of critical thinking abilities and creativity beyond the rote learning provided by traditional teacher-centered instruction.

4.4 Student Responses to Learning with the STEAM Approach

To assess students' perception of the effectiveness of the STEAM approach based on the PjBL learning model, a closed questionnaire was administered to students. The questionnaire comprised questions that were easy to comprehend and asked for feedback on whether the approach improved their critical thinking skills and creativity. The Likert scale was used to analyze the responses, and the results revealed that students strongly agreed with the effectiveness of the STEAM approach based on the PjBL learning model in improving their critical thinking skills and creativity.(Putri et al., 2023)The responses of the students to the application of the STEAM approach based on the PjBL learning model can be viewed in Figure 3.

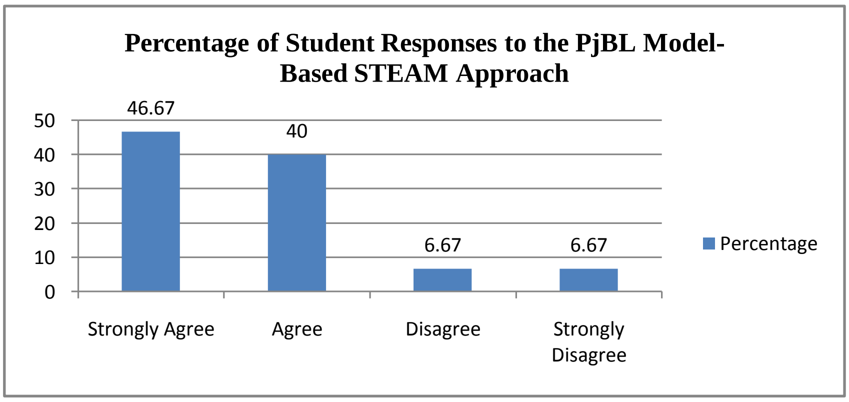

Figure 3 Recapitulation of the Percentage of Student Responses to the PjBL Model-Based STEAM Approach

Based on Figure 3, most of the students stated that they strongly agreed that the STEAM approach based on the PjBL model attracted their interest because the products made were related to everyday life and the presentation activities were fun because there was an activity of mutually assessing group products.(Suganda & Latifah, n.d.) Students feel that the PjBL-based STEAM approach can make it easier to understand the concept of environmental pollution and can develop the ability to think, interpret and draw conclusions. In addition, PjBL is also seen as being able to improve students' skills in planning and designing products. The results of PjBL are also considered by students to be very useful for use in everyday life so that most students strongly agree if PjBL learning steps that accommodate STEAM aspects are applied to other materials. Thus the results of the questionnaire can illustrate that the STEAM approach based on the PjBL model influences students' critical thinking skills and creativity. This is in accordance with the results of Barlenti et al (2017) which found that students' responses to the use of PjBL-based worksheets were that students were very happy and gave very high responses in participating in learning using project-based learning.

5. Conclusion

After conducting research and discussion, the following conclusions can be drawn: Firstly, there is a significant difference in the mean critical thinking abilities between the intervention and control groups in grade X SMA Negeri 1 Kuningan, after utilizing the online PjBL model-based STEAM approach for Environmental Pollution

Material. This is evident from the probability value (p) of 0.015, which is less than 0.05. Next, there exists a difference in the mean creativity score between the intervention and control cohorts following the implementation of the STEAM approach through the online PjBL model. The intervention group achieved a commendable average score of 86.88, falling under the "good" category, whereas the control group attained an average score of 76.25, which is classified as "sufficient". Thirdly, the students' responses towards the implementation of the STEAM approach based on the online PjBL model for enhancing their critical thinking abilities and creativity in Environmental Pollution material in grade X SMA Negeri 1 Kuningan are positive and considered good.

Several limitations should be acknowledged: (1) Sample Size and Generalizability: The research was conducted within a single school and involved a specific grade level. The sample size may limit the generalizability of the findings to broader student populations or different educational settings, (2) Duration of Study: The research was carried out over a relatively short period of two months. A longer duration could potentially provide a more comprehensive understanding of the sustained impact of the STEAM approach on critical thinking and creativity, (3) Homogeneity of Participants: The study may have included participants with similar backgrounds and prior experiences, potentially limiting the diversity of perspectives and responses to the intervention, (4) Influence of External Factors: Various external factors, such as students' personal circumstances, outside-of-school influences, and other teaching methods, could have affected the outcomes and should be considered as potential confounding variables.

This study has implications for the academic profession and industrial practitioners:

1) Curriculum Development: The findings highlight the potential benefits of incorporating the STEAM approach with online PjBL models into the curriculum. Educators and curriculum designers could consider integrating similar approaches to foster critical thinking and creativity across diverse subject areas.
2) Teacher Training: As the success of implementing innovative pedagogical approaches depends on teachers' understanding and skillset, future initiatives could focus on providing professional development opportunities to enhance educators' proficiency in employing the STEAM-PjBL model effectively.
3) Academic professionals need to develop learning methods that are compatible with the STEAM and PBL approaches. They must integrate concepts from multiple disciplines and design challenging projects to encourage students' critical thinking and creativity.
4) Applying the STEAM approach requires collaboration between various disciplines. Academic professionals need to collaborate with fellow educators from various fields to design a holistic learning experience.
5) Recruitment of Qualified Workforce: The application of the PBL-Based STEAM approach can produce graduates who have critical thinking skills and high creativity. Industry practitioners can benefit from graduates who are able to adapt quickly, solve problems and generate innovative solutions.
6) Collaboration with Education: Industry practitioners can collaborate with educational institutions to design real projects that are relevant to the industrial world. It provides students with practical experience in tackling real challenges faced by the industry.
7) Innovation Empowerment: Graduates who possess critical thinking skills and creativity can become a source of innovation for the industry. They can provide new perspectives, fresh ideas, and solutions that have never been thought of before.

Credit S tatements

Theauthorconfirmssoleresponsibilityforthefollowing:studyconception and design, data collection, analysis and interpretation ofresults,andmanuscriptpreparation.

Declarationsofinterest

The author declared no potential conflicts of interest with respect totheresearch,authorship,and/orpublicationofthisarticle

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