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# Improving Creative Thinking Skills and Learning Independence in Vocational High School Students through STEM-Integrated Project-Based Learning Models

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## Abstract

Background – Improving vocational high school students' creative thinking skills and learning independence is important to meet modern industry demands, requiring innovative approaches such as STEM-integrated Project-Based Learning (PjBL) that engage students in problem-solving and real-world projects.
Purpose - This study aims to analyze the application of the STEM-integrated PjBL model in improving students' creative thinking skills and learning independence.
Method/approach - This study used a quantitative approach with a quasi-experimental non-equivalent control group design involving pretest and posttest. The population consisted of grade XI vocational high school students in Purbalingga, Central Java. The sample was selected purposively from grade XI TKJ students at SMK N 1 Purbalingga and SMK N 1 Kemangkon. Data were collected through creative thinking tests, learning independence questionnaires, and observation sheets. Instrument validity was tested by comparing the calculated r-value with the r-table value (0.3809), and reliability was measured using Cronbach's alpha.
Findings - Several test items were declared valid, and the learning independence questionnaire showed factor loadings between 0.720–0.756. Reliability results showed Cronbach's alpha values of 0.74 for the creative thinking instrument and 0.773 for the learning independence questionnaire.
Conclusions - The N-Gain results showed that students' creative thinking skills improved more in the experimental class than in the control class. However, the increase in learning independence was minimal and showed no significant difference between the two groups.

**Keywords:** project-based learning, STEM, GeoGebra, creative thinking skills, learning independence.

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## INTRODUCTION

The current world has entered the era of the industrial revolution 5.0, where society is expected to be able to integrate technology into life in a smarter, more humane, and more sustainable way. An important element that can boost the nation's competitiveness in facing global competition is by improving the quality of human resources who are able to adapt in the era of the industrial revolution 5.0. One step in preparing quality human resources is by improving the competency of graduates who have 21st-century skills. 21st-century skills focus on critical thinking and problem solving, communication and collaboration, creativity and innovation.

According to (Harahap et al., 2021)creative thinking ability is the ability to connect or see things from a new perspective that has a broader scope, can develop unusual ideas and produce new thoughts that are different from the ideas produced by most people. Meanwhile, (Clarisa et al., n.d.) defines critical thinking ability as the activity of analyzing ideas or concepts in a more specific direction, distinguishing sharply, selecting, identifying, reviewing and developing them in a more perfect direction. (Mawaddah & Mahmudi, 2021) state that mathematical communication ability is the ability to convey information using spoken or written language about mathematical properties or concepts.

Today's dynamic changes require students to possess creative and innovative thinking skills to address various real-life problems. According to (Widana & Septiari, 2021), one of the competencies students must possess to adapt to dynamic change is the ability to think creatively. Through creative thinking, students can solve a problem in multiple or different ways. Creative thinking can be fostered by training students to think outside the box to generate or discover new ideas. These ideas can train students to solve problems more effectively and efficiently.

According to the World Intellectual Property Organization (WIPO), which released its global innovation index on September 29, 2022, Indonesia ranks 75th with an innovation index score of 27.9. WIPO conducts rankings based on criteria such as human capital, institutions, technology, and creative output. The results of the Program for International Student Assessment (PISA) 2022, volume III, also show that the average score obtained by Indonesian students was 19 out of a maximum possible score of 60. This score is significantly lower than the OECD average score for creative thinking, which is 33. Students' relative performance in creative thinking is below expectations for Indonesia based on achievement in mathematics and reading. This test explores how well students can generate diverse and creative ideas, as well as evaluate and improve ideas to achieve creative results. This low level of creative thinking ability can be caused by several factors, including an educational curriculum that does not support the development of creativity, conventional teaching methods, and a lack of opportunities for students to engage in activities that stimulate their creativity. Therefore, efforts are needed to improve students' creative thinking skills, so they are better prepared to face the challenges of the workplace.

The implementation of the independent curriculum at the secondary school level aims to create a more flexible, inclusive learning ecosystem that is oriented towards student needs and future challenges. The independent curriculum was developed with the main characteristic of project-based learning to develop students' soft skills and character by strengthening the Pancasila student profile. One characteristic is the Pancasila student profile strengthening project, which provides students with opportunities to explore knowledge and develop skills in depth, thus training them to carry out real-world work in response to issues tailored to their development and learning stages. The Pancasila student profile strengthening project can be implemented through the application of project-based learning.

Education in the 21st century requires students to possess strong independent learning skills. Independent learning is a key skill, enabling students to manage their own learning process, find solutions to problems, and continuously adapt to developments in science and technology. In the

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learning process, independent students are often more willing to try new approaches and think outside the box. Self-regulated learning enables students to choose learning strategies to effectively solve problems. Creative thinking can provide flexible ways of thinking to address complex issues. Student creativity can be fostered through questions that require open-ended strategies or offer multiple answers. Therefore, creative thinking is closely linked to self-regulated learning.

Mathematics learning is expected to foster higher-level skills, including creative thinking. One approach to fostering and training creative thinking is integrated learning with science and technology. The integration of science, technology, and engineering in mathematics learning is known as the science, technology, engineering, and mathematics (STEM) approach. Creative thinking and independent learning are essential competencies for vocational high school (SMK) students to face the challenges of the workplace and rapid technological developments. Today's workforce requires workers who possess not only technical skills but also the ability to solve complex problems, think analytically, and generate creative, technology-based solutions.

According to (Handayani et al., 2021), creative thinking skills developed in learning include the following aspects: 1) fluency (the ability to think fluently); 2) flexibility (the ability to think flexibly); 3) originality (the ability to think originally); and 4) elaboration (the ability to think in detail). According to (Rahayu et al., 2022), indicators of learning independence include: 1) initiative and intrinsic learning motivation; 2) the habit of diagnosing learning needs; 3) setting goals or targets; 4) monitoring, organizing, and controlling learning; 5) viewing difficulties as challenges; 6) utilizing and seeking relevant sources; 7) selecting and implementing learning strategies; 8) evaluating the learning process and outcomes; 9) having a self-concept/self-ability.

Based on initial observations and interviews with Vocational High School (SMK) teachers in Purbalingga, project-based learning is more suitable for vocational subjects in SMK. Therefore, not many teachers have implemented project-based learning, especially mathematics teachers. The implementation of learning in SMK Purbalingga Regency has not widely implemented project-based learning which is the main characteristic of the independent curriculum. Based on interviews with SMK mathematics teachers in Purbalingga, the results show that 1) students when given questions tend to give answers according to what the teacher exemplifies, meaning that students are not yet fluent in answering questions; 2) students tend not to dare to answer with answers that are different from other friends, this shows that students do not have the flexibility to find varied alternative answers; 3) students tend to still memorize what is given or exemplified by the teacher, this shows that students have not shown original/authentic thinking in solving a problem; 3) students have not been able to explain in detail or coherently from a problem given by the teacher, this shows that students' ability in elaboration has not been seen in solving a problem.

According to a tracer study conducted by the Special Job Exchange (BKK) team at SMK Negeri 1 Purbalingga in 2022-2023, less than 40% of graduates were employed, less than 20% continued their education to a higher level, and less than 25% became entrepreneurs, while the remainder engaged in other activities. These figures indicate a significant problem in the employment rate of graduates. One of the main factors identified as contributing to the low employment rate is the low level of creative thinking skills among graduates. Creative thinking skills are crucial in today's workplace, where innovation and creative problem-solving are sought-after values by many companies and institutions. However, the tracer study results indicate that many graduates lack these skills.

Based on observations made by researchers, the learning independence of vocational high school students in Purbalingga is still largely low. This is indicated by students' reliance on other students they consider most capable in class when completing individual or group assignments given by teachers, or their group leaders when working in groups. Students only study when there is an assignment or when an assessment is held. Students are not yet able to set their own learning targets. Students often

procrastinate in completing assignments, usually submitting them at the end of the day, resulting in less-than-optimal results. When students participate in discussions, many still rely on tutors. Some students are still afraid to express opinions that differ from those of their peers during discussions. Students still lack confidence and are afraid of making mistakes when completing assignments.

The challenge facing vocational high school students in Purbalingga is ensuring that they not only master practical aspects but also think innovatively, work independently, and develop relevant and applicable solutions to complex problems. The STEM-integrated project-based learning model provides students with opportunities to apply their knowledge in real-world contexts through projects that require collaboration, creativity, and technological expertise. This aligns with industry needs, which increasingly prioritize workers with adaptive and innovative skills. The purpose of this study is to analyze the application of the STEM-integrated project-based learning model to improve students' creative thinking skills and to analyze the application of the STEM-integrated project-based learning model to enhance students' learning independence.

Based on the analysis of research data by (Surmilasari et al., 2022) on the implementation of STEM-based project-based learning, it was concluded that there is an influence of the STEM-based project-based learning model on students' creative thinking skills in fifth-grade elementary school mathematics learning. Meanwhile, research conducted by (Othman et al., 2022) shows that a planned STEM approach can have a positive impact and build student creativity in creating interesting learning experiences. The results of research by (Widana & Septiari, 2021) stated that there is an influence of the STEM-based project-based learning model on creative thinking skills. Combining project-based learning with STEM can increase effectiveness, produce meaningful learning and influence students' attitudes in pursuing future careers in facing global challenges. This is related to student creativity (Amina G., 2024; Mutia Rahman et al., 2025).

Research by (Djam'an et al., 2021) also concluded that project-based learning can enhance students' creativity in city building through the application of mathematical concepts. According to (Susilowati & Wahyudi, 2020) research, it can be concluded that the learning process through the integration of STEM knowledge can enhance students' creativity in terms of creative thinking skills, which consist of fluency, flexibility, originality, and elaboration. Based on the research results by (Widyasmah et al., 2020), it was also concluded that learning with a STEM approach can enhance students' creative thinking and improve indicators of creative thinking skills. The results of (Septian, 2021) research revealed that students' self-regulated learning achievement when implementing the GeoGebra-assisted project-based learning model was better than students who only received the project-based learning model. According to (Monika et al., 2023) learning using PjBL STEM can improve cognitive learning outcomes, as seen from the higher N-gain value compared to using the PjBL learning model. Similar research by (Hasibuan et al., 2022) concluded that the implementation of STEM-integrated project-based learning can improve students' mathematical thinking skills and learning independence.

## METHODS

The design used in this study was a quasi-experimental design. According to (Abraham & Supriyati, 2022), a quasi-experimental design has a control group, but it cannot fully control external variables that influence the implementation of the experiment. In this study, the quasi-experimental design used is the non-equivalent group design, which requires an experiment and a control group. However, the determination of the experimental and control groups was not done randomly because the classes were already formed. Both groups were given a pre-test before being given the treatment. After that, the two groups were given different treatments: the experimental class implemented project-

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based learning integrated with STEM, while the control class implemented learning without using the project-based learning model integrated with STEM. After being given the treatment, both groups were given another post-test for measurement.

The population in this study was all 11th grade students at vocational high schools in Purbalingga in the 2024/2025 academic year. Vocational high school students were chosen as the population in this study because they are specifically prepared to enter the workforce, emphasizing practical skills and the application of theory in a real-world work environment. This requires students to have creative thinking skills in solving problems and independent learning to adapt to industrial developments.

The sampling technique in this study used a purposive sampling technique to determine the sample of class XI students majoring in Computer and Network Engineering (TKJ). Purposive sampling is a technique for determining research samples with several specific considerations according to the desired criteria to be able to determine the number of samples studied (Bell et al., 2022; Memon et al., 2024). This technique was chosen because it allows researchers to specifically select respondents who have obtained the basics of science in the field of technology and are beginning to face challenges in solving technical problems and technology-based projects. The sample in this study was class XI TKJ at SMK N 1 Purbalingga and SMK N 1 Kemangkon. Sampling in this study was carried out in class XI TKJ because this class applies more technology-based learning that is in accordance with the research to be conducted, namely STEM-integrated project-based learning. The instruments used in this study were a creative thinking ability test, while non-test instruments included a self-regulated learning questionnaire and observation sheets. The creative thinking ability test used descriptive items to measure students' creative thinking abilities. The learning instrument of independence was a questionnaire.

Before being tested, the test instrument was first tested to test its validity, reliability, discrimination power, and level of difficulty. Test instruments that have been declared valid and reliable can be used for research. The construct validity of the learning independence instrument was tested using the Confirmatory Factor Analysis (CFA) technique with the help of SPSS software. The analysis aims to determine the feasibility of the statement items in measuring the learning independence construct consistently and theoretically. The tests carried out were the KMO Test and Bartlett's Test. A good KMO value is ≥ 0.50, which indicates that the data is sufficient for factor analysis. In addition, the criteria for Bartlett's Test results are if the significance value does not exceed 0.05, there is a significant correlation between the statement items, so it is appropriate to proceed to the Anti-Image Correlation stage (Kwao Nkansah, 2018; Prihono et al., 2022).

An important component in this matrix is the Measures of Sampling Adequacy (MSA) value of each item. An item is considered valid if the MSA value is ≥ 0.50 (Harun Baharudin, 2021). The next step is to examine the factor loading value of each statement item. The factor loading value describes the strength of the relationship between an item and the factors formed. According to (Hair et al., 2019), items with a factor loading value ≥ 0.50 can be said to be construct valid. The next step is the reliability test, which is conducted using Cronbach's Alpha coefficient, with the help of SPSS software.

Statistical testing is a crucial step in analyzing quantitative data generated in research. The data obtained in this study were pretest and posttest data. This quantitative data analysis aims to answer the proposed hypothesis. Instrument test data were processed to determine validity, reliability, discriminatory power, and question difficulty. Pretest, posttest, N-gain, and student learning independence attitude scale data were processed using Microsoft Excel and SPSS.

For descriptive analysis of pretest and posttest data, the data descriptions were first calculated, including the mean, standard deviation, and median. Normality and homogeneity tests were then performed. The score for increasing creative thinking skills was then calculated using the N-gain

formula: Gain $= \frac{\text{skor postest} - \text{skor pretest}}{\text{skor ideal} - \text{skor pretest}}$. The results of the N-gain calculation are then interpreted, if the N-gain > 0.06 then the N-gain is classified as high.

## RESULTS AND DISCUSSION

Before presenting the findings, it is necessary to provide an overview of the analytical focus of this study. The discussion of results is directed toward understanding how the integrated STEM Project-Based Learning (PjBL) model influences two essential 21st-century competencies: creative thinking ability and self-regulated learning. Both competencies are regarded as core indicators of students' readiness to adapt to industrial and technological challenges in vocational education. Therefore, the results are interpreted not only in terms of statistical significance but also in terms of their educational implications for learning innovation in vocational schools.

The data analysis in this study involved several stages. First, instrument validation was carried out to ensure that both the creative thinking and self-regulated learning instruments met the validity and reliability criteria. Next, assumption tests including normality, homogeneity, and equality of means were performed before hypothesis testing. Statistical analyses such as t-tests, N-Gain, and MANOVA were used to determine the magnitude and significance of the model's effect. These tests were conducted separately for two schools—SMK N 1 Purbalingga and SMK N 1 Kemangkon—to strengthen the generalization of the findings.

The following discussion is divided into two major subsections: (1) Creative Thinking Ability and (2) Self-Regulated Learning. Each subsection presents the results of the instrument analysis, descriptive statistics, and inferential tests, followed by an interpretation that links the findings to relevant theoretical perspectives and previous research. This systematic presentation aims to provide a comprehensive understanding of the impact of integrated STEM project-based learning on students' creative and self-regulated learning development.

### Creative Thinking Ability

Testing of creative thinking ability test instruments was conducted to assess the extent to which the prepared test items could measure creative thinking ability according to the established indicators. The analysis process included testing validity, reliability, discrimination, and difficulty level with the aim of ensuring the instrument was truly suitable for use in the main research. Based on the results of expert judgment, the test items were declared to be in accordance with the indicators of creative thinking ability which include fluency, flexibility, originality, and elaboration. Several improvements were made to the wording of questions 1 and 5 to make them clearer and more appropriate to the level of development of students. For item validity, the calculated r value was obtained for each test item, which was then compared with the table r value of 0.3809. The test results showed that questions 2, 3, 4, and 6 had calculated r values greater than the table r, so they were declared valid. This indicates that the four test items are suitable for use in measuring creative thinking ability. Meanwhile, questions 1 and 5 have calculated r values that are lower than the table r, namely 0.3018 and 0.3024 respectively, so they are categorized as invalid.

The results of the reliability calculation show that the Cronbach alpha value is 0.74. This value is above the minimum reliability limit of 0.70. This indicates that the test instrument has a good level of reliability and can be used consistently to measure students' creative thinking abilities. The discrimination power test obtained that the questions were in the sufficient category, with details of questions number 1, 2, 3, and 6 having discrimination powers of 26.07%, 20.09%, 28.42%, and 24.79%, respectively. Overall, five of the six questions have sufficient to good discrimination quality, indicating

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that the instrument is generally suitable for use with minor improvements. The results of the difficulty index for questions number 1, 3, 4, and 5 were 0.75; 0.79; 0.80; and 0.73, respectively. This indicates that most students were able to answer these questions correctly, so the questions were considered relatively easy. Meanwhile, questions 2 and 6 are included in the moderate category with difficulty indexes of 0.49 and 0.55 respectively.

The pretest results in both schools, namely SMK N 1 Purbalingga, showed that the normality test for the calculated KS value was 0.08 for the experimental class and 0.12 for the control class. Both values were smaller than the table KS value of 0.224 at a significance level of 0.05. Meanwhile, the results of SMK N 1 Kemangkon showed that the calculated KS in the experimental class and the control class was 0.13. Thus, it can be concluded that the pre-test data for creative thinking ability in both sample groups, both the experimental class and the control class, met the normality assumption.

The homogeneity test shows that the calculated F value is 1.26 at SMK N 1 Purbalingga and the calculated F value at SMK N 1 Kemangkon is 1.49. Because the calculated F is smaller than the F table (1.77), it can be concluded that the data variance between the experimental class and the control class is homogeneous. This means that there is no significant difference in the distribution of data between the two groups or the initial conditions of the two groups are quite equal. After fulfilling the assumptions of normality and homogeneity, the next step is to conduct a test of equality of means to determine whether there is a difference in the means between the experimental class and the control class before being given treatment.

The results of the posttest of the normality test conducted using the Kolmogorov-Smirnov method obtained that the data in both groups, both the experimental class and the control class, were normally distributed. The homogeneity test at SMK N 1 Purbalingga found that the calculated F value was 1.04, while the F table value at a significance level of 0.05 was 1.77. Meanwhile, the results of the homogeneity test at SMK N 1 Kemangkon obtained that the calculated F value was 1.26, while the F table value at a significance level of 0.05 was 1.77. Because the calculated F is smaller than the F table (1.77), it can be concluded that the data variance between the experimental class and the control class is homogeneous.

After conducting normality and homogeneity tests, which showed that the posttest data from the experimental and control classes were normally distributed and had homogeneous variances, the next step was to conduct a mean difference test. The results of the mean difference test showed a significance value of 0.03 at SMK N 1 Purbalingga and 0.01 at SMK N 1 Kemangkon. This indicates a significant difference between the posttest results of students in the experimental and control classes. In other words, the treatment given to students in the experimental class had a positive effect on improving their creative thinking skills compared to the control class that was not given the treatment. This finding indicates that the method or intervention applied in the experimental class was successful in significantly improving students' creative thinking skills.

To measure the level of improvement that occurred after the treatment, an N-Gain test was conducted on the students' pretest and posttest results. The N-Gain test is used to evaluate the extent of improvement in students' creative thinking abilities, by calculating the difference between the pretest and posttest scores. Based on the results of the N-Gain test calculation, it is known that the average N-gain score at SMK N 1 Purbalingga, the increase in students' creative thinking abilities in the experimental class was 51.20%, while the control class only reached 20.82%. Meanwhile, the average N-gain score at SMK N 1 Kemangkon was 38.74% for the experimental class, while the control class obtained an N-Gain score of 20.88%. These results indicate that the treatment given to the experimental class had a greater influence in improving students' creative thinking abilities compared to the learning implemented in the control class.

## Learning Independence

Instrument testing was conducted through confirmatory factor analysis (CFA). Data suitability was first tested using the Kaiser-Meyer-Olkin (KMO) test and Bartlett's Test of Sphericity. Data are considered to meet the requirements for factor analysis if the KMO value is >0.5 and the Bartlett's Test shows a significance value <0.05. The KMO value of 0.721 indicates that the sampling size is considered adequate because the KMO value is above 0.5. This indicates that the data has sufficient sample size for further analysis using factor analysis techniques. Meanwhile, the Bartlett's Test of Sphericity results in a significance value of 0.000, which is less than 0.05. This result indicates a significant correlation between the variables, making the data suitable for use in factor analysis.

The next step in factor analysis is to examine the Anti-Image Correlation matrix. The Anti-Image Correlation results are presented in Table 1 as follows:

**Table 1.** *Anti-Image Correlation*

| Indicator | Anti Image Value | Reference Value | Conclusion |
|---|---|---|---|
| Initiative and Motivation 1 | 0,732 | 0,50 | Asumsi *Measure of Sampling Adequacy* (MSA) Terpenuhi |
| Initiative and Motivation 2 | 0,654 | | |
| Initiative and Motivation 3 | 0,672 | | |
| Learning needs 1 | 0,729 | | |
| Learning needs 2 | 0,786 | | |
| Learning needs 3 | 0,808 | | |
| Learning needs 4 | 0,571 | | |
| Have a goal 1 | 0,709 | | |
| Have a goal 2 | 0,806 | | |
| Have a goal 3 | 0,776 | | |
| Controlling learning 1 | 0,678 | | |
| Controlling learning 2 | 0,629 | | |
| Controlling learning 3 | 0,799 | | |
| Difficulty becomes a challenge 1 | 0,688 | | |
| Difficulty becomes a challenge 2 | 0,747 | | |
| Difficulty becomes a challenge 3 | 0,833 | | |
| Looking for references 1 | 0,775 | | |
| Looking for references 2 | 0,626 | | |
| Looking for references 3 | 0,790 | | |
| Looking for references 4 | 0,797 | | |
| Learning strategy 1 | 0,544 | | |
| Learning strategy 2 | 0,590 | | |
| Learning strategy 3 | 0,538 | | |

Table 1 shows that the anti-image correlation for all tested indicators showed Measure of Sampling Adequacy (MSA) values above 0.50. The highest MSA value was found for the "Difficulty becomes a challenge 3" indicator, at 0.833, while the lowest value was found for the "Learning strategy 3" indicator, at 0.538. Because all values were above the required minimum threshold of 0.50, it can be concluded that each indicator has a sufficiently high partial correlation with the other indicators and is worthy of further factor analysis. These results indicate that no indicators need to be eliminated from the analysis because each indicator adequately explains the measured variable. Therefore, the data is deemed suitable for proceeding to the factor extraction stage, as the assumption of sampling adequacy has been met.

Next, the factor loading value analysis. The complete results of the factor loading value analysis are presented in Table 2 as follows:

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**Tabel 2.** *Factor loading*

| Indikator | Nilai Faktor Loading | Nilai Acuan | Kesimpulan |
|---|---|---|---|
| Initiative and Motivation 1 | 0,738 | 0,50 | Valid |
| Initiative and Motivation 2 | 0,785 | | |
| Initiative and Motivation 3 | 0,706 | | |
| Learning needs 1 | 0,827 | | |
| Learning needs 2 | 0,739 | | |
| Learning needs 3 | 0,782 | | |
| Learning needs 4 | 0,928 | | |
| Have a goal 1 | 0,839 | | |
| Have a goal 2 | 0,737 | | |
| Have a goal 3 | 0,723 | | |
| Controlling learning 1 | 0,831 | | |
| Controlling learning 2 | 0,818 | | |
| Controlling learning 3 | 0,724 | | |
| Difficulty becomes a challenge 1 | 0,743 | | |
| Difficulty becomes a challenge 2 | 0,720 | | |
| Difficulty becomes a challenge 3 | 0,947 | | |
| Looking for references 1 | 0,837 | | |
| Looking for references 2 | 0,918 | | |
| Looking for references 3 | 0,777 | | |
| Looking for references 4 | 0,822 | | |
| Learning strategy 1 | 0,720 | | |
| Learning strategy 2 | 0,774 | | |
| Learning strategy 3 | 0,808 | | |

Based on Table 2, it can be seen that all indicators used in this study showed values above the minimum limit of 0.50. The highest factor loading value was obtained by the difficulty-to-challenge indicator 3 with a value of 0.756, while the lowest value was obtained by the Learning Strategy 1 indicator at 0.720. Although there were variations in values between indicators, all still met the criteria for validity and relevance in measuring the factors formed. Thus, it can be concluded that these indicators have a significant contribution in forming the latent construct studied, so that the instrument used has met the requirements for construct validity. These results also indicate that there is no need to delete indicators because all factor loading values have exceeded the specified threshold, which is 0.50.

The reliability test results yielded a Cronbach's alpha value of 0.773. This value indicates that the instrument used in the study has a fairly good level of internal consistency. Generally, a Cronbach's alpha value above 0.70 is considered adequate and indicates that the items in the instrument are positively correlated and consistently measure the same construct. Therefore, it can be concluded that the learning independence instrument is reliable and suitable for use in measuring the variables studied.

The pretest data from the normality test using the Kolmogorov-Smirnov method at SMK N 1 Purbalingga showed a calculated KS value of 0.13 for the experimental class and 0.11 for the control class, while at SMK N 1 Kemangkon the calculated KS value was 0.09 for the experimental class and 0.11 for the control class. Both values were smaller than the table KS value of 0.224 at a significance level of 0.05. This indicates that the data in both groups, both the experimental and control classes, were normally distributed. The homogeneity test showed that the calculated F value was 1.15 at SMK N 1 Purbalingga and 1.50 at SMK N 1 Kemangkon. This indicates that the data variance between the experimental and control classes was homogeneous.

The results of the average similarity test showed that the significance value was 0.90 in SMK N 1 Purbalingga and 0.31 in SMK N 1 Kemangkon. This means that the significance value is > 0.05. Thus, it

can be concluded that there is no significant difference between the average pretest scores of students' learning independence in the experimental class and the control class before being given treatment. The hypothesis test conducted using an independent sample t-test obtained a significance value of 0.655 in SMK N 1 Purbalingga and a significance value of 0.14. This value is greater than the significance level of 0.05 set in the study, so it can be concluded that there is no significant difference between students' learning independence in the experimental class and the control class after the treatment was given. This means that the STEM-integrated project-based learning model applied to the experimental class has not had a significant impact on increasing learning independence compared to the control class. Although there may be a difference in the average value numerically, the difference is not statistically strong enough to be considered significant.

The N-Gain test was used to evaluate the extent to which students' learning independence increased, by calculating the difference between the pre-test and post-test scores. The results of the N-Gain test for students' learning independence at SMK N 1 Purbalingga in the experimental class were 6.94% and in the control class 2.9%. Meanwhile, the results of the N-Gain test for students' learning independence at SMK N 1 Kemangkon in the experimental class were 4.47%, while in the control class it was 0.15%. The difference in N-Gain scores between the experimental and control classes was very small. This indicates that although there was a slight increase in learning independence after the treatment, the increase did not show a significant difference between the two groups. In other words, the treatment or STEM-integrated project-based learning model given to the experimental class did not have a significant impact on increasing students' learning independence compared to the learning received by the control class. To determine the effect of the implementation of STEM-integrated project-based learning on students' creative thinking skills and learning independence, a MANOVA analysis was used. Prior to conducting the MANOVA test, the assumptions were first tested to ensure the analysis was valid and interpretable.

The results of the normality test indicated that the data on creative thinking skills and learning independence were normally distributed for both schools. The homogeneity of variance test using Levene's test at SMK N 1 Purbalingga yielded a significance value of 0.168 for the creative thinking ability variable and 0.850 for the learning independence variable. At SMK N 1 Kemangkon, the significance value was 0.950 for the creative thinking ability variable and 0.241 for the learning independence variable. Thus, the assumption of homogeneity of variance was met, and the MANOVA analysis could proceed to the next stage. In addition to the normality test and the homogeneity of variance test, another prerequisite for MANOVA analysis is the homogeneity of the covariance matrix. This test aims to determine whether the covariance matrices between groups are equal. The test was conducted using the Box's M Test, with the criterion that if the significance value is greater than 0.05, the covariance matrix is homogeneous. The Box's M test significance value at SMK N 1 Purbalingga was 0.524, while at SMK N 1 Kemangkon it was 0.113. Thus, the assumption of homogeneity of the covariance matrix was met, allowing the MANOVA analysis to proceed.

After all prerequisite tests, the normality test, the homogeneity of variance test, and the homogeneity of the covariance matrix—were met, the main analysis was conducted using Multivariate Analysis of Variance (MANOVA). This analysis was used to determine the effect of the STEM-integrated Project-Based Learning (PjBL) learning model on students' creative thinking skills and independent learning. The MANOVA test results are as follows. The MANOVA test results showed a significance value of 0.000 for all four statistical tests (Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root). This significance value is less than 0.05, so it can be concluded that the implementation of STEM-integrated project-based learning has a significant multivariate effect on students' creative thinking skills and learning independence.

The STEM approach specifically plays a role in enhancing creativity because it requires students

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to think interdisciplinary and systematically. As stated by (Kusyanto et al., 2022), the STEM approach encourages students to see the interconnections between disciplines and use that knowledge to create meaningful solutions. In conventional learning, students tend to view problems linearly and from only one scientific perspective, whereas in STEM, students must consider aspects of science, technology, engineering, and mathematics simultaneously.

The results of this study indicate that the implementation of PjBL-STEM has not provided any tangible benefits in enhancing student learning independence. This finding contradicts several previous studies, such as those by (Nurhamidah & Nurachadijat, 2023) and (Prihatin et al., 2024), which showed that the PjBL model can significantly improve learning independence because students are actively involved in contextual projects that encourage decision-making, problem-solving, and responsibility for their learning process. The results of this study indicate that the implementation of PjBL-STEM has not been able to significantly contribute to improving student learning independence. The development of a person's independent learning ability does not occur instantly, but rather through a gradual process within the Zone of Proximal Development (ZPD), which requires scaffolding from a more competent individual (Sage, 2022). In the context of this study, most students were still at a stage of high dependence on teacher direction. When directly exposed to the PjBL-STEM approach, which demands high autonomy, students experienced difficulty managing their own learning process, thus limiting its impact on increasing independence.

## CONCLUSION

Based on the problem formulation, research data analysis, and discussion, it can be generally concluded that the STEM-integrated project-based learning model has been proven to improve students' creative thinking skills. This is indicated by an increase in the average creative thinking ability score which is included in the medium category in the experimental class, while the control class is included in the low improvement category. STEM integration in PjBL has been proven effective in improving creativity because it requires students to think across disciplines. In conventional learning, the approach to a problem tends to be linear and limited to one field of science. However, in the STEM-approach PjBL learning model, students must consider aspects of science, technology, engineering, and mathematics simultaneously, which stimulates them to think holistically and systematically.

The STEM-integrated project-based learning model did not show significant improvement in student learning independence. This indicates that the learning model's influence on improving student learning independence is not optimal or is influenced by factors other than the learning intervention. Nevertheless, it is important to note that the PjBL-STEM approach remains relevant for development, as it provides a more meaningful, enjoyable learning experience, and is in line with the needs of the 21st century. In an era that increasingly demands lifelong learning skills and independence in work, involvement in challenging and cross-disciplinary projects such as those offered by PjBL-STEM is a potential training tool for students to become accustomed to independent learning. Based on the results of data analysis using the MANOVA test, it can be concluded that STEM-integrated project-based learning has a simultaneous effect on students' creative thinking skills and learning independence. This indicates that the implementation of PjBL-STEM not only contributes to improving one aspect of competence but also has a comprehensive impact on developing students' cognitive and affective potential.

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