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STEM (Science, Technology, Engineering, and Mathematics) Instructional Analysis Towards Learning Competencies Achievement as Reviewed from Vocational Education Students' Critical Thinking

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Abstract
A proper instructional process is a process that is designed to meet the expected educational goals; hence, an innovative strategy in the learning process is required. One of the instructional models appropriate for use in teaching vocational lesson material is the STEM model. The aim of this study was to analyze the level of usefulness of the STEM model on the learning competencies achievement of vocational students' in Kupang as reviewed from their critical thinking, with a focus on the materials about automotive engine components maintenance and reparation. The method of this study was a pre-experimental in the form of one group pretest post-test. The subjects studied were twenty-six Light Vehicle Engineering students of Class X Group B of 2022/2023. The data collection techniques used in this study were documentation and 20-question item test sheets implemented in the pre-test and post-test. The data were analyzed with a T-test using SPSS version 29. The descriptive test results showed a significant difference between the means of tests, which was of 23% proving that the STEM model significantly improved students' critical thinking skills. Therefore, it is recommended that the STEM approach be used as an alternative model for teaching engineering subjects.

Keywords: STEM Model, Critical Thinking, Vocational Education

1. Introduction

The principle of vocational education is to equip students with broad competencies in their chosen area of expertise. This means that vocational education is essential to producing quality human resources to address the issues and challenges of technological advancement. The Act of the Republic of Indonesia No. 20 of 2003, Section 15, explicitly defines vocational education as one educational pathway that equips human resources to work in a specific field of interest. On that basis, teachers are at the forefront of providing qualified human resources. According to Rochmawati et al. (2019), a teacher plays a critical role in the classroom learning. Teachers are the spearheads in the learning process, enabling students to understand the materials (Fathurrohman & Suryana, 2012). Although teachers are not the exclusive source of learning, they are the directors of their learning scenario. In this context, teachers must use their creativity to create appropriate and enjoyable learning scenarios for students to boost their curiosity and make learning more meaningful. Hence, students' learning competency achievement highly depends on the teachers' approach and methods used to respond to students' learning needs. Thus, the focus of this study is students' critical thinking skills as the indicator of their learning competencies of students.

Critical thinking is the process and ability to make the right decisions with persistent and scientific efforts to test knowledge based on supporting facts and evidence (Rohmah et al., 2021). Students' critical thinking skills must be enhanced through a specific learning process to accustom themselves to solving issues efficiently and accurately. Thus, a proper learning approach is needed to help students train and accustom themselves to thinking critically.

A proper approach to enhancing students' critical thinking skills is by improving the use of existing learning instructional models and methods (Lestari et al., 2020). The learning process will be considerably more effective when the instructional model being implemented is appropriate for the student's level of learning. Agustin and Lasmawan (2019) claimed that teachers are supposed to master the implementation of diverse pedagogical approaches that align well with the content of the materials. Instructional models and methods implemented in vocational schools must follow the standardized curriculum. One of the appropriate instructional models implemented in vocational schools, particularly in the Light Vehicle Engineering program, is the STEM model (Science, Technology, Engineering, and Mathematics).

STEM is an instructional model that can bring significant changes in the twenty-first century (Khairiyah, 2019). The STEM instructional model is appropriate for vocational teaching because it focuses not only on theoretical learning but also on practical implications, allowing students to have meaningful learning experiences firsthand (Solikha, 2021). The STEM instructional model has advantages that impact learning quality. Rivai et al. (2018) found that the problem-based STEM model has affected students' concept mastery. This means that the STEM model has a significant impact. A literature review conducted by Norlail et al. (2022) also found that implementing the STEM model as an instructional model substantially impacts increasing students' learning outcomes. Izzati et al. (2019) conducted community outreach and found that 93.75 percent of the participants found the STEM model exciting and intriguing. Furthermore, Izzati et al. argue that the STEM instructional model is a learning innovation that emerged during the 4.0 industrial revolution era. Meanwhile, in his study, Wahono (2020) also concluded that STEM is an up-and-coming innovation in the instructional process, especially in preparing students to sharpen their higher-order thinking skills and attract their interest in learning to be adaptable in this competitive era. Accordingly, it is necessary to implement a proper instructional model in the vocational learning proces.

2. Methods

The research employed a descriptive quantitative approach, a pre-experimental method using one group pretest-posttest research design. The research design model can be seen in Figure 1. The subjects in this experimental study are the tenth-grade students (group B) majoring Light Vehicle Engineering (TKR) at SMK Negeri 2 Kupang, totaling 26 students. The main topic of learning in the experimental class is Automotive Component Maintenance, particularly focusing on the car engines. The research instrument employed in this research is teaching stuffs in the form of ATP Instructional Flows), pre-test and post-test sheets, observation sheets and teaching modules of Independent Curriculum. The pre-test and post-test questions include 20 questions, consisting of 15 multiple-choice questions and 5 essay questions. Then, the indicators of the instrument of the essay and multiple-choice questions are the Car engine involving components, damage analysis, damage diagnosis, causes of damage, tune-up, and maintenance. In addition, the research instrument was first validated by the expert in the field of learning media and automotive engineering to ensure the instrument's feasibility. The data collection technique used in this learning competency achievement analysis towards vocational education students' critical thinking as their learning competencies achievement was pre-test and post-test, covering the aspects of focusing on analysis, reason, inference, circumstance, clarity, and overview (Ennis, 2011). The pre-tests and post-tests were administered to students in class X, group B of the Light Vehicle Engineering program.

O_1 X O_2

Figure 1. One Group Pre-test – Post-test Research Design

Note: O_1 is score of pre test
O_2 is score of post-test
X is STEM

3. Result and Discussion

Students' learning competencies achievement in the materials about automotive engine component maintenance and reparation was reviewed based on their cognitive competencies, particularly their critical thinking skills, which were observed during the learning process. The approach and instructional model used in teaching these materials on engine components was the STEM instructional model, which was conducted in multiple phases. The first phase was conducted before the STEM instructional model was implemented, in which students took a pre-test intending to obtain a description of their prior knowledge and measure to what extent their understanding of the subject matter was. After this pre-test, the STEM model was implemented with the aim of training the students to think scientifically when creating a project based on their ideas. The STEM-based instructional model can contribute to training students' thinking skills at various levels, ranging from the medium to the extremely high level (Sulfawati & Mayasari, 2021). After the intervention, a post-test was given to the students to examine whether there was a statistically significant difference in their pre-and post-test scores. The questions used in both pre-and post-tests are of the same level of difficulty.

This study was conducted on twenty-six Grade X Group B students of Light Vehicle Engineering (TKR). This research was put into practice for four meetings. This research was started by creating research instruments pertaining to the independent learning curriculum, which were instructional flow, learning materials, and assessment instruments such as a grid and tests. During the first meeting, the Grade X students were given a pre-test with a total number of 20, consisting of 15 multiple-choice questions and five essay questions. After that, the mean scores obtained were tested statistically through prerequisite tests and hypothesis testing. However, before the prerequisite and hypothesis tests, the researchers conducted descriptive analysis to analyze the data to determine the high and low scores of students' learning competencies achievement before and after the STEM model.

The t-test procedure was used to test the hypothesis on the scores of pre-test and post-test. The data had to pass the homogeneity and normality tests as a prerequisite for a t-test. Therefore, a normality test was conducted as a prerequisite before testing the hypothesis test. The SPSS version 29 program was used to perform a normality test through the analysis-descriptive-statistic-explore procedure. Table 1 shows the results of the normality test.
Results are the main part of scientific articles, containing: final results without data analysis process, hypothesis testing results. Results can be presented with tables or graphs, to clarify the results verbally.

Table 1 Normality Test Result

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Pretest of Critical Thinking skills	.138	26	.200*	.937	26	.116
Post-Test of Critical Thinking skills	.121	26	.200*	.956	26	.318

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table 1 shows the normality test results, indicating that these two numbers satisfied the normality test. It can be seen from the critical thinking pre-test score with a sig value of 0.116 or greater than the 0.05 sig value, and the post-test score with a sig value of 0.318 or greater than the 0.05 sig value. After that, the homogeneity test was conducted and the results were shown in Table 2.

Table 1.2 Homogeneity Test Result

Test of Homogeneity of Variance

		Levene Statistic	df1	df2	Sig.
Results of Critical Thinking Skills	Based on Mean	.013	1	50	.909
	Based on Median	.014	1	50	.907
	Based on Median and with adjusted df	.014	1	49.934	.907
	Based on trimmed mean	.020	1	50	.889

According to homogeneity tests performed with SPSS software, the research data had the same two variance values, as demonstrated by the sig value of 0.909, which is greater than 0.05. It is then evident that the homogeneity test passed the data testing. This indicates that the data cleared the prerequisite tests, allowing for a t-test. The results of the t-test are shown in Table 3.

Table 3 Paired Sample T-Test Result

Paired Samples Test

		Paired Differences					t	df	Significance	
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	Upper			One-Sided p	Two-Sided p
Pair 1	Critical Thinking Skills Pre-test–Post-test	-23.000	4.050	.794	-24.636	-21.364	-28.960	25	<,001	<,001

The hypothesis testing done using the SPSS program, as seen in Table 3.5, reveals that the t-test result was 28.960 and the p-value was 0.001. Meanwhile, the standard deviation number was 4,050. This was supported by the paired sample statistics test results, which are displayed in Table 4.

Table 4 Mean Scores for the Pre- and Post-Tests

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Pretest of Critical Thinking skills	55.62	26	8.791	1.724
	Post-Test of Critical Thinking skills	78.62	26	8.471	1.661

The results of the paired sample statistics test showed that 26 students' mean score of critical thinking skills pre-test was 55.62 with a standard deviation value of 8.791. Meanwhile, their post-test mean score for critical thinking skills was 78.62, with an 8.471 standard deviation.

Discussion

A quality learning process cannot be separated from teachers' implementation of a proper instructional model and strategy. To achieve the targeted learning process, it is necessary to first analyze the usefulness of the chosen instructional model by considering the material's difficulty level, students' characteristics, and learning facilities. available. The STEM instructional model implemented in this study effectively guided students to enhance their critical thinking skills, enabling them to address difficulties that arise during the learning process properly. Another distinctive feature of the STEM model is that it can simultaneously be integrated into the areas of science, technology, engineering, and mathematics.

Implementing the STEM instructional model on the automotive engine components maintenance and repair materials can be done in several phases (Indarwati et al., 2021; Supriyatin et al., 2023). The first syntax is Reflection. In this phase, students can view animations and demonstrations presented by their teachers. After that, students can use their critical thinking skills to solve the given topic in an organized way with reliable sources. The second syntax is Research, where students are grouped and given worksheets to complete to analyze and answer material concepts in a scientific manner collaboratively. The third syntax is Discovery, where students work in groups to use their learned ideas to solve the learning content, which involves analyzing how an automobile engine operates. The fourth syntax is Application, students test or diagnose a car engine directly using the scan module. The last syntax is Communication, where students in groups report the outcomes of their engine performance testing and get feedback from other student groups.

The test results showed a difference in the mean scores of students' critical thinking skills pre-test and post-test results which is significant statistically. As seen in the results, the mean score of pre-test was 55.62 with a standard deviation of 8.791 while the mean score of post-test was 78.62 with a standard deviation of 8.471. Therefore, the difference between both critical thinking skills tests' mean scores on engine component maintenance and repair was 23%. Substantially, this STEM-based instructional model has a significant influence on the quality of the learning process. This is evident during the learning process when students favoured the model positively by actively participating in every stage. Students showed respect in each learning phase through their enthusiasm and sense of challenge from the problem themes they had to tackle individually and collaboratively. Through the STEM approach, students also accustomed themselves to using technology in learning, i.e., using car scanners to detect damage to engine components. This subsequently increased their confidence and enabled them to convey ideas and opinions boldly.

The results analysis demonstrates how the STEM instructional model can enhance students' critical thinking skills. This is consisted with the findings of Dywan & Airlanda (2020), Rohmah (2021), and Zulfawati et al. (2022), who discovered that the STEM-based model might enhance critical thinking abilities and be effective when used. Rohmah's research also revealed that this model also gets positive student responses besides enhancing students' critical thinking skills. Meanwhile, Salsabila and Arif's study (2022) found that the STEM-based instructional model effectively increases students' logical thinking. Furthermore, Triastuti (2021) also agreed that the STEM-based model can positively impact critical thinking skills.

The results of this recent study and previous studies have consistently shown that the STEM-based instructional model has a positive impact on students' learning process achievement. The results are evident because this model helps students become skilled at applying critical and creative thinking to solve learning problems quickly and accurately. In addition, this model also facilitates students' ability to quickly acquire new knowledge through reliable sources, group work, and discussion between peers and teachers. This STEM-based instructional model gives students the space and opportunity to explore broader topics, enhancing the significance of their knowledge.

The study by Nurbayani et al. (2023) revealed that STEM-integrated instructional activities improve students' engineering skills. Their study also proved that STEM-based project learning showed better results for students' engineering skills than non-STEM-based project learning. Additionally, a study by Dwita, Susana (2020), and Rahmawati et al. (2022) emphasized how the STEM model can enhance learning results. According to their research, this model enhances students' participation, as well as encouraging student learning results. A study by Rosana (2022) also discovered that the STEM model influences students' creativity. Similarly, Syukuri and Ernawati's (2020) analysis showed that the STEM model can increase students' interest in learning. Principally, the STEM instructional model has positive value for the learning process quality. It is evident that students must be given opportunity to voice their thoughts when the STEM model is put into practice, with the goal of practicing how to present ideas in front of their peers effectively. Furthermore, the STEM model allows students to enhance their inherent potential through creative and systematic means. This model also encourages a dynamic learning environment where students can freely voice their opinions and ask questions without hesitation, thus increasing their curiosity and encouraging them to explore new information and knowledge through creative and scientific methods. This environment stimulates a sense of enjoyment among students throughout each learning phase, thus facilitating the achievement of the intended learning objectives.

4. Conclusion

This study showed that the STEM (science, technology, engineering, and mathematics)-based instruction model can enhance students' critical thinking skills on automotive engine component maintenance and repair. This is indicated by the paired sample test results obtained using the SPSS software (p = 0.001 and t-test result = 28.960). Meanwhile, paired sample test statistics showed a 23% difference in the mean scores of both critical thinking skills pre-test and post-test. It is then concluded that the STEM model has a statistically significant difference when being used in teaching automotive engine component maintenance and repair materials, as seen from the difference in the students' critical thinking skills pre-test and post-test scores. During the implementation of the STEM-based model, students showed their enthusiasm and actively participated in each phase of the learning process, so their learning process has become more meaningful. Based on those, the STEM instructional model is a proper model to be used in the learning process based on the material's difficulty level and students' characteristics. It is then recommended that further study be conducted on using the STEM model for unexplored variables.

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