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IoT Light Switch Project in Smart Home to Enhance Concept Mastery of Vocational High School Students

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Abstract

This research aims to improve vocational school students' mastery of dynamic electricity through STEM-PJBL learning in the TPACK framework. This dynamic electrical material is important for vocational school students in Technology and Information expertise because it is the basis for productive vocational learning at the next level. Facts in the field show that the mastery of the concept of vocational school students still needs to improve. Thus, to increase the mastery of the concept, a web-based interactive media, Google Sites, was used with a student project to prototype an IoT light switch on a smart home. This study is a pseudo-experimental research with a pretest-posttest group design with 32 students in class X TJKT. The results of this study show that STEM-PJBL learning in the TPACK framework can significantly increase concept mastery (sig 2-tailed < 0.05) with Ngain by 0.59.

Keywords: concept mastery; dynamic electricity; STEM-PJBL; TPACK

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INTRODUCTION

In the current era of Industry 4.0, students are required to master technology and compete on a global scale (Jing et al., 2024; Lim et al., 2024; Shafie et al., 2019). Therefore, teaching and learning processes must be adapted to this era (Mo & Guo, 2024; Wannapiroon et al., 2021; Weng et al., 2024). Teachers must also be able to determine the appropriate learning approaches and models to enhance students' skills. The use and implementation of appropriate models and strategies in learning can optimize student learning outcomes (Laumann et al., 2024; Nyirahabimana et al., 2024; Sukarno & Widdah, 2020).

Physics education in vocational high schools (VHS) aims to support and equip students for productive vocational subjects, particularly in technology and engineering (Kemdikbud, 2013). One physics topic that can support productive vocational learning is dynamic electricity. However, students' mastery of electrical concepts still needs to improve. This situation is attributed to students' need for more interest in electricity-related learning (Fahruddin et al., 2022). The abstract nature of electrical material (Chen et al., 2013), makes it challenging to grasp the associated concepts (Jaakkola et al., 2011; Musliman & Kasman, 2022).

Most learning in VHS involves practical vocational education to prepare students for work (Higley, 2017; Liu & Gao, 2021). However, observations reveal that many students engage in practical exercises without paying attention to the underlying scientific concepts being applied. For instance, students should consider whether the voltage is appropriate for that device to use an adapter for a device. Therefore, strategies are needed to ensure successful physics learning (Sukarno & Widdah, 2020). Students can be provided with learning experiences that cultivate scientific processes and meaningful experiences (Higley, 2017; Salsabillah et al., 2018). The goal is for students to address real-life problems using their academic knowledge (Winarno & Maulana, 2020).

On the other hand, research into physics education in VHS tends to emphasize concept development alone. For example, Purba and Hwang (2017) developed an application to train vocational high school students in interpreting graphs and understanding simple pendulum concepts. Such learning approaches may need to be revised. Because, in reality, learning at vocational schools is mostly practical. This aims to prepare vocational high school students to be competent in working in their field (Winarno & Maulana, 2020) and be capable of developing their potential (Hayat et al., 2023).

Therefore, learning that can enhance students' concepts and practical skills is necessary in VHS. Science, technology, engineering, and mathematics (STEM) education serves as a bridge between practical skills and the integration of multidisciplinary concepts aligned with industry needs (Plasman & Gottfried, 2020). Previous research conducted by Prastiyan et al. (2021) involved the application of STEM-PjBL and TPACK to enhance students' mastery of static fluid concepts using Moodle e-learning media. In contrast, this study utilizes web-based interactive media, specifically Google Sites, and focuses on the project of an IoT light switch prototype for smart homes.

This study's IoT light switch prototype project employs Arduino technology, which aligns with the student's vocational competencies. Learning with Arduino can enhance students' interest in dynamic electricity material (Latifah & Novia, 2019). Additionally, Arduino can be utilized as a learning medium in physics education (Suari, 2017) and the introduction of electronic components (Fahruddin et al., 2022).

STEM education can be effectively implemented and is relevant to vocational high school students (Wannapiroon et al., 2021; Winarno & Maulana, 2020). STEM represents a multidisciplinary approach that integrates four fields (science, technology, engineering design, and mathematical analysis) to understand the universe (Gardner & Tillotson, 2019; Kelley & Knowles, 2016) and solve real-world problems (Fan & Yu, 2017). The principle of STEM learning is integrating STEM content, inquiry-based learning, problem-centered learning, design-based learning, and cooperative learning (Thibaut et al., 2018).

This STEM learning is integrated with a Project-Based Learning (PjBL) model. This integrated approach is referred to as STEM-PjBL (Capraro et al., 2013; Halawa et al., 2024). The learning process follows project-based learning steps in a STEM learning environment (Suryadi, 2021). Previous research has shown that STEM-PjBL learning can provide pedagogical guidance during the learning process and assist students in developing conceptual and procedural understanding (Lee et al., 2019).

In the Technological Pedagogical Content Knowledge (TPACK) framework, integrating technology with pedagogy and content knowledge can be effectively organized (Koehler & Mishra, 2013). The TPACK framework in STEM education enhances the effectiveness of STEM teaching (Prastiyan et al., 2021; Morales, 2022). TPACK allows teachers to design learning experiences using technology that aligns with student characteristics, thus increasing the likelihood of success in STEM-PjBL (Project-Based Learning) (Capraro et al., 2013; Chai, 2019; Dolgopolovas & Dagiene, 2024). Consequently, the integration of TPACK and STEM within physics education becomes evident (Freese et al., 2023). This study aims to explore the impact of STEM-PjBL within the TPACK framework on students' mastery of physics concepts through an IoT-based lamp switch project.

METHOD

This study is a quasi-experimental research with a Pretest-Posttest One Group Design (Creswell, 2019; Gall et al., 2002). In this design, only one group, the experimental class, was selected randomly (Sugiyono, 2017). The study was conducted at a public vocational high school (Sekolah Menengah Kejuruan Negeri) in Malang during the second semester of the 2022/2023 academic year, with a research sample consisting of 32 students from grade X CTNE (Computer and Telecommunications Network Engineering). The research design is illustrated in Figure 1.

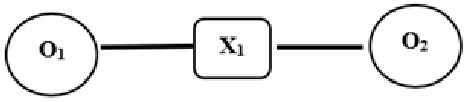

Figure 1 Pre-experimental design

As shown in Figure 1, the experimental class (X1) was given two written concept mastery tests. The first test (pretest) was administered before the learning intervention, and the second test (post-test) was conducted after the STEM-PjBL learning within the TPACK framework. The concept mastery instrument consists of multiple-choice questions based on the revised Bloom's taxonomy, specifically in the cognitive domains C1, C2, C3, C4 and C5 (Anderson et al., 2001) with indicators as shown in Table 1. The instrument has been evaluated by experts (1 lecturer and 1 teacher) and underwent empirical validation testing. Fifteen questions out of the sixteen that were tested were accepted as valid and reliable (α = 0.812) (Sugiyono, 2017). Meanwhile, the Google Site is displayed in Figure 2.

Table 1 Concept mastery instrument indicators

Cognitive Domain	Indicator	Question Number
C1 (Remembering)	Students can select statements about factors that affect electrical resistance.	9
	Students can select statements about electric current flow and electron flow.	10
	Students can select statements about the characteristics of DC current when presented with statements about AC and DC current.	11
C2 (Understanding)	Students can determine the resistance used in Ohm's Law experiments from the data obtained when presented with experimental data.	7
	Students can determine the reading value of electrical measuring instruments when shown images of measurement results.	8
	Students can determine the voltage of an adapter used in productive practice when presented with images of device specifications and various adapter voltages available on the market.	12

Cognitive Domain	Indicator	Question Number
C3 (Applying)	Students can apply the concept of voltage sources in simple electrical circuits when presented with battery and lamp data used in the circuit.	5
	Students can apply Kirchhoff's First Law to determine the current in an electrical circuit when shown a circuit diagram.	6
	Students can calculate the total resistance in a mixed resistor circuit by showing a circuit diagram.	13
C4 (Analyzing)	When shown a circuit diagram with instrument placement, students can analyze the placement of measuring instruments in a closed electrical circuit.	3
	Students can analyze the condition of lamps in a closed circuit where two points are short-circuited when shown a diagram of two lamps connected in parallel.	4
	Students can analyze the amount of electrical energy a power plant produces based on provided data in a reading passage.	14
C5 (Evaluating)	Students can evaluate which electrical appliance consumes the most energy, when presented with a table of appliances along with their resistance and voltage values.	1
	Students can evaluate the brightest lamp setup by showing a lamp installation circuit diagram.	2
	Students can evaluate the amount of electrical energy produced by a power plant in one day based on data in a reading passage.	15

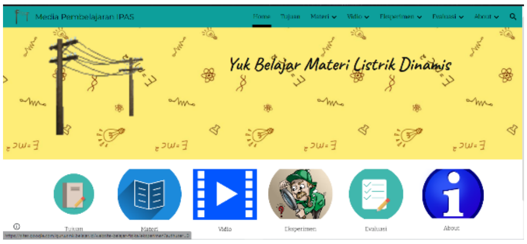

Figure 2 Google Site display

The data analysis for concept mastery was conducted by determining the improvement in pretest and post-test scores (N-gain). The Wilcoxon statistical test was used to assess the effect of STEM-PjBL learning within the TPACK framework on the experimental class, following a Shapiro-Wilk normality test. The data analysis was facilitated by using SPSS Version 22.

RESULTS AND DISCUSSION

Before the learning process, the researcher developed instructional materials aligned with the curriculum implemented at the school. These materials included teaching modules, student worksheets, reading materials, and interactive media based on Google Sites about dynamic electricity. Through this interactive media, students could access the worksheets and reading materials using their digital devices (smartphones, tablets, laptops). The teaching module followed the STEM-PjBL steps, framed within the TPACK model, as outlined in Table 2.

Students' activities in studying teaching modules and observing images and videos on interactive media can train students to learn independently in solving problems. These activities train the mastery of the concept of dynamic electricity at the remembering (C1) and understanding (C2) indicators (Sigit et al., 2022). Meanwhile, students' activities in the LKPD for project completion can train the mastery of the concept of dynamic electricity at the applying (C3), analyzing (C4), and evaluating indicators. (C5).

Table 2 STEM-PjBL learning steps in the TPACK framework

Syntax	Learning Steps	TPACK Components	Technology Used
Reflection	Observe images of electrical circuits and videos about IoT technology.	TP, PK, CK, TK	Web-based interactive media
Research	Find solutions to energy-efficient electrical circuit problems. Create electrical circuits. Learn about Arduino and practice configuring it.	TP, PK, TK, TCK, K	Web-based interactive media, browser, Lifeware app, smartphone, Arduino, Telegram app
Discovery	Design the project and create the project according to the design.	TK, CK	Web-based interactive media, browser, Lifeware app, smartphone, Arduino, Telegram app, Microsoft Word
Application	Test the product and make improvements based on the test results.	TCK, CK	Browser, smartphone, Arduino, Telegram app
Communication	Present the results of the IoT lamp switch prototype project for smart homes.	TCK, PK, PCK, CK, TCK	Browser, smartphone, Arduino, Telegram app, LCD, Microsoft PowerPoint/Canva/video

Based on Table 3, the normality test for the pretest scores of the experimental class yielded a significance value of p = 0.027, which is less than the significance level of α = 0.05. This indicates that the pretest data were not normally distributed. In contrast, the normality test for the post-test scores resulted in a significance value of p = 0.129, which is greater than α = 0.05, indicating that the post-test data were normally distributed. Therefore, the non-parametric Wilcoxon test was used to determine the effect of STEM-PjBL learning within the TPACK framework on concept mastery.

Table 3 Normality test of pretest and post-test scores

Normality Test	Shapiro-Wilk		
	Statistic	df	Sig.
pretest	0.924	32	0.027
posttest	0.948	32	0.129

The results of the Wilcoxon test in Table 4 show a significance value of 0.00, which is less than the significance level of α = 0.05 (H0 is accepted). This indicates that the STEM-PjBL learning within the TPACK framework has a significant effect on the mastery of dynamic electricity concepts among VHS students

Table 4 Wilcoxon test results for pretest and post-test scores

	posttest - pretest
Z	-4.955
Asymp. Sig. (2-tailed)	0.000

The N-Gain index value of 0.59 in Table 5 indicates improved pretest and post-test scores. According to Hake (1999), this value falls within the medium category. This suggests a significant increase in students' mastery of dynamic electricity concepts after implementing STEM-PjBL learning within the TPACK framework.

Table 5 N-gain analysis of pretest and posttest scores

N-Gain Percentage		Statistic	Std. Error
Mean		59.2694	2.43743
95% Confidence Interval for Mean	Lower Bound	54.2982	
	Upper Bound	64.2405	
5% Trimmed Mean		58.5701	
Median		57.4468	
Variance		190.114	
Std. Deviation		13.7881	
Minimum		39.08	
Maximum		100.00	
Range		60.92	
Interquartile Range		16.88	
Skewness		0.822	0.414
Kurtosis		0.994	0.809

This study demonstrates that implementing STEM-PjBL learning within the TPACK framework can enhance the concept mastery of VHS students. These results align with previous studies (Baran et al., 2021; Chang & Chen, 2022; Prastiyan et al., 2021; Purwaningsih et al., 2020). In PjBL-STEM learning, students can directly apply a concept to complete a project. This can help students understand the concepts applied in the project (Budiarti et al., 2023).

This study uses web-based interactive media to implement the TPACK framework. The use of web-based interactive learning media further optimized students' mastery of dynamic electricity concepts. As shown in the research by Sigit et al. (2022), the integration of STEM-PjBL with technological media (e-learning, web) significantly improves concept mastery. Figure 3 illustrates students presenting the results of their IoT lamp project.

As shown in Figure 3, this project enabled students to build knowledge about dynamic electricity and enhance their understanding by experiencing the scientific process firsthand, similar to how scientists work (Lehane, 2020). The TPACK framework was utilized to maximize the successful implementation of STEM in learning. STEM education succeeds when teachers possess strong pedagogical skills related to STEM (Kelley & Knowles, 2016).

Figure 3 Students presenting during the communication stage

CONCLUSION

Implementing STEM-PJBL learning in the TPACK framework can increase VHS students' mastery of dynamic electricity concepts with an N-gain score of 0.59. Physics, often less favoured by VHS students due to its heavy focus on theory and concepts, becomes more engaging when presented through project-based learning with the support of interactive media like Google Sites. The IoT switch prototype project for a smart home related to vocational training helped students better understand and apply dynamic electricity concepts to complete the project.

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