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ENHANCING LEARNING OUTCOMES: PROJECT-BASED LEARNING WITH FLUIDSIM IN ELECTRIC MOTOR CONTROL SYSTEM CIRCUIT

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Abstract

This study aims to: (1) find significant improvement on students' learning outcomes on electric motor control system circuits using the Project-Based Learning (PjBL) model with FluidSIM software; and (2) find significant differences in learning outcomes between Electrical Power Installation Engineering (TITL) students taught using PjBL with FluidSIM and conventional method. This experimental study employed a non-equivalent control group design. The experimental class (XI TITL 1) received treatment using PjBL with FluidSIM software, while the control class (XI TITL 2) used PjBL with the conventional method. Data were collected through assessments of learning outcomes and analyzed using t-tests to assess both improvements and differences. The results indicated significant improvements in learning outcomes for the experiment group following the implementation of PjBL using FluidSIM software. Additionally, a significant difference was found between the two groups' learning outcomes, with a t value greater than the critical value (5.906 > 2.00). In conclusion, the PjBL model combined with FluidSIM effectively improves student learning outcomes.

Keywords: FluidSIM software, learning outcomes, Project-Based learning

Introduction

Vocational education serves as a critical foundation for developing a skilled and competitive workforce amid rapid industrial growth. In Indonesia, Vocational High Schools (SMK) are specifically designed to equip students with practical competencies aligned with industry demands, as mandated by Law No. 20 of 2003 on the National Education System. One essential competency in the electrical engineering field is mastery of electric motor control system circuits, which are widely applied in various industries (Hughes, 2013). However, learning outcomes in this subject at SMKN 1 Sidoarjo remain suboptimal. This situation is attributed to several factors, including the predominance of conventional teaching methods, low student engagement, and limited opportunities for students to engage in real-world problem solving relevant to industrial contexts.

This view aligns with the findings of Chen and Yang (2019), who, through a meta-analysis, reported that conventional instructional approaches are generally less effective in improving students' academic achievement compared to project-based learning, particularly in complex and technical subjects. Their study highlights that project-based learning not only enhances academic outcomes but also addresses motivational and engagement issues commonly found in traditional settings. Furthermore, Adhyatma (2013) found that the complexity involved in designing and implementing electric motor control circuits presents significant challenges for students, impeding their full comprehension of underlying concepts.

To overcome these challenges, the adoption of innovative learning models is necessary. Project-Based Learning (PjBL) is recognized as an effective student-centered approach that engages learners through meaningful projects, fostering not only theoretical knowledge acquisition but also collaboration, problem-solving, and critical thinking skills (Thomas, 2000; Hmelo-Silver, 2004). In technical education, PjBL has been demonstrated to enhance student motivation and learning outcomes by providing authentic tasks that simulate real industrial problems (Arief Dwiantoro, 2021). The effectiveness of PjBL can be further enhanced by integrating digital simulation tools, which allow students to experiment with and visualize complex systems in a safe and interactive environment.

FluidSIM, developed by Festo, is a widely used software for modeling, simulating, and analyzing control circuits in pneumatics, hydraulics, and electrical engineering. Research indicates that using FluidSIM in vocational education significantly improves students' conceptual understanding and practical skills in designing and troubleshooting control systems (Ahmad and Wrahatnolo, 2024; Isna, 2019). Despite the potential benefits of both tools, empirical research directly comparing the effectiveness of FluidSIM within a PjBL framework in enhancing learning outcomes and digital skills in electric motor control system circuits remains scarce.

The main reason for conducting this study stems from the observed suboptimal learning outcomes in electric motor control system circuits at SMKN 1 Sidoarjo, which is largely influenced by conventional teaching methods using Simurelay application and limited hands-on experience for students. Additionally, although digital simulation tools like FluidSIM has shown promise individually, there remains a lack of empirical research comparing their effectiveness within a Project-Based Learning (PjBL) framework to enhance both learning outcomes and digital skills. This gap motivates the present research, as it aims to identify the most effective approach to improve vocational education quality and better prepare students for industry demands.

Therefore, the objectives of this study are as follow: (1) to analyze the significant improvement in student learning outcomes after applying PjBL integrated with FluidSIM software; (2) to determine whether there are significant differences in student learning outcomes between the two groups. By addressing these objectives, this research aims to provide valuable insights for educators and policymakers on optimizing teaching strategies in vocational education.

Literature Review

Learning models in vocational education

A learning model serves as a conceptual framework guiding the planning, implementation, and evaluation of educational processes, aiming to make learning more systematic, efficient, and effective (Joyce, Weil, and Calhoun, 2015). In vocational education, the selection of an appropriate learning model is crucial, as it must bridge theoretical knowledge with practical skills directly applicable to the workplace. Effective learning models for vocational students are those that are contextual and relevant to their everyday experiences, enabling them to utilize available learning tools and media and to apply classroom knowledge in real-life situations (Dwiantoro, 2021). Theoretically, such models are expected to enhance students' understanding, motivation, and participation, while also fostering the development of critical and creative thinking skills (Hmelo-Silver, 2004).

An effective learning model in vocational schools should foster critical thinking, creativity, and problem-solving skills, competencies essential for adapting to the dynamic demands of the industrial sector (Isna, 2019). Additionally, the model should promote collaboration and communication, which are increasingly valued in modern workplaces. By providing structured and meaningful learning experiences, the right learning model can significantly improve students' learning outcomes and better prepare them for professional challenges.

Project-based learning (pjbl)

Project-Based Learning (PjBL) is a student-centered instructional approach that engages learners in exploring and responding to authentic, complex questions or problems through sustained projects (Thomas, 2000). In vocational education, PjBL is particularly effective because it mirrors the types of tasks and challenges students will encounter in their future careers. Through project work, students develop not only technical expertise but also essential soft skills such as teamwork, communication, and time management (Guo, Saab, Post, and Admiraal, 2020).

Theoretically, PjBL supports the development of higher-order thinking skills by challenging students to solve real-world problems, make decisions, and reflect on their learning experiences (Hmelo-Silver, 2004). Empirical research has shown that students engaged in PjBL demonstrate higher motivation, improved learning outcomes, and greater retention of knowledge compared to those in traditional instructional settings (Thomas, 2000). In the context of vocational education, PjBL enables students to integrate theoretical concepts with hands-on practice, such as designing and simulating electric motor control systems, which helps build confidence and technical competence (Han et al., 2015).

Digital simulation for electric motor control learning

The integration of digital simulation in vocational and technical education has transformed the way students learn complex concepts, particularly in electric motor control systems. Digital simulation tools provide a safe, interactive, and cost-effective environment for students to design, test, and analyze electrical circuits without the risks and material constraints of physical laboratories (Ahmad and Wrahatnolo, 2024). Theoretically, these tools enable repeated practice and experimentation, which are crucial for mastering the intricacies of control circuits and troubleshooting real-world problems. Simulation-based learning is also believed to enhance students' conceptual understanding and practical skills, bridging the gap between theory and industrial practice (Isna, 2019).

Empirical studies further support the effectiveness of simulation-supported PjBL in STEM and engineering education. For example, De Jong et al. (2019) found that integrating online laboratories and digital simulations within project-based frameworks significantly enhances both conceptual understanding and practical competencies among students. Similarly, Han et al. (2015) found that project-based learning, when integrated with digital tools, not only improves student engagement and higher-order thinking but also leads to significant gains in learning outcomes in engineering and STEM education.

The integration of simulation tools like FluidSIM into project-based learning environments amplifies their educational benefits. By working on authentic projects that require the application of simulation software, students not only gain technical expertise but also develop digital literacy, problem-solving abilities, and collaborative skills essential for the modern workforce (Zhong et al., 2017). Furthermore, simulation tools address the limitations of traditional labs, such as limited equipment and safety concerns, making advanced technical training more accessible (Ahmad and Wrahatnolo, 2024).

Methodology

Research design and approach of the study

This research used a quasi-experimental, non-equivalent control group design, which is widely used in educational research when random assignment is not feasible (Sugiyono, 2017; Creswell, 2014). In this design, two intact classes are assigned as the experimental and control groups. The use of a control group and an experimental group is fundamental in experimental research, as it allows for the assessment of the impact of the independent variable (the digital learning tool) by comparing outcomes between groups (Fraenkel et al., 2019). The control group serves as a baseline for comparison, while the experimental group allows for the evaluation of the specific treatment being tested. This design strengthens the internal validity of the study and provides robust evidence regarding the effectiveness of the interventions (Creswell, 2018).

While the control group (Class B) used the conventional Simurelay program, the experimental group (Class A) received the intervention of Project-Based Learning using FluidSIM software. To determine their baseline knowledge and abilities, both groups take a pretest, then following the both groups complete a post-test to measure learning outcomes. This structure enables the researcher to evaluate not only the improvement within each group but also to compare the effectiveness of the two methods.

Research site and participants

The research was conducted at SMK Negeri 1 Sidoarjo, focusing on students enrolled in the Electrical Power Installation Engineering (TITL) program. The students enrolled in this program were 72 students that became the population of this research. The students were divided into two class: SI TITL 1 class and XI TITL 2 class. For this study, total population sampling was used because the population of the study was under 100. According to Sugiyono (2017), in the case of whole member of the research population are treated as sample, total population sampling can be applied for sampling technique. Participant selection was based on accessibility and similarity in academic background to ensure comparability between groups. The use of intact classes is common in quasi-experimental research when randomization is not possible (Fraenkel et al., 2019). With that two intact classes were selected, Class A and Class B. Class A was the experiment group which applied the FluidSIM software learning model during the learning process. Meanwhile, Class B as the control group do not receive treatment and followed conventional learning method using Simurelay on the material of electric motor control system circuits that has been applied by teachers beforehand.

Data collection and analysis

The data collection process in this study was systematically designed to ensure the validity and reliability of the findings. Data were gathered using several instruments including: (1) expert validation sheets to assess the quality of the learning media, (2) pretest and post-test questions to measure cognitive learning outcomes, (3) response questionnaires to evaluate the practicality of the media, and (4) observation sheets to assess students' attitudes and skills during learning activities. These instruments were developed and validated based on established educational research guidelines (Creswell, 2018; Fraenkel et al., 2019). All instruments were validated by both material and media experts using a Likert scale, which converts qualitative judgments into quantitative data for further statistical analysis (Sugiyono, 2017). The results of the validation process are presented as percentages to facilitate interpretation and comparison. The percentage range used by validators to assess the quality of the learning media in this study is summarized in Table 1.

Table 1. *Range percentage validator*

Score	Quantitative Assessment	Qualitative Assessment
4	82% - 100%	Very Good
3	63% - 81%	Good
2	44% - 62%	Not Good
1	25% - 43%	Very Bad

Note: Received from Sugiyono, 2017

To calculate the percentage of responses the following formula was used:

$$Total\ Score\ (\%) = \frac{Total\ score\ obtained}{Max\ Score\ x\ Number\ of\ Validators} \times 100\%$$

The results that were obtained from the data collection and analysis were then organized and presented in tables to facilitate the interpretation of the research findings.

Results

Significant improvement on pjbl with fluidsim

A paired sample t-test was used to evaluate the efficacy of PjBL supported by FluidSIM in the experimental group. The findings showed that after the intervention, student learning outcomes increased significantly (see Table 2).

Table 2. *Paired sample t-test results for experiment group*

Group	Pretest Mean	Posttest Mean	Sig. (2-tailed)	Interpretation
FluidSIM	61.25	86.75	0.001	Significant Gain

The N-gain analysis for the FluidSIM group revealed an improvement categorized as "high" (N-gain = 0.68), suggesting that integrating FluidSIM into PjBL is highly effective in improving both theoretical and practical competencies. These results are consistent with prior studies that emphasize the value of advanced simulation tools in facilitating active, project-based technical learning (Ahmad and Wrahatnolo, 2024; Hmelo-Silver, 2004).

Significant differences on conventional and pjbl with fluidsim

The post-test results were subjected to an independent sample t-test in order to ascertain whether the learning outcomes of the two groups differed significantly. The FluidSIM group outperformed the Control group, according to the results, which showed a statistically significant difference (see Table 3).

Table 3. *Independent sample t-test results: fluidsim vs. control*

Sig.	Sig. (2-tailed)	Interpretation
0.567	**0.001**	Higher than Control

These findings demonstrate that while both groups' learning outcomes showed significant improvement, FluidSIM was more effective than the conventional in the context of PjBL for electric motor control system circuits. This result aligns with international research indicating that the choice of simulation tool can influence the magnitude of learning gains in technical education (De Jong et al., 2019).

Discussion

The impact of Project-Based Learning (PjBL) with FluidSIM in enhancing student learning outcomes in electric motor control system circuits at SMK Negeri 1 Sidoarjo was methodically examined in this study. The discussion below addresses each research question, integrates the findings from the results, and relates them to previous studies.

Significant improvement on pjbl with fluidsim

Sstudents in the FluidSIM-assisted PjBL group showed a significant increase in learning outcomes, with mean scores rising from 61.25 (pretest) to 86.75 (posttest), and a p-value of 0.001. This indicates that FluidSIM is highly effective in supporting both theoretical and practical aspects of learning electric motor control systems.The superior effectiveness of FluidSIM can be attributed to its advanced simulation features and user-friendly interface, which allow students to experiment with various circuit designs and immediately observe the results. This finding is consistent with the work of Festo Didactic (n.d.), who highlighted FluidSIM's capability to provide safe, repeatable, and realistic simulations for technical education. Furthermore, Hmelo-Silver (2004) and Thomas (2000) argue that project-based and technology-supported learning environments foster deeper understanding, critical thinking, and problem-solving skills, which are essential for vocational students.

Significant differences on conventional and pjbl with fluidsim

A paired sample t-test was used to compare pretest and post-test results in order to assess the learning outcomes within each group. The complete results are shown in Table 4. The independent sample t-test revealed a statistically significant difference in the post-test scores between the two groups, with the FluidSIM group outperforming the Control group (86.75 vs. 78.42, p = 0.001). This suggests that although both teaching method are useful, integrating FluidSIM into PjBL improves learning outcomes more.

This result extends previous findings by Ahmad and Wrahatnolo (2024), who found that FluidSIM enhances students' motivation and practical skills more effectively than other simulation tools. International studies support this conclusion as well. De Jong et al., (2019) found that online laboratories and simulation-based project learning environments significantly improve both conceptual and practical skills in STEM education. Similarly, Han et al., (2015) found that project-based learning, when integrated with digital tools, leads to increased student engagement, higher-order thinking, and significant gains in learning outcomes in engineering and STEM education.

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The study's conclusions have significant ramifications for vocational education. First, they attest to the significant enhancement in cognitive and psychomotor learning outcomes that may be achieved by incorporating digital simulation tools into PjBL. To establish more efficient and captivating learning environments, educators are urged to use simulation-based methods and verified modules. In order to better prepare students for the demands of Industry 4.0, the findings encourage policymakers to include technology-enhanced, project-based training into vocational curriculum (Ahmad and Wrahatnolo, 2024).

This study has limitations, even with the encouraging outcomes. The findings may not be as broadly applicable as they could be because the study was limited to a single vocational school with two full courses. The study concentrated on short-term learning results, and complete randomization was not possible due to the quasi-experimental design. To evaluate the long-term effects of digital simulation-based PjBL, future studies should include longitudinal designs, various schools, and bigger, randomized samples. Furthermore, qualitative information like student interviews or reflective journals may offer more profound understandings of the educational process and the experiences of students.

Conclusions and Suggestions

This study found that the implementation of Project-Based Learning (PjBL) assisted by FluidSIM produced an even greater positive impact on student learning outcomes than conventional means. The FluidSIM group achieved a higher mean post-test score (86.75) with statistically significant gains ($p = .001$). This superior performance can be attributed to FluidSIM's advanced simulation features and user-friendly interface, which facilitate deeper engagement and more effective mastery of complex technical concepts (Ahmad and Wrahatnolo, 2024). These findings are supported by international studies, such as De Jong et al. (2014), who found that simulation-based project learning environments significantly improve both conceptual and practical skills in STEM education, and Kokotsaki et al. (2016), who found that project-based learning, especially when supported by digital resources, promotes student motivation, collaboration, and achievement in technical education

This highlights the importance of selecting appropriate digital simulation tools to maximize learning gains in vocational education. Based on these findings, it is recommended that teachers and schools integrate validated digital simulation tools, particularly FluidSIM, within PjBL frameworks to optimize student engagement and learning outcomes. Policymakers should support this approach by investing in digital infrastructure, teacher training, and curriculum development aligned with industry needs. Future research should involve larger and more diverse samples, longer-term studies, and qualitative methods to further explore the impact and sustainability of simulation-based PjBL in vocational education (De Jong et al., 2014).

Disclosure Statement

The authors confirm that there are no conflicts of interest regarding the publication of this work.

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