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Simulation Techniques Using MATLAB Simulink to Enhance The Effectiveness of Physics Lectures

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Abstract

Difficulties in analyzing current and voltage variables in Direct Current (DC) electrical circuits remain a common challenge among students in physics courses. To address this issue, the researcher conducted action research aimed at enhancing the effectiveness of physics instruction. This study integrated the TPACK (Technological Pedagogical Content Knowledge) framework by implementing simulation-based learning through MATLAB Simulink, enabling students to visualize and analyze current and voltage behavior in DC circuits more effectively. The research adopted the Hopkins action research model, which includes the stages of problem identification, intervention planning, implementation, observation, and reflection. The findings revealed that: (1) students successfully developed DC circuit simulations using MATLAB Simulink, and (2) students demonstrated improved ability in analyzing current and voltage variables within the circuits. These results suggest that simulation-based learning grounded in the TPACK framework is a practical and effective approach for improving students' analytical skills and conceptual understanding of DC electrical circuits, particularly in terms of current and voltage analysis.

Keywords: *Simulation Techniques, Learning Effectiveness, Matlab Simulink, Physics Material*

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1. INTRODUCTION

MATLAB Simulink offers an interactive approach to enhance students' comprehension of direct current (DC) circuit concepts. Students can construct visual models of DC circuits, incorporating resistors, voltage sources, and other components. Simulink allows users to readily modify resistance values, voltage levels, and circuit configurations, and directly observe the resulting effects on current and voltage at various points within the circuit. Real-time visualization of current flow and voltage distribution facilitates an intuitive understanding of Ohm's Law and Kirchhoff's Laws. Students can simulate various circuit configurations, such as series, parallel, or combinations thereof, and analyze the resulting changes in circuit characteristics. This method aids in connecting theory with practical applications, deepening the understanding of DC concepts, and fostering a more robust intuition regarding circuit behavior (Rahim et al., 2021).

MATLAB stands out as a programming platform that offers several advantages over other languages when applied in physics education. Firstly, it provides a comprehensive set of tools for analyzing both theoretical and experimental physics problems. Its wide array of built-in functions and toolboxes simplifies complex numerical and visual tasks for both students and educators. As noted by Attaway (2020), MATLAB is particularly effective in handling mathematical computations and data visualization within scientific and engineering disciplines. Secondly, MATLAB employs a high-level programming language that is accessible and easier to learn, especially for students with limited programming experience. This user-friendly syntax allows learners to focus more on problem-solving rather than technical coding details. Palm (2018) supports this by explaining that the high-level nature of MATLAB makes it ideal for teaching technical subjects because it reduces the learning curve for programming. Thirdly, MATLAB includes Simulink, a graphical environment that allows users to build and simulate models of dynamic systems virtually. This feature enhances the understanding of abstract physics concepts and enables the visualization of scenarios that cannot be demonstrated directly in a classroom setting, such as large-scale or hazardous systems. As emphasized by Chapman (2020), Simulink facilitates the comprehension of dynamic behaviors by representing them visually, thus making complex systems more tangible. These features collectively position MATLAB as a powerful and effective tool for enhancing the teaching and learning of physics in higher education settings.

Furthermore, MATLAB Simulink significantly improves students' analytical capabilities concerning DC electrical circuits. Simulink provides powerful simulation data analysis tools, including graph generation, current and voltage measurements, and power calculations. Students can utilize these tools to validate circuit laws, calculate power dissipated by resistors, and evaluate circuit efficiency. Simulink also facilitates sensitivity analysis, enabling students to investigate how minor changes in component values affect overall circuit performance. For example, they can analyze the influence of resistance variations on the total current. These capabilities are crucial for developing problem-solving and circuit design skills. As demonstrated by Permatasari et al. (2020), the use of Simulink in electrical circuit learning can enhance students' abilities to analyze and solve circuit-related problems. With Simulink, students can conduct virtual experiments, test various configurations, and optimize designs to meet specific requirements, thereby preparing them for real-world applications.

Higher education serves as a platform for students to expand their knowledge through academic learning activities. According to Kholiqin et al. (2022), student engagement and the effectiveness of the learning process are crucial elements in classroom instruction. Physics education, as one of the core subjects, aims to develop students' analytical abilities, logical thinking, and critical reasoning skills. Physics lectures play a vital role in shaping students' scientific understanding. Through guided instruction from lecturers, students gain knowledge of physics concepts during classroom sessions. However, the process of transferring physics knowledge often encounters various challenges. As a result, the learning process between lecturers and students may not be optimized. The researcher's observations identified several factors that contribute to the ineffectiveness of physics lectures. Therefore, it is essential to identify and analyze these issues in order to develop effective solutions to improve the quality of physics education in higher education institutions.

The incorporation of MATLAB Simulink into physics coursework demonstrably enhances the quality of education by fostering deeper conceptual understanding and cultivating crucial analytical skills among students. Simulink empowers students to construct interactive visual models of physical systems, manipulate parameters, and observe system responses in real-time. This approach mitigates the limitations of conventional instruction, which often relies on abstract and theoretical frameworks, thereby promoting active engagement and improved intuition. Consistent with Moore's (2019) findings on the use of simulations in science education, simulations provide a dynamic and interactive learning environment that can enhance student engagement and understanding of complex scientific concepts.

Furthermore, Simulink equips students with essential analytical and problem-solving competencies vital for careers in science and engineering. Students can analyze simulation data, identify patterns, and conduct "what-if" analyses to explore the consequences of various design choices. These capabilities stimulate critical thinking and the development of sophisticated problem-solving skills. In accordance with research by Smith & Jones (2022), the integration of computational tools like Simulink into physics curricula can significantly improve students' ability to model and analyze real-world phenomena. Consequently, Simulink represents a valuable instrument for improving the overall quality of physics education.

Low motivation to learn physics among students is a major factor contributing to the ineffective transfer of knowledge. Direct observations revealed that this was the most frequently mentioned issue in students' responses. The lack of motivation in physics lectures is a serious and significant problem. Several factors contribute to this low motivation, such as unengaging teaching methods, students' difficulties in understanding physics concepts, and a lack of support from the learning environment. These issues often lead students to lose interest and enthusiasm in studying physics. According to

Rismawati et al. (2020), factors that influence low learning motivation include learning facilities, personal interest, attention span, self-confidence, peer influence, and health conditions. Similarly, Rohman & Karimah (2018) identified several contributing factors such as the learning environment, students' physical condition, intelligence, infrastructure, study time, learning habits, teachers, parents, emotional state, and overall health. Therefore, research is needed to develop a more conducive and engaging learning environment, along with more interactive teaching methods. It is important for educators to implement various types of learning media to enhance students' motivation. As stated by Ndraha & Harefa (2023), instructional media can significantly boost students' interest and motivation to learn. The main goal is to encourage students to be more enthusiastic about learning. Additionally, the use of educational media can foster curiosity and deeper engagement with the subject matter, ultimately improving students' motivation to learn.

Students' lack of physics literacy and numeracy skills often leads to difficulties in understanding and analyzing physics concepts. Strong literacy and numeracy skills are essential for studying physics effectively at the university level. These competencies serve as a foundation for students to think critically and analytically. Both aspects complement each other in helping students comprehend and apply physics concepts effectively. According to Syaifudin (2022), numerical literacy refers to the knowledge and ability to use various numbers and symbols to solve practical problems in everyday life. This skill is particularly useful in analyzing information presented in the form of graphs, tables, and charts, and in using the results of these analyses to make predictions and informed decisions. There are several factors that contribute to the low levels of literacy and numeracy among students. Hazimah and Sutisna (2023) identified several causes, including low intelligence, lack of interest in learning, poor self-reliance, insufficient parental support, a lack of innovation in teaching methods, limited understanding of subject concepts, and inadequate learning facilities and infrastructure. Similarly, research by Pardede and Mujazi (2024) categorizes the factors affecting low literacy into internal and external factors. Internal factors include students' ability to understand material and low reading interest, while external factors include parental guidance, teachers' ability to innovate, and the availability of adequate educational resources and infrastructure.

A lack of independent learning is one of the contributing factors to students' poor mastery of physics material. When students lack the ability to learn independently, they often struggle to find adequate references and resources to solve problems encountered during lectures. Developing independent learning skills is essential for fostering critical and analytical thinking. Students who are self-directed in their learning tend to be more proactive in seeking information, analyzing data, and solving problems—skills that are particularly vital in physics education, where managing one's learning process effectively is key. As noted by Arista et al. (2022), independent learning is a crucial skill that every student should possess. To achieve meaningful learning outcomes, students must develop the capacity to learn and grow autonomously. This view is supported by research from Dewi et al. (2020), which found that learning independence contributes significantly—up to 24%—to academic performance. Therefore, cultivating students' ability to learn independently is essential for achieving optimal academic results. Moreover, independent learning is closely linked to the development of self-efficacy. According to Saputra, Hariyadi, and Sarjono (2021), students' learning independence can be strengthened through high levels of self-motivation. The more motivated students are, the more autonomous they become in managing their studies. In turn, strong self-efficacy reinforces learning independence, creating a positive cycle that supports academic success.

In addition to internal student-related challenges, external factors also contribute to the ineffectiveness of physics lectures. One significant issue is that some lecturers have not yet implemented TPACK (Technological Pedagogical Content Knowledge) in their teaching practices. According to Silvester et al. (2024), the TPACK framework equips educators with the ability to effectively integrate technology into instruction, making learning experiences more relevant, engaging, and contextually meaningful. TPACK refers to the understanding of how to apply appropriate technology within suitable pedagogical approaches to effectively deliver specific subject matter (Rahmadi, 2019). In the context of physics education, the application of TPACK can greatly enhance the learning process. One key benefit is that it helps students stay focused and better comprehend complex physics concepts due to more engaging and interactive content delivery. Therefore, as emphasized by Yudiana et al. (2024), it is essential for educators to develop TPACK competencies in order to align technological tools with instructional strategies that match both the content and the learners' characteristics.

To address the existing gap in connecting learning challenges with the proposed solution, which is simulation-based learning using MATLAB Simulink, explicit affirmation is needed at the beginning of the introduction. This solution directly targets a lack of motivation by providing an interactive and visual learning environment, which has been shown to increase student engagement (Keller & Suzuki, 2018). Simulink enhances conceptual understanding by facilitating visual representations of abstract concepts, helping students build stronger mental models (Chiou et al., 2021). Furthermore, Simulink encourages self-directed learning by providing immediate feedback and allowing students to test their own hypotheses (Ruiz-Primo et al., 2019). Thus, simulation-based learning using MATLAB Simulink offers a comprehensive approach to addressing the challenges of motivation, understanding, and self-directed learning in physics education. This study focuses on the field of educational technology, specifically the application of simulation techniques in physics lectures. The instructional model used is based on the TPACK framework (Technological Pedagogical Content Knowledge). According to Ilhami and Permana (2023), TPACK represents a set of competencies that integrates Technological Knowledge, Pedagogical Knowledge, and Content Knowledge within the context of teaching and learning. Simulation techniques involve creating virtual models that replicate real-world systems. These methods are widely recognized for their value in supporting learning activities across all levels of education, from primary to higher education. Klee and Allen (2018) describe simulations or models as general terms referring to conceptual or physical representations that imitate, explain, predict, or convey information about the behavior of a process or system. The advantage of using models lies in their ability to explore the internal dynamics of a system in a cost-effective and safe manner. In today's era, simulation technologies rely heavily on computer-generated imagery to achieve these outcomes.

MATLAB Simulink is a highly relevant software tool for developing simulation instruments in physics lectures. There are several reasons why MATLAB Simulink is well-suited for designing physics simulations, including: (1) its ease of data processing, (2) powerful capabilities for numerical analysis and data visualization, and (3) the ability to design interactive graphical user interfaces (GUIs). Simulation, in this context, refers to the process of replicating real-world phenomena along with their surrounding environments. This replication involves representing the key characteristics and behaviors of the system being modeled. Simulations are often used to demonstrate the effects of specific conditions or alternative actions on a given system. They are particularly valuable when real systems are inaccessible, impractical to operate, located in hazardous environments, or when direct human involvement poses significant risks. As explained by Nasrudin and Yunida (2022), MATLAB is an effective and robust platform for simulation, capable of modeling complex systems with precision. The use of simulation plays a vital role in helping students better understand learning materials, especially in physics education at the university level.

Modeling and simulation are utilized to study the properties and behaviors of operational variables within a system. These virtual models are often employed to support analysis and draw meaningful conclusions. According to Yaumi (2021), the application of simulation methods offers several benefits, such as enhancing practical skills, deepening conceptual understanding, and fostering problem-solving abilities. Additionally, simulations contribute to increased student engagement, boost learning motivation, and promote collaborative learning experiences. Nurulhidayah et al. (2020) also found that physics learning outcomes significantly improved in experimental classes where discovery learning was integrated with simulation media. Furthermore, Pilendia (2024) emphasized that the use of interactive multimedia allows for deeper conceptual exploration through visualizations and simulations. With such tools, students can engage more actively in learning physics by exploring concepts in a dynamic and immersive way.

This research holds significant relevance in the advancement of both physics education and information technology. In the face of increasingly complex and dynamic technological developments in the era of the Fourth Industrial Revolution, this study serves as a foundation for understanding emerging phenomena, identifying students' learning needs, and formulating effective solutions to address existing challenges. The primary objective of this research is to analyze the difficulties encountered by students during physics lectures and to generate actionable insights that can be applied in instructional practice. As a proposed solution, the researcher suggests the integration of simulation-based technology into physics education. This action research not only contributes to theoretical development but also offers practical benefits for improving the teaching and learning process. Designed in a structured and strategic manner, this study aims to foster educational innovation and enhance the overall quality of learning within academic institutions.

2. METHODS

This study employs a qualitative approach aimed at understanding the learning processes within a physics course. Qualitative methods are highly suitable for action research because they enable a deep understanding of specific contexts. These methods allow for flexibility in exploring the nuances and complexities of the situation being studied. The cyclical nature of action research is supported by continuous data collection and adaptation of actions through qualitative approaches. Collaborative participation is facilitated by qualitative methods, allowing for diverse perspectives. Ultimately, qualitative methods empower participants for change, aligning with the core goals of action research. The research subjects consist of a group of students enrolled in the physics course at Indraprasta PGRI University. The selection of participants was carried out using purposive sampling, where individuals were chosen based on their relevance and ability to provide insightful information related to the phenomenon under investigation. The data collection methods employed to understand the problem, monitor the impact of actions, and reflect on the process in this research are participant observation. Through this method, the researcher actively engages in the research environment and observes events, interactions, and student behavior. In addition, reflection sheets are used as instruments to record the experiences, thoughts, and learning perceived by students during the action research process. To strengthen data validity, data triangulation is performed by comparing the results of student interviews and classroom observations to examine the consistency between students' statements and their demonstrated behavior. The action research approach in this study was designed by adopting the Hopkins Model.

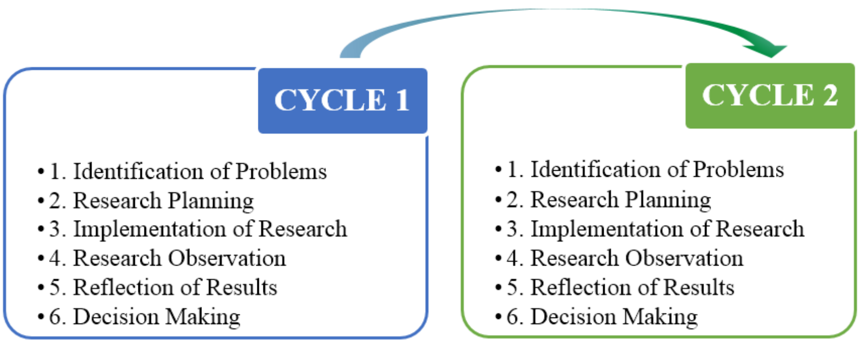

Figure 1. Research Stages

Figure 1 illustrates the stages of action research employed by the researcher, which were adapted from the Hopkins Model. This model is relevant for use in action research, particularly in educational settings. This model consists of sequential and interconnected stages, namely planning, action, observation, and reflection. Each stage is designed to complement the others in order to promote continuous improvement of practice. Moreover, the model emphasizes collaboration between researchers and practitioners, such as teachers or lecturers, thereby reflecting the participatory nature of action research. Another strength of this model lies in its adaptability, clarity, and applicability across various contexts. Therefore, the Hopkins model can serve as a strategic approach to enhancing the quality of learning and professional development in education through action research. The activities carried out at each stage of the research process are described as follows:

1. Problem Identification
   The researcher conducted direct observations of the study subjects to analyze the contributing factors affecting the learning process, both from internal aspects of the students and the teaching

methods used by lecturers. This information served as a foundational reference for designing an appropriate solution through action research.

2. Action Planning
   Based on the problems identified, the researcher designed an intervention strategy tailored to the needs of the students. A TPACK-based learning plan was developed, incorporating simulation techniques using Matlab Simulink software. The researcher also prepared supporting materials, including lesson plans, instructional resources, and evaluation instruments to assess the effectiveness of the intervention. The integration of the TPACK (Technological Pedagogical Content Knowledge) framework into the lesson plan is carried out systematically and is oriented toward achieving specific learning objectives, namely the analysis of current and voltage in direct current (DC) circuits. In this context, MATLAB Simulink is utilized as a technological tool to support students' understanding of physics concepts through dynamic and interactive simulations. The lesson plan is designed by taking into account the three core components of TPACK: content knowledge, pedagogical strategies, and technological integration. This ensures that each learning activity not only delivers theoretical material but also promotes deeper conceptual understanding through visual experiences and hands-on practice. The simulations developed using Simulink is specifically tailored to represent complex physical phenomena such as electrical circuits analisys which are often difficult to visualize through verbal explanations or static diagrams alone. These simulations are directly aligned with the learning objectives outlined in the semester lesson plan (RPS) and are mapped to ensure consistency with graduate learning outcomes and core competencies defined in the curriculum. Therefore, the use of Simulink is not merely an auxiliary tool, but an integral component of a TPACK-based instructional strategy that effectively combines content, pedagogy, and technology to enhance the quality and meaningfulness of physics learning.
3. Implementation of the Action
   The intervention was carried out during physics lectures. The researcher delivered course content using simulation techniques with Matlab Simulink to assist students in understanding concepts and analyzing direct current (DC) electrical circuits.
4. Observation and Data Collection
   The researcher observed student activities during the learning sessions to assess their engagement and responses. Additional data were collected through interviews, questionnaires, and documentation to gain a comprehensive understanding of the students' conceptual grasp and analytical skills. The collected data were then used to evaluate the effectiveness of the simulation-based intervention.
5. Reflection on the Results
   The researcher analyzed the success of the simulation technique implemented using Matlab Simulink in improving students' comprehension and analytical abilities in physics. Observational notes, interview responses, and documentation were reviewed to determine changes in students' learning behaviors and their academic performance.
6. Decision Making
   At this stage, the researcher assessed whether the learning objectives had been achieved and whether the simulation method had a positive impact on student understanding. If a significant improvement was observed, the researcher recommended the continued use of this method in future lectures. Conversely, if limitations were identified, adjustments or enhancements would be considered for the next cycle of action research.

3. RESULT AND DISCUSSION

The results of the study indicate an improvement in student learning outcomes on the topic of Direct Current (DC) electricity through the use of simulation techniques with MATLAB Simulink. Reflections from classroom activities revealed several benefits of implementing MATLAB Simulink, including: (1) increasing student motivation to understand DC current concepts, (2) enhancing student engagement by designing virtual electrical circuits, (3) providing clarity for abstract concepts, (4) improving students' skills in assembling electronic components, and (5) strengthening their ability to analyze current and voltage variables in circuits. Performance assessments demonstrated that simulation techniques effectively supported students' comprehension of direct current material. The use of simulations in physics education not only improved academic performance but also helped foster motivation, active participation, critical thinking, and analytical skills among students.

Formative assessment results 35 student on Y4L class indicate that the use of a TPACK-based approach integrated with MATLAB Simulink effectively supports the achievement of learning indicators. Students not only demonstrate a theoretical understanding of the concepts but also show improvement in practical skills and active participation throughout the learning process. Recent research emphasizes that effective integration of technology in STEM education enhances students' engagement and conceptual comprehension, particularly when tools like simulation software are applied in contextually meaningful ways (Chai et al., 2020). In addition, studies have shown that the application of MATLAB and Simulink helps bridge the gap between theoretical physics concepts and real-world applications through interactive visual learning experiences (Sulaiman et al., 2018). These findings affirm that the combination of sound pedagogical strategies and technological tools such as Simulink significantly contributes to deeper and more active learning in physics education.

Table 1. Recapitulation of Formative Assessment Results for DC Circuit Learning

No	Learning Indicator	Percentage of Students Achieving Mastery (%)	Description
1	Improvement in understanding of DC circuit concepts	85%	Most students correctly understand series and parallel configurations
2	Student activeness in class	75%	Students actively engage in discussions, ask questions, and express opinions
3	Ability to explain Ohm’s Law and Kirchhoff’s Laws I & II	80%	Students are able to explain the application of damental electrical laws
4	Improvement in assem ling electronic components	70%	Students recognize component symbols and functions fairly well
5	Ability to calculate current and voltage at each point in the circuit	78%	Students can perform quantitative analysis using mathematical approaches

Source: Primary Data Research Results 2024

The student-developed simulation focused on DC voltage source circuits with resistors arranged in series and parallel configurations. This simulation proved useful in helping students grasp the concepts of Kirchhoff's First and Second Laws. Additionally, the DC circuit simulation supported students in analyzing current and voltage variables at various points within the circuit. This aligns with research by Nasution and Yahfizham (2024), which highlights MATLAB as a powerful platform for data analysis, algorithm development, mathematical problem-solving, and modeling—making it a valuable tool for enhancing students’ understanding of mathematics. Teachers can creatively utilize MATLAB as an instructional medium to improve students’ computational skills, provided it is used under appropriate supervision and guidance. Furthermore, Kalsum and Fathurohman (2023) reported that the use of MATLAB in physics learning received a "Very Good" rating, with a score of 83%, indicating its effectiveness in addressing learning challenges and supporting its broader application in physics education.

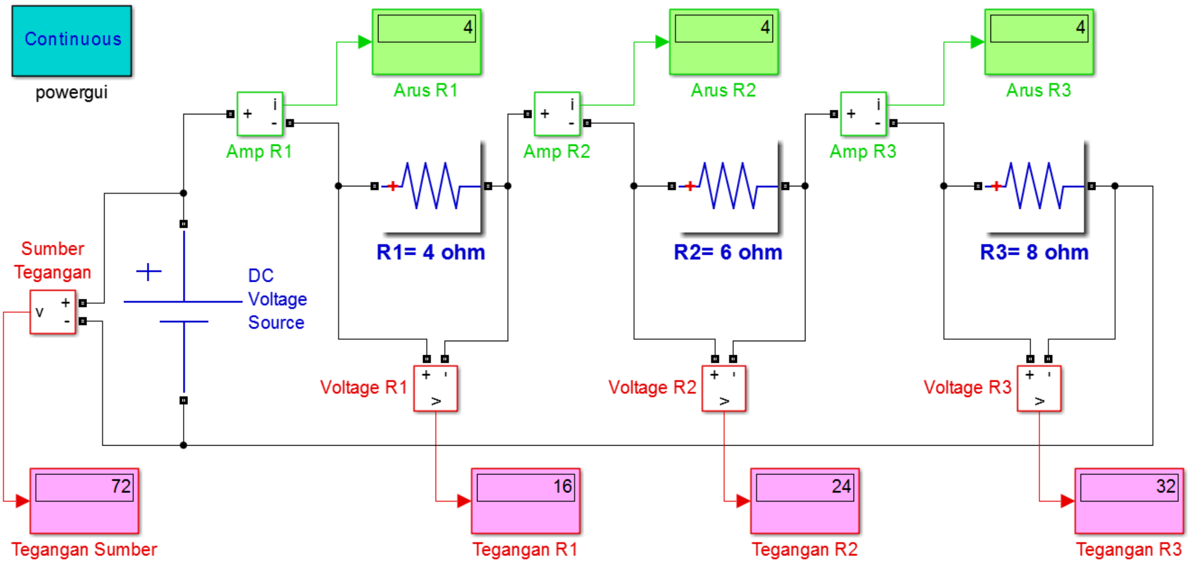

Figure 2. Simulation of DC Voltage Source and Resistor Circuits in Series

Figure 2 displays a simulation of a DC voltage source circuit connected to three resistors in series. This simulation was developed using MATLAB Simulink. The voltage of the DC source and the resistance values can be modified according to the user's needs. Students are then able to analyze the electric current and voltage flowing through each resistor. The current passing through each resistor is shown on a green ammeter display, while the voltage across each resistor is indicated on a pink voltmeter display. The modified values of voltage, current, and resistance in the series configuration are then recorded and presented in a table, as shown in **Table 2.**

Table 2. Tabulation of Sample Data from Series Circuit Simulation Results

Voltage Source *(Volt)*	**Resistance *(Ω)***	**Voltage *(Volt)***	**Current *(Ampere)***
72	4	16	4
72	6	24	4
72	8	32	4

Source: Primary Data Research Results 2024

The use of simulation techniques offers significant advantages for students, particularly in enabling them to easily adjust or modify electrical values and perform in-depth analyses of DC circuits where resistors are connected in a series configuration. Through these simulations, students gain a hands-on opportunity to explore how various electrical quantities interact within a circuit. The effectiveness of this method is evident in its ability to strengthen students' conceptual understanding as well as their analytical thinking skills when solving physics-related problems. From the experiments conducted during the simulation sessions, students were able to draw an important conclusion: "The amount of electric current in a series circuit remains constant throughout each component." This observation aligns well with established physics principles and reinforces theoretical knowledge through practical experience. Supporting this, Putra and Rosiyanti (2021) highlighted that MATLAB serves as a powerful platform for developing educational tools that can increase both teacher and student engagement in the learning process. Moreover, MATLAB offers educators the opportunity to design ICT-based learning media that are more interactive and enjoyable, which in turn enhances the delivery of complex concepts and improves students' comprehension during classroom activities.

Figure 3 presents a detailed view of a simulated parallel resistor circuit connected to a DC voltage source, which was developed using MATLAB Simulink. In this simulation, three resistors are arranged in parallel and linked to the same DC power source. This setup allows students to explore and understand how current and voltage behave in a parallel circuit configuration. One of the key features of this simulation is that it provides real-time visualization of electrical quantities, helping students grasp abstract concepts more effectively. The amount of electric current flowing through each individual resistor is displayed using a green-colored ammeter, allowing students to observe variations based on resistance values. Similarly, the voltage across each resistor is shown using pink-colored voltmeters, clearly indicating that the voltage remains constant across all components in a parallel circuit. The simulation also allows students to modify the values of the voltage source and resistor ratings to see how these changes affect current distribution. After running several simulations and modifying parameters, students are required to record their observations systematically.

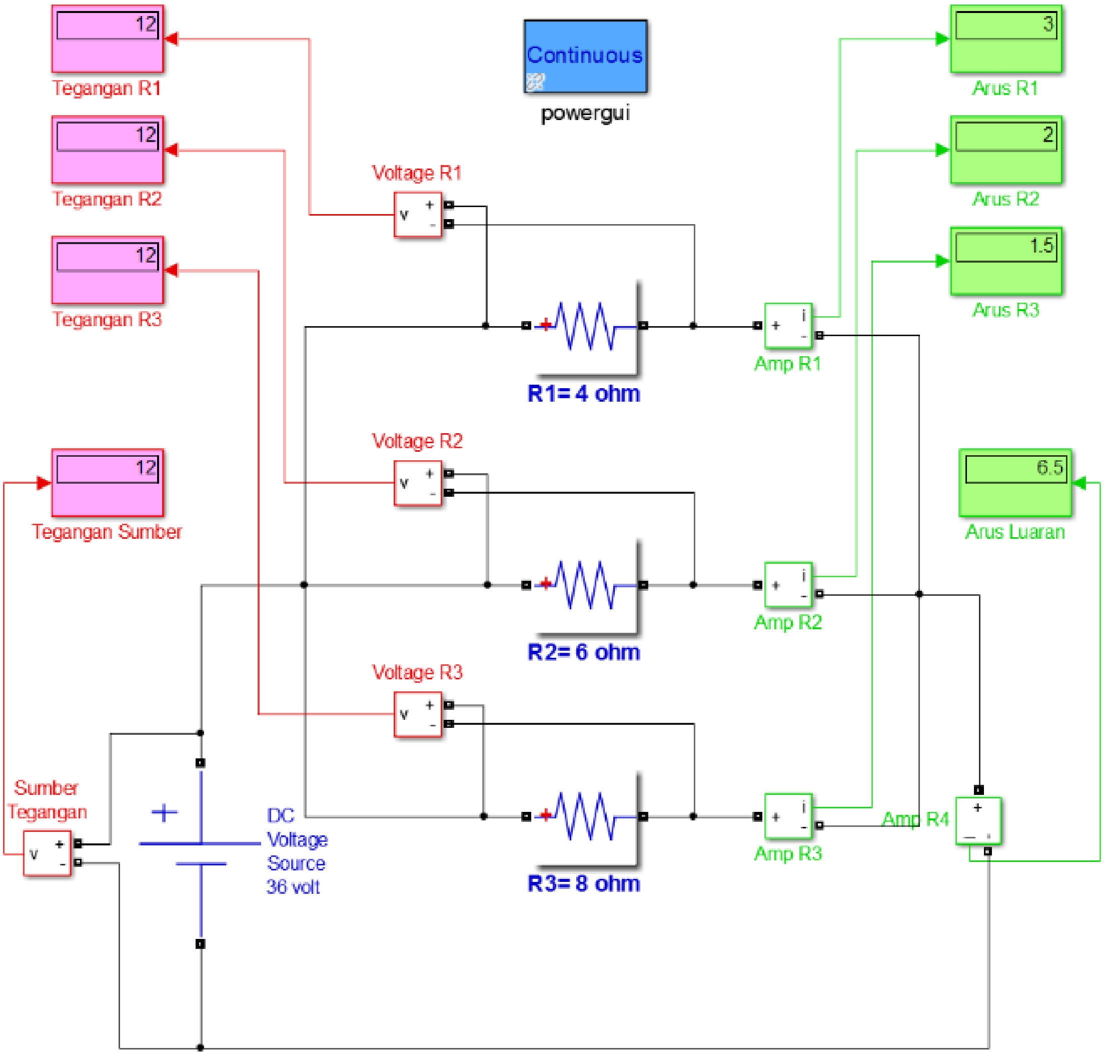

Figure 3. Simulation of DC Voltage Source and Resistor Circuits in Parallel

The collected data—covering values of voltage, current, and resistance—is then compiled into a table format for further analysis, as presented in Table3. This hands-on activity not only reinforces theoretical knowledge but also enhances students' skills in using technology to solve physics problems.

Table 3. Tabulation of Sample Data from Series Circuit Simulation Results

Voltage Source *(Volt)*	**Resistance *(Ω)***	**Voltage *(Volt)***	**Current *(Ampere)***
12	4	12	3
12	6	12	2
12	8	12	1,5

Source: Primary Data Research Results 2024

A key characteristic of a parallel circuit is the presence of branching points, where all resistors share the same two terminals. In the parallel circuit simulation shown in **Figure 3**, the DC voltage source and the resistance values can be modified by the user. Students can then analyze the electric current and voltage flowing through each resistor arranged in parallel. The amount of current flowing through each resistor can be observed on the green-colored ammeter display, while the voltage across each resistor can be read on the pink-colored voltmeter display. This simulation technique allows students to easily modify values and analyze DC electrical circuits with resistors arranged in parallel. It has proven to be an effective method for enhancing student engagement and understanding. Based on the results of the simulation experiment, students can conclude that the voltage across each resistor in a parallel circuit is equal.

The use of Matlab Simulink in physics courses enables students to design and model direct current (DC) electrical circuits in an interactive and dynamic way. Observations conducted during the learning process indicate that this simulation technique allows students to manipulate variables such as source voltage and resistance, as well as to analyze the resulting data in real time. This flexibility fosters active student engagement, as evidenced by increased participation in class through questioning, discussion, and collaborative problem-solving. Furthermore, the simulation approach significantly enhances students' understanding of fundamental electrical concepts, particularly Kirchhoff's Current Law (KCL) and Kirchhoff's Voltage Law (KVL). According to Shalahuddin et al. (2021), simulation-based laboratory activities offer several advantages, including reducing the dependency on expensive physical equipment, expanding the range of possible experimental scenarios, and providing students with the opportunity to conduct experiments repeatedly, anytime and anywhere, thus reinforcing their conceptual mastery.

The application of simulation techniques in physics courses has been shown to enhance students' learning satisfaction and increase their motivation to actively engage in the learning process. Through simulations related to direct current (DC) circuit topics, students are able to conduct hands-on virtual experiments in real time. This approach allows them to grasp physics concepts in a more interactive, practical, and tangible manner, thereby improving both their conceptual understanding and interest in the subject. Educators are expected to adapt to the evolving demands of the times. As highlighted by Nurhidayati (2024), advancements in science, technology, and the arts—particularly in the field of education—require instructors to possess adequate knowledge and skills in utilizing technology within the learning context. Based on the researcher's observations during the intervention process, simulation-based learning has proven effective in enhancing students' motivation by facilitating conceptual understanding. Through visual representations of abstract and complex physics concepts, which are often difficult to comprehend through verbal explanations alone, students gain a deeper and more meaningful learning experience.

The implementation of simulation techniques in physics lectures enables students to visualize various physical phenomena, particularly in the topic of direct current (DC) circuits. Through simulation, students gain a clearer understanding of how to properly connect measuring instruments such as ammeters and voltmeters, as well as how to assemble electrical components in series or parallel configurations. This visual representation helps bridge the gap between theoretical knowledge and practical application, making complex concepts more accessible. Therefore, it is essential for educators to possess the ability to integrate technology effectively into the learning process. According to Siregar and Tambunan (2024), mastery of Technological Pedagogical Content Knowledge (TPACK) is vital for teachers, as it allows them to combine technological tools, pedagogical strategies, and subject content in a cohesive manner. This integration aims to create meaningful learning experiences and enhance students' academic abilities. This view is supported by Ristiana (2022), who emphasizes that technological proficiency plays a critical role in fostering student motivation and developing process skills throughout the learning experience.

The findings of this study indicate that the implementation of Matlab Simulink in instructional activities significantly enhances students' understanding of engineering and scientific concepts through visual and interactive approaches. Viewed through the lens of the Technological Pedagogical Content Knowledge (TPACK) framework, the use of Simulink demonstrates an effective integration of the three core components: content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK). In this context, teachers not only possess mastery of subject matter such as control systems and system dynamics (CK), but are also able to design simulation-based learning strategies that actively engage students in conceptual exploration (PK). Furthermore, they exhibit proficiency in operating and adapting the features of Simulink to match students' learning needs and cognitive levels

(TK). Consistent with these findings, Rahmat and Nugroho (2020) state that "technology-based simulations such as Matlab Simulink strengthen the understanding of complex concepts through dynamic visualization that supports the integration of content, pedagogical, and technological knowledge" (p. 149). Project-based approaches like these are considered effective in fostering TPACK competence in technical education. As Suryani, Pratama, and Yuliana (2018) assert, "the application of TPACK in technical education requires a project-based approach and the use of engineering software to enhance 21st-century skills" (p. 60). In addition, digital simulations have been proven to improve student engagement and the overall quality of technical instruction. According to Wijaya and Hidayat (2017), "digital simulations in technical education are effective in increasing student engagement and reflect the practical implementation of TPACK principles in classroom contexts" (p. 205). Therefore, the integration of Matlab Simulink not only enriches instructional strategies but also reinforces the theoretical and pedagogical foundation of technology-enhanced teaching practices.

The implementation of the TPACK (Technological Pedagogical Content Knowledge) framework, particularly through MATLAB Simulink-based simulations in coursework, positively impacts the deepening of students' conceptual understanding. This simulation technique proves effective in enhancing analytical skills related to direct current (DC) circuits. By manipulating voltage variables, students can directly observe how these changes affect current and voltage at various points in the circuit. This allows them to explain fundamental principles such as Ohm's Law and Kirchhoff's Laws I and II more comprehensively and intuitively. Thus, the integration of TPACK and MATLAB Simulink simulations creates an interactive and effective learning environment, bridging the gap between theory and practical application in the study of electrical circuits. The findings of this study suggest that educators should consider integrating technology, particularly simulation-based tools, into physics learning activities. To ensure effective implementation, the use of a scientific approach is recommended. According to Sulistiawati et al. (2022), the scientific approach is a learning model grounded in scientific principles, involving stages such as observing, questioning, experimenting, processing data, and communicating results. This approach is expected to foster students' critical thinking skills through structured and inquiry-based learning processes. Incorporating simulations into instruction offers new, engaging, and meaningful learning experiences. These findings indicate that simulation can serve as a valuable tool in enhancing the quality of education and student learning outcomes. Indicators of improved educational quality can be seen in students' increased understanding of physics concepts, heightened motivation, and greater classroom engagement. The integration of Problem-Based Learning (PBL) methods with simulation techniques creates a positive learning atmosphere that encourages students to be more enthusiastic and active participants. This is supported by Subeki et al. (2022), who state that simulation-based learning helps students better understand problems while also enhancing their scientific process skills, motivation, and overall participation in learning activities.

This study presents several limitations, particularly in terms of sample size and the duration of implementation. Technical challenges also affected the effectiveness of the process, including: (a) not all students had hardware with sufficient specifications to run Matlab software; (b) varying levels of programming background among students; (c) differences in students' data analysis skills; and (d) some students faced difficulties in operating the software optimally. These factors posed distinct challenges during the integration of simulation as a learning tool. To overcome internal obstacles originating from the students themselves, Fricticarani et al. (2023) suggest that critical and analytical thinking skills can be developed through active learning strategies such as group discussions, case studies, situational analyses, and problem-based projects."

Although students differ in programming experience and hardware access, the integration of the TPACK framework through MATLAB Simulink consistently leads to significant improvements in conceptual understanding and practical skills, particularly for those enrolled in introductory physics courses. In the context of learning direct current (DC) circuits, Simulink allows students to visualize current flow, voltage, and resistance interactively through circuit simulations. Its visual block-diagram interface is especially helpful for students without prior programming experience, as it enables them to build and analyze circuits without writing code. While students with access to higher-performance hardware may benefit from faster simulation runtimes, this advantage does not necessarily translate into deeper conceptual comprehension. The TPACK approach—combining content knowledge (electrical circuit concepts), pedagogical strategies (exploration and visualization), and technological tools (Simulink)—creates a meaningful and equitable learning experience for all students. In line with this, Song et al. (2016) noted that "MATLAB-based computer simulations and exercises enable more concrete and detailed understanding of the material" (p. 1). Similarly, Rodrigues and Neto (2025) reported that MATLAB/Simulink is the most widely used simulation tool among engineering and science students in Brazil, particularly for basic electricity topics, due to its real-time modeling capabilities. Therefore, implementing MATLAB Simulink within the TPACK framework is highly effective in enhancing the quality of learning DC circuits in physics courses, regardless of students' technological backgrounds.

"On the other hand, addressing external challenges is more related to the availability of supporting infrastructure and the competence of educators. In the context of 21st-century education, Permana et al. (2024) emphasize that the rapid growth of internet access and digitalization in the era of the Industrial Revolution 4.0 requires educational institutions to adapt to the use of technology. Technology is no longer just a supporting tool but also serves as an essential medium for creating more innovative and engaging learning environments. Therefore, educators are expected to possess strong digital skills and the ability to understand and master technological tools comprehensively in order to facilitate effective teaching that aligns with the demands of the modern era.

4. CONCLUSION

The use of simulation techniques has proven to be an effective instructional medium for enhancing students' understanding of direct current (DC) circuit analysis in university-level physics courses. In addition to deepening conceptual comprehension, simulations also promote increased student engagement and creativity throughout the learning process. This effectiveness is evident from formative assessment results conducted during the instructional intervention, which revealed several key findings. First, students showed greater motivation and participation through the design of physics simulations using Matlab Simulink. Second, the ability to conduct virtual experiments without physical limitations allowed students to freely explore various scenarios and variables related to current and voltage. Third, the use of simulations significantly reinforced students' conceptual grasp of DC circuit topics. Based on these findings, the integration of simulation-based learning into physics courses is highly recommended to improve both instructional effectiveness and students' academic performance.

Future research is recommended to expand the scope of studies on the effectiveness of simulations in physics education at the university level. This can be achieved by developing and testing various types of interactive simulations designed to support learning across a wide range of physics topics, such as mechanics, electricity and magnetism, thermodynamics, and waves and optics. To obtain more comprehensive findings, it is advisable to involve multiple higher education institutions with diverse backgrounds, resources, and curricula, allowing for broader applicability of the results. Furthermore, the effectiveness of simulations should be analyzed in relation to other influencing factors, including students' learning styles (visual, auditory, kinesthetic), analytical thinking skills, and interpersonal interaction abilities within the learning environment. By considering these aspects, future studies can provide deeper insights not only into students' conceptual understanding but also into how individual and social factors contribute to the overall learning process.

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