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The Development of a Digital Electronics Trainer for Teaching Fundamentals of Electronics Engineering

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Abstract

The teaching of Fundamentals of Electronics Engineering often faces challenges in bridging theoretical knowledge with practical application. A lack of interactive and contextual learning media hinders students' comprehension of foundational concepts and diminishes their motivation to learn. This study addresses these challenges by developing a digital electronics trainer as an instructional tool to support the learning process. The trainer is designed and implemented to help students explore digital electronics concepts—specifically logic gates—through relevant problem-solving activities. The aim is to enhance students' conceptual understanding and engagement. This research employs a Research and Development (R&D) approach, utilizing the ADDIE model (Analysis, Design, Development, Implementation, Evaluation). The results demonstrate the significant effectiveness of the digital electronics trainer in improving students' cognitive abilities. An N-Gain score of 0.71 indicates a high level of cognitive improvement in the experimental group using the trainer, compared to the control group that relied on textbook-based learning.

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INTRODUCTION

The rapid advancement of technology has significantly transformed the field of education, particularly in the development of instructional media. Efforts to enhance the efficiency and effectiveness of the teaching and learning process have driven many educational institutions to create more innovative and engaging learning environments. Despite these advancements, the teaching of *Fundamentals of Electronics Engineering (FEE)* often remains heavily focused on theoretical content, with limited application of practical concepts. The continued reliance on conventional teaching methods presents challenges for students in gaining a deep understanding of the subject matter and limits the development of essential technical skills required in the workforce. Moreover, the instructional tools currently available are often inadequate or suboptimal in supporting hands-on practice, making it difficult for students to develop practical competencies (Arsyad, 2019).

Based on the researcher's observations conducted at SMK Negeri 1 Tonjong reveal several challenges in the teaching of Fundamentals of Electronics Engineering. The limited availability of instructional tools and the definite time of practicum hinder students from understanding the key concepts and applying them in practical contexts. These issues have contributed to subpar student competency outcomes, affecting both students' readiness for higher education and employability in technical fields. The low level of student mastery in the FEE subject highlights the need for improvements in the teaching and learning process to create more effective, accessible, and engaging classes. Increasing student engagement is crucial, as it influences the learning outcomes. One instructional model that has shown potential in motivating students is the problem-based learning (PBL) approach. PBL encourages students to think critically and creatively by placing them in situations where they must solve real-world problems. As Manurung and Surya (2017) suggest, the presence of a problem compels students to develop their reasoning and problem-solving skills. Therefore, the careful selection of challenges introduced during the learning process plays a crucial role in optimizing students' comprehension and overall learning experience.

The Problem-Based Learning (PBL) model has strong potential to foster students' creative thinking skills and promote collaborative problem-solving in response to real-world challenges. The problems presented in this model serve to spark students' curiosity and engagement with the subject matter. PBL not only cultivates curiosity but also provides individuals with repeated opportunities to practice and develop the skills needed to solve problems they may encounter. By engaging with real-life issues, students are encouraged to explore solutions through active learning and teamwork. As Aldila and Mukhaiyar (2020) emphasize, PBL equips learners with the necessary training and cognitive strategies to address and resolve the problems they face. In light of these challenges, the objective of this study is to develop an instructional media tool—a digital electronics trainer—that effectively supports students in analyzing the basic principles of logic gates within the *Fundamentals of Electronics Engineering* course.

RESEARCH METHODOLOGY

This study employed a Research and Development (R&D) approach, utilizing the ADDIE instructional design model, which consists of five systematic phases: Analysis, Design, Development, Implementation, and Evaluation. This model was selected for its structured framework, which supports the iterative process of designing and refining instructional media to ensure both effectiveness and relevance in educational contexts.

Design and Development of the Instructional Media

The product design phase establishes the initial framework for the instructional media, specifically a digital electronics trainer that functions as a primary hardware tool in practical sessions focused on basic logic gates (Chuan, 2021). The design and development process of this digital electronics trainer involved several key stages, as illustrated in the following figure:

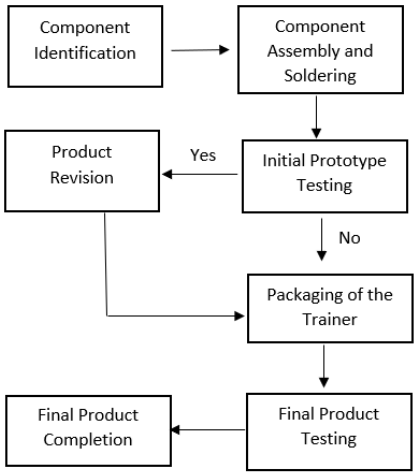

Figure 1. Development Stages of the Instructional Media

Data Sources and Research Participants

The study was conducted with Grade X students from the Electrical Engineering (TE) program at SMK Negeri 1 Tonjong, comprising a total of 102 students distributed across three classes. For the limited trial, 36 students were assigned to the experimental group and another 36 students to the control group. Furthermore, a small group trial was conducted with 10 students. The data sources in this study included subject matter experts, media experts, students, and teachers. These sources provided data for assessing the practicality of the developed instructional media (Sugiyono, 2020).

Data Collection Techniques

This study employed several data collection techniques, including observation, questionnaires, and interviews. The observation technique was used to assess the instructional media feasibility through the use of structured observation sheets (Arikunto, 2019). Practicality testing was carried out using questionnaires with a dichotomous scale, administered to both students and teachers. To evaluate the effectiveness of the instructional media, observation and performance test instruments were utilized. The research instruments developed for this study of the digital electronics trainer in the *Fundamentals of Electronics Engineering* course consist of four main tools: questionnaires, interview guides, observation sheets, and test items.

Data Analysis Techniques

The data analysis in this study employed descriptive quantitative methods aligned with the predetermined development procedures. Research data were obtained from evaluations conducted by ten media experts, ten subject matter experts, and feedback from users. The media experts involved in the study consisted of teachers specializing in Electronics Engineering. The subject matter experts were Electronics Engineering teachers who specifically taught the fundamentals of digital logic gates. User feedback was collected from productive subject teachers and Grade X students of the Electronics Engineering program at SMK Negeri 1 Tonjong. To assess the effectiveness of the instructional media, the researcher compared an experimental class that used the digital electronics trainer and a control class that adopted conventional instructional materials.

RESEARCH AND DISCUSSION

Research Result

The instructional media developed in this study is a digital electronics trainer designed to support student competency in analyzing the basic principles of logic gates (Kaleka, 2023). This trainer incorporates two interchangeable integrated circuits (ICs) representing basic logic gates, which can be removed and replaced with other logic gate ICs based on practical needs. The trainer is equipped with five toggle switches that serve as inputs to the ICs, allowing users to provide binary input values (0 and 1). Additionally, the trainer incorporates five light-emitting diodes (LEDs) to indicate the output signals of the ICs. An output value of 0 results in the LED remaining off, while an output of 1 causes the LED to light up. This real-time visual representation enhances students' conceptual understanding of logic gate operations. The trainer is further enhanced with a 7-segment display and a voltage parameter display, which shows the voltage levels generated by the logic gate circuit (Islamadina, 2023). These additional components provide learners with a more comprehensive and interactive experience when engaging with digital logic concepts. The following section presents several examples of logic gate experiments conducted using the developed trainer.

Testing the AND Gate Trainer

This test was conducted to ensure that the AND logic gate functions properly and produces the expected output (Khuraibut, 2022). The results of the AND gate testing are presented in Figure 2, Table 2, and Table 3.

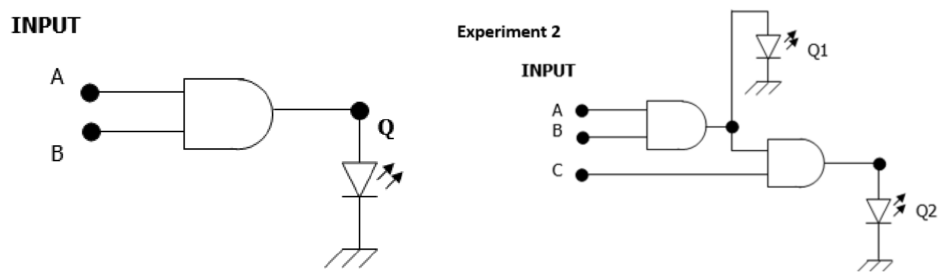

Figure 2. AND Gate Testing

Table 2. Truth Table of the AND Gate

INPUT		OUTPUT
A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

Table 3. Truth Table of a 3-Input AND Gate with Dual Outputs

INPUT			OUTPUT	
A	B	C	Q1	Q2
0	0	0	0	0
0	0	1	0	0
0	1	0	0	0
0	1	1	0	0
1	0	0	0	0
1	0	1	0	0
1	1	0	1	0
1	1	1	1	1

1. **Effectiveness Results of the Fundamentals of Electronics Engineering Digital Trainer**

The effectiveness of the developed digital electronics trainer was assessed using a post-test instrument. Before its implementation, the post-test was reviewed and validated by a supervisory lecturer, the head of the Electronics Engineering Expertise Program, and the subject teacher for *Fundamentals of Electronics Engineering* (FEE) at Grade X TE, SMK Negeri 1 Tonjong, Brebes Regency. This validation ensured that the test instrument aligned with the core competencies and intended learning outcomes. The cognitive assessment focused on students' ability to analyze the basic principles of logic gates. The results of the post-test are presented in the following table.

The effectiveness of the developed media was assessed through the administration of a post-test. Before its implementation, the post-test underwent a validation process involving consultation with a supervising lecturer, the head of the Electronics Engineering Expertise Program (TEI), and the subject teacher for Fundamentals of Electronics Engineering (FEE) at Grade X TE of SMK Negeri 1 Tonjong, Brebes Regency. This review process ensured that the test items were appropriately aligned with the course's core competencies and learning objectives. The cognitive assessment specifically measured students' ability to analyze fundamental logic gate concepts. The results of the post-test are presented in the table below.

Table 4. Post-test Result

No	Description	Post-test Result
1	Highest Score	92
2	Lowest Score	78
3	Minimum Mastery Criterion (KKM)	72
4	Total Number of Students	36
5	Number of Competent Students	36
6	Number of Non-Competent Students	0
7	Percentage of Competent Students	%

Based on the data presented in Table 4, the post-test results demonstrate that 100% of the students achieved the minimum mastery criterion in the cognitive assessment on analyzing the fundamental principles of logic gates. This outcome falls under the excellent category of learning achievement. Therefore, it can be concluded that the developed digital electronics trainer is effective in enhancing students' cognitive understanding of the subject *Fundamentals of Electronics Engineering*.

2. Descriptive Analysis

The performance test results related to the practicum on analyzing the fundamental principles of logic gates were obtained through post-testing of both the experimental and control classes. The experimental class received treatment using the digital electronics trainer, whereas the control class used conventional instructional media such as textbooks or teaching modules. The post-test outcomes are presented in Table 5 below.

Table 5. Descriptive Statistics of Post-Test Result

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
Experiment Class	36	76	92	83.44	3.097
Control Class	36	68	84	75.78	2.864
Valid N (listwise)	36				

Based on the data presented in the table above, the average post-test score for cognitive ability in the experimental class was 83.44, while the control class scored an average of 75.78. The experimental class obtained a minimum score of 76 and a maximum of 92, whereas the control class ranged from 68 to 84. These results indicate a notable difference in the average cognitive performance between the experimental and control groups, suggesting that the use of the digital electronics trainer had a positive impact on students' learning outcomes.

3. Independent Sample t-Test

The statistical analysis employed in this study was the Independent Sample t-test, as outlined by Sugiyono (2020). This test determines the significance of the difference in learning outcomes between the experimental group and the control group. The hypothesis in the Independent Sample t-test, Ha is accepted if *t count* > *t table* (95%), or it can be concluded that the digital electronics trainer is effective in enhancing students' cognitive abilities in analyzing the fundamental principles of logic gates. Conversely, the alternative hypothesis is rejected if *t count* < *t table* (95%), implying that the trainer is less effective in improving cognitive performance. The Independent Sample t-test was calculated using SPSS software, and the results of the analysis are presented in Table 6 below.

Table 6. t-Test Result

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	T	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Post test and Cognitive Ability	Equal variances assumed	.784	.379	20.279	70	.000	14.222	.699	12.829	15.615
	Equal variances not assumed			20.279	69.315	.000	14.222	.699	12.829	15.616

Based on the data above, *the t-count* was 20,279 while *the t-table* with *df* = 70 at the significance level gained 0.05. Also, the result depicted that *the t-count* was 20,279 > *t table* 0,669. It can be concluded that the use of the digital electronics trainer is effective in enhancing students' cognitive abilities in analyzing the fundamental principles of logic gates.

4. N-Gain

Normalized Gain (N-Gain) analysis was conducted to measure the improvement in students' cognitive abilities following the implementation of the treatment (Sugiyono, 2020). The N-Gain score is calculated by comparing participants' cognitive performance on the pretest and posttest. The results indicate that the experimental group achieved an average N-Gain score of 71.11%, or it can be categorized as a high category, with a minimum score of 62,50 and a maximum score of 83,33. In contrast, the control group recorded an average N-Gain score of 57.56, categorized as moderate, with a minimum score of 50.00 and a maximum of 66.67.

5. Practicality Test of Instructional Media

The practicality test of the digital electronics trainer as an instructional tool for teaching logic gate circuits was conducted at the end of the learning sessions in the experimental class. This evaluation aimed to assess students' responses to the use of the trainer as a learning medium for logic gate circuits. After implementing the instructional media, a student response questionnaire was distributed to 36 students in Class X TE 1 (the experimental group). The purpose of this questionnaire was to measure the extent of students' positive responses toward the learning media. The aspects assessed in the questionnaire focused on the media practicality, which included: (1) ease of use; (2) support for the learning process; (3) alignment with the subject matter; (4) attractiveness; and (5) its potential for use in self-directed learning (Hapsari, 2017).

Based on the coefficient of scalability (Ks), values of 0.79 for student responses and 0.75 for teacher responses were obtained. The coefficients of reproducibility and scalability were then evaluated against the practicality criteria as outlined by Rianse (2008:99). The coefficient of reproducibility (Kr) for student responses was 0.91, while the Kr for teacher responses was 0.77, yielding an average of 0.77. These findings indicate that the use of the digital electronics trainer is practical and supports the enhancement of students' cognitive abilities in analyzing the fundamental principles of logic gates

Discussion

The feasibility of utilizing the digital electronics trainer has been demonstrated in its potential to enhance students' analytical skills in mastering the fundamental principles of logic gates. The feasibility of the trainer was validated through assessments conducted by both media and subject matter experts. A total of ten media experts and ten material experts participated in the validation process. According to the media expert evaluations, the instructional media was deemed feasible based on analysis using the Content Validity Ratio (CVR), Content Validity

Index (CVI), and Percentage of Agreement (Fitriyanto, 2019)

The CVR analysis results indicated that all assessed indicators achieved values ranging from 0.8 to 1.0. Additionally, the overall Content Validity Index (CVI) was recorded at 0.84. These findings suggest that all aspects of the media instrument, intended to improve students' cognitive analytical abilities in understanding logic gates, are considered valid, as both the CVR and CVI scores exceeded the minimum threshold of 0.62. To further verify the consistency of the CVR and CVI scores, the Percentage of Agreement was calculated, yielding a result of 84%, which is higher than the minimum acceptable level of 80%. Based on this, the panel of experts agreed and concluded that all indicators within the media feasibility instrument were both valid and reliable. Similarly, validation from subject matter experts showed CVR values ranging from 0.8 to 1.0, with a CVI score of 0.85, reinforcing the instrument's overall validity and reliability.

The results indicate that all aspects (indicators) of the material instrument for analyzing the operation of basic logic gate circuits are valid, as the obtained CVR and CVI values exceeded 0.62. The percentage of agreement was recorded at 85%, surpassing the agreement value that gained 80%, thereby affirming that the subject matter experts unanimously agreed that the instrument is both valid and reliable. The feasibility of the media, as confirmed by the CVR and CVI analysis, implies that the developed digital electronics trainer is appropriate and ready for implementation in the limited trial phase. This finding aligns with Dewantara (2022), who stated that instructional media should be designed and developed according to specific models and dimensions that suit their intended functions and purposes. It is essential to recognize that instructional media can take various forms, sizes, and designs, all of which aim to support students' learning activities in acquiring knowledge effectively.

The learning media developed in this study are categorized as practical based on an analysis using the coefficients of reproducibility (Kr) and scalability (Ks). The results indicate that the Kr values obtained from students and teachers were 0.91 and 0.90, while the Ks values were 0.79 for students and 0.75 for teachers. These values meet the practicality criteria established by Usman Rianse (2008, p. 99), which require Kr > 0.90 and Ks > 0.60. These findings are in line with the perspective of Siregar and Parinduri (2017), who elaborated that digital circuits and systems, particularly those used to demonstrate basic logic gates, serve as effective tools to enhance students' understanding and practical skills in digital electronics. This result is also supported by Izza and Al Azhar (2022), who stated that a digital electronics basic logic gate trainer or instructional aid to be considered of good quality, feasible, and valid, it must meet crucial requirements. These requirements are essential for its effective application in practical learning activities related to basic logic gates in digital electronics. Therefore, the presented media can be categorized as feasible and appropriate learning media in teaching and learning activities, especially in the Fundamentals of Electronics Engineering subject.

Based on the previous discussion, the researcher has undertaken an innovation to design and develop a digital electronics trainer that serves as an interactive learning medium for fundamental electronics subjects. This trainer is equipped with two interchangeable basic logic gate ICs, which can be removed or replaced with other logic gate ICs as needed for practical exercises. Additionally, it includes five toggle switch inputs, five outputs consisting of LEDs, and a seven-segment display, as well as one voltage parameter display. The implementation of this instructional tool enables students to engage more actively in the learning process, enhances cognitive achievement, improves practical skills, and better prepares them to meet the demands of the industrial sector (Sharma, 2022).

CONCLUSION

Based on the results of the development and analysis of the digital electronics trainer designed to support the understanding of basic logic gate principles, this research employed the ADDIE development model. The findings indicate a statistically significant difference in the average psychomotor abilities between the experimental group and the control group. This result supports the acceptance of the alternative hypothesis (Ha accepted, while Ho is rejected), indicating that the digital electronics trainer is significantly effective in enhancing both the cognitive and psychomotor skills of students in analyzing the basic principles of logic gates.

Therefore, it can be concluded that the presented media were categorized as 'feasible and practical' for use as an instructional medium in teaching digital logic gate circuits to students in the Electronics Engineering program.

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