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Development of Interactive Learning Media Based on Deep Learning in the Course Programmable Logic Controller

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ABSTRACT

This study aims to develop web-based interactive learning media integrated with Deep Learning methods for the Programmable Logic Controller (PLC) course, with a focus on Omron PLC material. The development addresses key challenges in PLC learning, including limited access to practical equipment, the lack of interactive digital media, and the absence of intelligent adaptive learning systems. This study employs a Research and Development (R&D) approach by synthesizing the 4D, ADDIE, and Borg & Gall models into five stages: needs analysis, design, development, evaluation, and dissemination. The main novelty of this study lies in the implementation of a Deep Learning–driven adaptive learning mechanism embedded within a web-based PLC simulation environment, which goes beyond conventional web-based PLC learning systems that typically provide static content and rule-based feedback. Unlike existing approaches, the proposed system utilizes an Artificial Neural Network (ANN) model to analyze student interaction patterns, identify learning difficulties in ladder diagram logic, and generate personalized feedback and adaptive learning pathways in real time. The developed system integrates PLC learning materials, JavaScript-based ladder diagram simulations, and AI-driven adaptive assessment features. Validation results indicate a very high level of feasibility (99% for content and 97% for design). Practicality testing shows scores ranging from 81% to 91%, categorized as very feasible. The effectiveness test reveals a statistically significant improvement in student learning outcomes based on pretest–posttest analysis (p-value 0.000 < 0.05), indicating the system's effectiveness in enhancing conceptual understanding, ladder diagram skills, and learning motivation. This study contributes to the advancement of intelligent vocational learning systems by introducing an adaptive, data-driven PLC learning environment that bridges the gap between simulation-based learning and artificial intelligence–supported personalization. Therefore, the proposed media is considered highly feasible, practical, and effective for implementation in vocational education.

INTRODUCTION

The rapid development of information technology and industrial automation in the era of the Fourth Industrial Revolution has significantly transformed the demands of engineering education. The integration of automatic control systems has become a key component in modern industry (Haque & Jakaria, 2023). One of the core technologies is the Programmable Logic Controller (PLC), which is widely applied in manufacturing, energy, transportation, and smart systems (Silaban & Rizal, 2024). Therefore, mastery of PLC competencies is essential for engineering students, as it reflects their readiness to meet industry requirements (Widodo, 2020).

In vocational education, PLC learning is designed to equip students with both conceptual understanding and practical skills in control systems. One of the widely used platforms in industry is the Omron PLC, known for its flexibility and reliability (Suyono & Hariyanto, 2021). However, effective PLC learning requires not only theoretical

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knowledge but also strong logical reasoning, particularly in understanding and constructing ladder diagram logic as the core of PLC programming.

Despite its importance, several challenges remain in the implementation of PLC learning. At the macro level, PLC instruction demands interactive and practice-oriented learning environments. However, at the micro level, learning practices at Makassar State University indicate several limitations, including limited availability of practical tools, the dominance of lecture-based instruction, and the lack of interactive digital learning media. These findings are consistent with previous studies highlighting similar challenges in vocational education contexts (Nugroho, 2022; Pratama, 2023).

One critical issue identified is that ladder diagram logic is difficult to explain effectively without interactive and visual learning support. As a result, students often experience difficulties in understanding control logic and translating it into functional programs. Previous studies have shown that conventional lecture-based approaches are less effective for technical learning (Prasetyo, 2019), while interactive digital media and simulation tools can significantly improve understanding and engagement (Nugroho & Arifin, 2023; Widyastuti et al., 2023). However, most existing web-based PLC learning systems still rely on static content and lack adaptive features that can respond to individual learning needs (Silaban & Rizal, 2024).

Unlike conventional PLC simulation software such as CX-Programmer or rule-based web learning systems, the proposed media does not merely provide static simulations or predefined feedback pathways. Conventional systems generally function as programming and simulation tools without analyzing student learning behavior or adapting instructional support dynamically. In contrast, the developed system integrates an Artificial Neural Network (ANN)–based Deep Learning mechanism capable of identifying student response patterns, detecting common errors in ladder diagram construction, and generating adaptive feedback and personalized learning recommendations in real time. Therefore, the novelty of this study lies not only in the development of web-based PLC simulations, but also in the implementation of intelligent adaptive learning features that support individualized vocational learning experiences.

At the same time, advances in artificial intelligence, particularly Deep Learning, have opened new opportunities in educational technology. Deep Learning models are capable of analyzing user behavior, identifying learning patterns, and providing personalized feedback (Goodfellow et al., 2016). In addition, the application of AI in education enables adaptive learning systems that can adjust content based on student performance (Romero & Ventura, 2022). Recent studies also demonstrate that Deep Learning can improve technical learning outcomes and address limitations in practical learning environments (Bian & North, 2023).

However, there remains a clear research gap in the integration of Deep Learning into web-based PLC learning media, particularly in developing systems that not only provide interactive simulations but also deliver adaptive and intelligent feedback based on student performance. Most existing PLC learning platforms have not yet incorporated data-driven personalization mechanisms, limiting their effectiveness in supporting individualized learning.

To address this gap, this study proposes the development of web-based interactive learning media integrated with Deep Learning methods for PLC learning, specifically focusing on Omron PLC material. The proposed system combines ladder diagram simulations, interactive learning content, and an AI-based adaptive mechanism to

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enhance conceptual understanding and practical skills while supporting independent learning.

Therefore, this study aims to develop and evaluate web-based interactive learning media integrated with Deep Learning methods for the Programmable Logic Controller (PLC) course. The developed media is expected to improve students' understanding of ladder diagram logic, enhance learning engagement, and provide adaptive learning experiences through intelligent feedback.

In line with these objectives, the research questions are formulated as follows: (1) How is the process of developing web-based interactive learning media integrated with Deep Learning for PLC learning? (2) How feasible is the developed learning media based on expert validation in terms of content and design aspects? (3) How practical is the learning media based on user responses in individual, small group, and large group trials? (4) How effective is the learning media in improving students' learning outcomes in PLC courses?.

RESEARCH METHOD

Research and Development Model

This study employs a Research and Development (R&D) approach aimed at developing and evaluating web-based interactive learning media integrated with Deep Learning methods for the Programmable Logic Controller (PLC) course. The R&D approach is used to produce a functional educational product and to test its feasibility, practicality, and effectiveness in real learning contexts. The development procedure adopts a systematic and analytical approach by integrating the 4D, ADDIE, and Borg & Gall models, which are synthesized into five main stages: (1) needs analysis, (2) design, (3) development, (4) evaluation, and (5) dissemination and implementation. These stages are interconnected and iterative, ensuring continuous refinement of the product based on evaluation results.

In this study, the integration of the 4D, ADDIE, and Borg & Gall models was intended to combine the strengths of instructional design, product development, and iterative evaluation. The 4D model contributed to the systematic definition and development of learning materials, the ADDIE model supported the instructional design and implementation process, while the Borg & Gall model emphasized product validation and field testing. The synthesis of these models enabled the development process to become more flexible, iterative, and suitable for vocational technology-based learning media development.

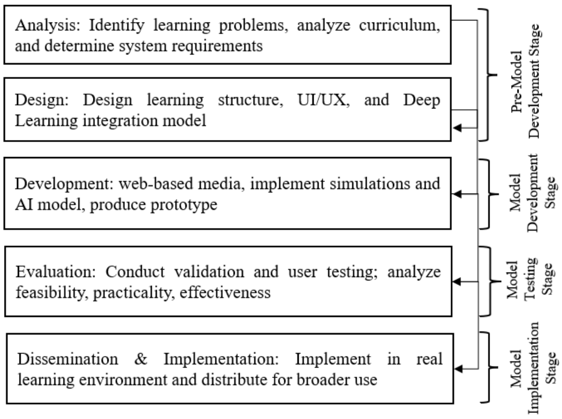

Figure 1. Systematic Development Procedure of Web-Based Interactive Learning Media Integrated with Deep Learning

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As illustrated in Figure 1, the development process follows a structured workflow from problem identification to real-world implementation. The figure provides a clear visual representation of the development procedure, enhancing transparency and supporting a more rigorous and systematic analysis of each stage. This combined model was chosen because it provides a systematic and iterative development process, so that the resulting product can be tested for feasibility, practicality, and effectiveness before being implemented more widely.

Development Procedure

Needs Analysis, This stage aims to systematically identify the fundamental problems in PLC learning. Data are collected through observations, interviews with lecturers, students, and laboratory assistants, as well as literature review. The analysis focuses on key issues, including the limited availability of practical tools, the lack of interactive learning media, and the absence of adaptive learning systems. The results of this stage are used to define system requirements and learning objectives.

The design stage translates the results of the needs analysis into a structured plan for the development of learning media. This includes the design of instructional materials, user interface (UI/UX), navigation flow, and system architecture. In addition, the conceptual design of the Deep Learning model is formulated to enable adaptive feedback based on student performance. This stage ensures alignment between pedagogical objectives and technological implementation.

Development, At this stage, the designed system is implemented into a functional web-based interactive learning media. The development process includes content creation, programming of ladder diagram simulations using JavaScript, and integration of the Deep Learning model. The output of this stage is a prototype of the learning media, which is then prepared for evaluation.

The evaluation stage is conducted to assess the quality of the developed media in terms of feasibility, practicality, and effectiveness. This stage includes expert validation (subject matter experts and media/design experts) as well as user trials consisting of individual testing, small group testing, and large group testing. Quantitative data are analyzed using percentage techniques, normalized gain (N-gain), and statistical tests (independent sample t-test), while qualitative data are analyzed descriptively. The evaluation results are used to refine the product, indicating an iterative development process.

The final stage involves the application and dissemination of the developed media in real learning environments. The media is implemented in PLC learning activities and disseminated through academic forums such as seminars and publications. This stage aims to evaluate the broader applicability and scalability of the product in vocational education contexts.

Data Source and Research Subjects

Trial Design a. Expert Validation Validation was carried out by: subject matter experts, media/design experts. Assessment used a Likert scale instrument covering aspects of content feasibility, presentation, relevance, and display quality. b. User Response After validation, students participated in: individual trials, small group trials, large group trials. This stage aims to assess the practicality and user experience aspects.

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Research Subjects The research subjects consisted of subject matter experts, media experts, and students from the Mechatronics and Electrical Engineering Vocational Study Program. Types of Data The data collected included: qualitative data: expert comments, user suggestions, evaluation notes; quantitative data: validation scores, practicality questionnaire results, pretest and posttest scores.

Data Collection and Analysis

Data were collected using multiple techniques to ensure the validity and reliability of the findings. Interviews were conducted during the needs analysis stage to identify learning problems. Questionnaires using a Likert scale were employed for expert validation and user trials to assess feasibility and practicality. Learning outcomes were measured using pretest and posttest instruments.

Quantitative data were analyzed using percentage analysis to determine feasibility and practicality levels. The effectiveness of the learning media was measured using normalized gain (N-gain) and hypothesis testing through an independent sample t-test, with a significance level of 0.05. Qualitative data from expert feedback and user responses were analyzed descriptively to support the interpretation of quantitative results. Pretest and Posttest Items were reviewed through expert judgment and categorized as: (a) accepted, (b) revision, (c) major revision, (d) not acceptable.

Table 1. Research Design

Group	*Pre-test*	Treatment	*Pos-test*
E	T_1	X	T_2
K	T_1	-	T_2

Source: Sugiyono, 2010

Data Analysis Techniques

1) Qualitative Analysis Qualitative data is reduced, categorized, and summarized descriptively.
2) Quantitative Analysis The percentage of assessment is calculated using the formula:

$$P = \frac{X}{X_1} \times 100$$

Tabel 2. Feasibility Criteria

Category	Qualifications	Criteria
A	80-100 %	Very suitable
B	60-79 %	Suitable
C	50-59 %	Fairly suitable
D	0-49 %	Less suitable

Source: Mulatiningsih, 2014

3) Practicality Analysis Using the same percentage categories as the feasibility assessment.
4) Effectiveness Analysis Effectiveness is measured using normalized gain (N-gain):

$$< g >= \frac{Skor\ posttest - Skorpretest}{Skor\ maksimum - Skor\ pretest}$$

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Table 3. Feasibility Criteria

Gain Index	Interpretation
g > 0.70	Height
0.30 ≤ g ≤0.70	Medium
g < 0.30	Low

Source : Meltzer dalam Archambault, 2008

Prerequisite Tests Normality test: Lilliefors Homogeneity test: F test or Levene. Hypothesis test: independent sample t-test (Sig < 0.05 indicates a significant difference). Impact Analysis The analysis was conducted to examine: increased understanding of concepts, independent learning, student engagement, and readiness to face the competencies of Industry 4.0 automation.

RESULTS AND DISCUSSION

Results

This research produced web-based interactive learning media with integrated Deep Learning methods for Omron's Programmable Logic Controller (PLC) course. The media was developed to support theoretical and practical learning, particularly in ladder diagrams, motor control, timers, and counters. The media was developed using a synthesis of the 4D, ADDIE, and Borg & Gall models, which were simplified into five main stages, namely needs analysis, design, development, evaluation, and dissemination and implementation. The results of the needs analysis showed that PLC learning is still dominated by conventional methods, limited practical tools, and the unavailability of interactive and adaptive AI-based digital media.

The learning media was designed in the form of a responsive web application containing interactive material, ladder diagram simulations, adaptive exercises based on Artificial Neural Networks (ANN), and a chatbot to support PLC learning. During the development stage, the media was validated by subject matter experts and design experts. The validation results showed a very high level of feasibility, with an average validation percentage of 99% for subject matter experts and 97% for design experts, indicating that the media is highly valid in terms of content, presentation, language, appearance, and ease of use.

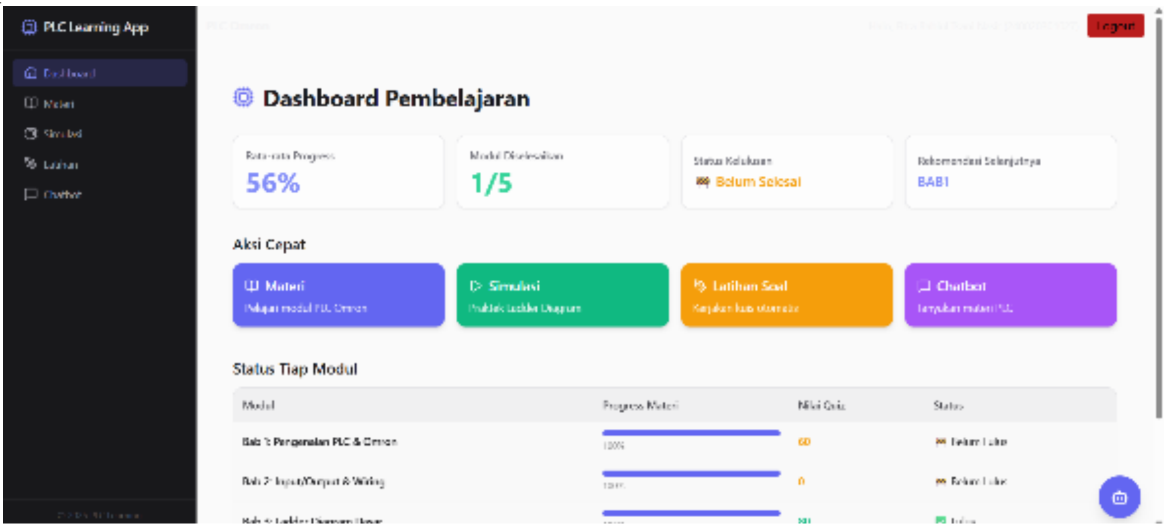

Figure 2. Media Display

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Practicality tests were conducted through individual trials, small groups, and large groups. The practicality test results showed scores of 81%, 81%, and 91%, respectively, which were in the very feasible category. These findings indicate that the media is easy to use, has clear navigation, supports independent learning, and is able to increase student engagement in PLC learning.

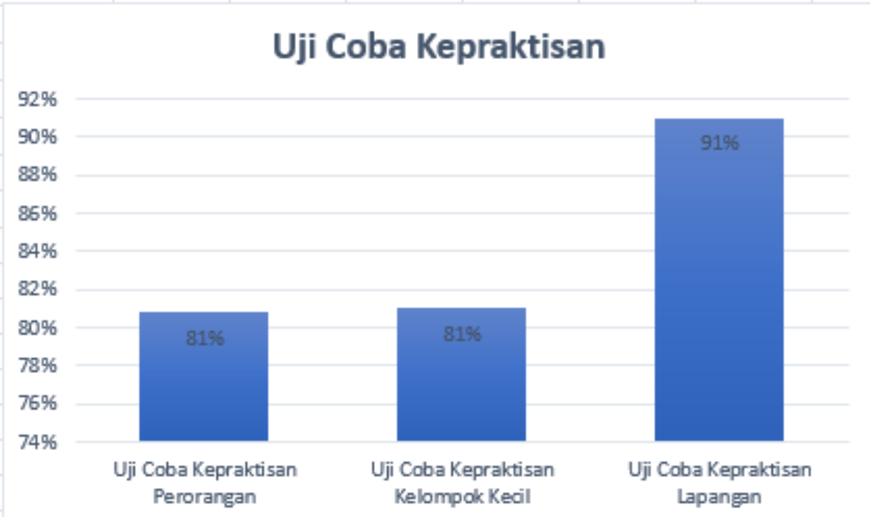

Figure 3. Percentage of Practicality Test Results

The effectiveness test was conducted through student response questionnaires and learning outcome analysis using pre-tests and post-tests. The questionnaire results showed an effectiveness level of 79% in individual tests, 81% in small groups, and 84% in large groups.

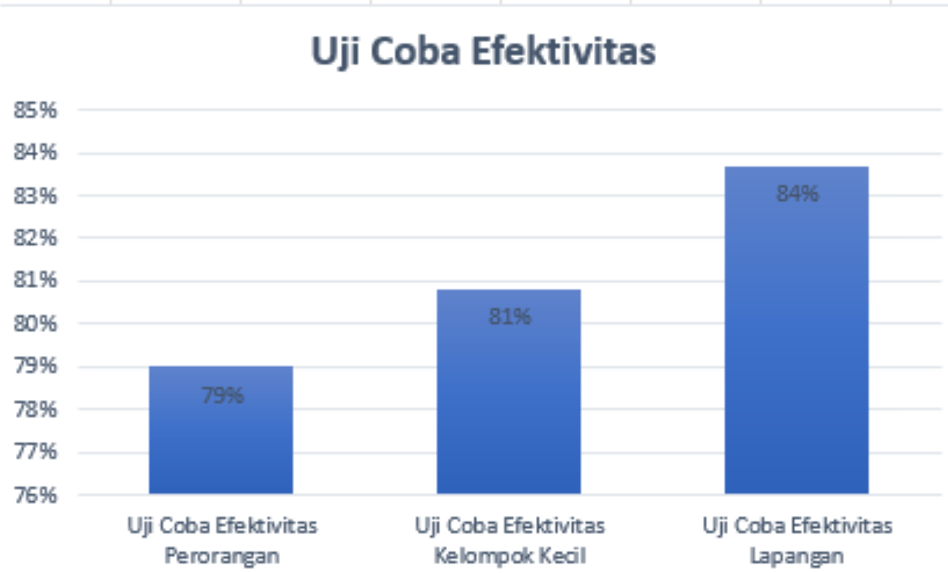

Figure 4. Percentage of Effectiveness Test Results

To obtain data on learning improvement, students were given a pretest as initial data and a posttest as final data. There were 15 students in the experimental class, while the control class consisted of 15 students from the Electrical Engineering and Mechatronics Vocational Education Study Program who participated in learning without using interactive media. The results of the pretest and posttest for these two groups formed the basis of analysis to measure the effectiveness of Omron PLC learning media.

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Table 4. pretest and posttest data

Nu	Experimental Classes			Control Class		
	Pre-test	Post-test	Gain Skor	Pre-test	Post-test	Gain Skor
1	70	70	0	40	30	-0.17
2	90	100	1	50	30	-0.4
3	60	100	1	40	70	0.5
4	80	90	0.5	60	30	-0.75
5	60	70	0.25	40	50	0.17
6	40	70	0.5	70	70	0
7	50	70	0.4	30	20	-0.14
8	60	90	0.75	30	20	-0.14
9	30	40	0.14	80	70	-0.5
10	70	90	0.67	50	40	-0.2
11	60	90	0.75	60	50	-0.25
12	90	100	1	50	50	0
13	60	70	0.25	40	40	0
14	40	70	0.5	30	30	0
15	30	60	0.43	50	40	-0.2

To provide a clearer interpretation of the results presented in Table 4, it is important to explain the instructional conditions experienced by the control group. The control group did not receive adaptive or simulation-based learning support; instead, learning was conducted using conventional lecture-based instruction and printed modules. Although students still received explanations from the lecturer, the learning process lacked interactive visualization and immediate feedback mechanisms that are essential for understanding ladder diagram logic.

The decline in several post-test scores observed in the control group may be associated with the increasing complexity of the post-test items, which were designed to evaluate higher-order cognitive skills such as logic analysis, troubleshooting, and ladder diagram interpretation. Without interactive simulations and adaptive feedback, some students experienced difficulties in retaining and applying PLC concepts consistently during the post-test session.

In addition, conventional instruction tends to rely heavily on passive learning activities, limiting opportunities for repeated practice and self-correction. This condition may contribute to inconsistencies in student performance and explain the decrease in several scores. Since both groups were assessed using the same instruments and testing procedures, the differences in learning outcomes can reasonably be attributed to the enhanced instructional support provided by the AI-integrated interactive learning media rather than to testing bias.

Table 5. Independent Sample T-Test Results

		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
Hasil Belajar	Equal variances assumed	.048	.827	5.738	28	.000	36.000	6.274
	Equal variances not assumed			5.738	27.997	.000	36.000	6.274

In addition, the results of the independent sample t-test showed a significance value of 0.000 < 0.05, indicating a significant increase in learning outcomes in the experimental class compared to the control class. Thus, web-based interactive learning media with

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Deep Learning integration is declared valid, practical, and effective for use in Omron PLC learning in vocational education.

Discussion

The development of web-based interactive learning media for Omron PLC material was carried out through a systematic integration of the 4D, ADDIE, and Borg & Gall models, which were synthesized into five main stages: needs analysis, design, development, evaluation, and dissemination and implementation. The needs analysis identified key challenges, including limited access to practical equipment, the dominance of conventional instructional media, and the need for more interactive and flexible learning environments. Addressing these issues, the developed system integrates PLC learning materials, ladder diagram simulations, practice exercises, chatbot assistance, and Deep Learning–based recommendation features. This structured development process supports previous findings that systematic instructional design contributes to the development of high-quality vocational learning media (Putri et al., 2019; Fikri & Edidas, 2023; Al-Qahtani & Higgins, 2022).

Although previous studies by Al-Qahtani and Higgins (2022) and Lee and Kim (2021) emphasized the importance of instructional design and web-based learning environments, their systems primarily focused on content delivery and usability aspects without incorporating intelligent adaptive learning mechanisms. In contrast, the present study integrates an Artificial Neural Network (ANN)–based adaptive feedback system capable of analyzing student response patterns and providing personalized recommendations in real time. Therefore, the unique contribution of this study lies in combining interactive PLC simulation with AI-driven adaptive learning support specifically designed for vocational technical education.

The high feasibility results obtained from expert validation (99% for content and 97% for design) indicate that the developed media meets established standards in terms of instructional quality, interface design, and usability. These findings are consistent with previous studies suggesting that well-structured content, clear navigation, and consistent visual design are key determinants of effective interactive learning media (Fikri & Edidas, 2023; Agarwal & Kaushik, 2022). However, beyond confirming feasibility, these results also suggest that the integration of multiple features within a single platform can enhance the overall coherence and usability of the learning system.

In terms of practicality, the increasing scores from individual to large group trials (81% to 91%) indicate that students were able to progressively adapt to and effectively utilize the learning media. This trend reflects not only the usability of the system but also the role of interactive features in supporting independent and self-paced learning. These findings align with previous research indicating that web-based learning environments improve accessibility, flexibility, and learner engagement (Ferdiansyah, 2022; Lee & Kim, 2021).

The effectiveness results demonstrate a significant improvement in student learning outcomes, as indicated by the questionnaire results and the paired sample t-test (p-value $0.000 < 0.05$). Improvements were observed in conceptual understanding, ladder diagram construction, and control logic analysis. These findings are consistent with prior studies highlighting the effectiveness of interactive simulations in enhancing technical learning (Jakfar et al., 2022; Liu et al., 2022).

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To further analyze these results, it is important to examine the contribution of Deep Learning integration within the developed system. Unlike conventional web-based learning media that rely on static content or rule-based branching logic, the Artificial Neural Network (ANN) in this study enables the system to analyze student response patterns and identify common errors in ladder diagram logic. Based on this analysis, the system provides adaptive feedback in the form of targeted recommendations, such as revisiting specific materials or attempting additional exercises.

Observations during implementation indicate that students actively engaged with these adaptive features by revisiting recommended materials and repeating exercises, resulting in a more iterative learning process. This interaction suggests that the adaptive mechanism contributes to improved learning outcomes by providing personalized support that is not available in non-adaptive systems. Therefore, the effectiveness of the developed media is not solely attributed to the use of digital simulations, but also to the presence of AI-driven adaptive feedback that supports individualized learning pathways.

However, it should be noted that the ANN model used in this study is relatively simple, and its capability to model complex learning behaviors is still limited. As a result, the accuracy of the recommendations is primarily based on observable response patterns rather than deeper cognitive modeling. Despite this limitation, the findings indicate that even a basic implementation of Deep Learning can provide meaningful support in enhancing student learning experiences.

Overall, this discussion confirms that the developed web-based interactive learning media, integrated with Deep Learning, not only meets the criteria of feasibility, practicality, and effectiveness but also demonstrates the added value of adaptive learning mechanisms in supporting vocational education, particularly in PLC learning contexts.

CONCLUSION

Fundamental Finding

This study successfully developed web-based interactive learning media integrated with a Deep Learning approach for the Programmable Logic Controller (PLC) course, particularly for Omron PLC material. The developed media was proven to be feasible, practical, and effective based on expert validation, user responses, and statistical analysis of learning outcomes. The integration of ladder diagram simulations, interactive exercises, and ANN-based adaptive feedback significantly improved students' conceptual understanding, programming logic skills, and learning engagement.

Implication

The findings indicate that AI-integrated web-based learning media can support adaptive and personalized learning experiences in vocational education. The developed system provides an alternative solution to overcome the limitations of physical PLC laboratory equipment while promoting independent learning and flexible access to instructional resources. Furthermore, the integration of Deep Learning mechanisms demonstrates the potential of intelligent educational systems to enhance technical learning effectiveness in Industry 4.0 contexts.

Limitation

This study has several limitations. First, the Artificial Neural Network (ANN) model implemented in the system is relatively simple and limited in modeling complex

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cognitive learning behaviors. Second, the developed media focuses only on Omron PLC material, which may limit its applicability to other PLC platforms. Third, the research involved a relatively limited sample size within a specific educational context, which may affect the generalizability of the findings.

Future Research

Future research is recommended to implement more advanced Deep Learning models and expand the developed system to other industrial PLC platforms, such as Siemens S7, Mitsubishi FX Series, Allen-Bradley ControlLogix, and Schneider Electric PLC systems, in order to improve interoperability and industrial relevance. In addition, future studies should involve larger and more diverse samples to strengthen the generalizability of the findings. Further integration with emerging technologies such as the Internet of Things (IoT), virtual laboratories, and augmented reality may also enhance the scalability and effectiveness of PLC learning in vocational education.

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