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ORIGINAL

Integrating AI-Based Natural Language Processing in Vocational Education: Usability, Learning Gains, and Student Engagement in Indonesia

Integración del Procesamiento de Lenguaje Natural Basado en Inteligencia Artificial en la Educación Vocacional: Usabilidad, Aprendizajes y Participación Estudiantil en Indonesia

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ABSTRACT

Introduction: the advancement of Artificial Intelligence (AI) has brought substantial changes to education, particularly through AI-based digital assistants.
Objective: this study developed and evaluated an AI-powered digital assistant equipped with Natural Language Processing (NLP) capabilities, specifically designed for Indonesian vocational schools.
Method: adopting the 4D development model (Define, Design, Develop, Disseminate), the system was created using machine learning algorithms and NLP to enhance interactivity and personalization. The assistant enables natural language interaction, provides real-time feedback, and adapts learning material difficulty to students' comprehension levels. The system was tested with 100 vocational school students, with usability assessed using the System Usability Scale (SUS) and learning gains measured through pre- and post-tests.
Results: results showed a SUS score of 71,05, indicating good usability, and a significant improvement in post-test scores compared to pre-test scores ($p < 0,001$), reflecting enhanced conceptual understanding, engagement, and motivation.
Conclusions: these findings demonstrate the potential of AI-powered NLP assistants to enrich vocational education and prepare students for technology-driven industrial demands.

Keywords: Artificial Intelligence; Natural Language Processing; 4D Development Model; Digital Assistant; Vocational Education.

RESUMEN

Introducción: el avance de la Inteligencia Artificial (IA) ha traído cambios sustanciales a la educación, particularmente a través de los asistentes digitales basados en IA.
Objetivo: este estudio desarrolló y evaluó un asistente digital impulsado por IA, equipado con capacidades de Procesamiento de Lenguaje Natural (PLN), específicamente diseñado para escuelas vocacionales en Indonesia.
Método: adoptando el modelo de desarrollo 4D (Definir, Diseñar, Desarrollar, Difundir), el sistema fue creado utilizando algoritmos de aprendizaje automático y PLN para mejorar la interactividad y la personalización. El asistente permite la interacción en lenguaje natural, proporciona retroalimentación en tiempo real y adapta la dificultad del material de aprendizaje al nivel de comprensión de los estudiantes. El sistema fue probado

con 100 estudiantes de escuelas vocacionales, evaluando la usabilidad mediante la Escala de Usabilidad del Sistema (SUS) y midiendo el aprendizaje a través de pruebas antes y después de la intervención.
Resultados: los resultados mostraron una puntuación SUS de 71,05, lo que indica una buena usabilidad, y una mejora significativa en las calificaciones de las pruebas posteriores en comparación con las pruebas iniciales ($p < 0,001$), reflejando una mayor comprensión conceptual, compromiso y motivación.
Conclusiones: estos hallazgos demuestran el potencial de los asistentes de IA con PLN para enriquecer la educación vocacional y preparar a los estudiantes para las demandas industriales impulsadas por la tecnología.

Palabras clave: Inteligencia Artificial; Procesamiento de Lenguaje Natural; Modelo de Desarrollo 4D; Asistente Digital; Educación Vocacional.

INTRODUCTION

Artificial Intelligence (AI) has emerged as a transformative force across multiple sectors, including education. Among the most rapidly advancing innovations is the development of AI-powered digital assistants with Natural Language Processing (NLP) capabilities, hereafter referred to as AI-NLP assistants. NLP enables systems to understand, interpret, and generate human language in a natural manner, thereby facilitating the creation of interactive, adaptive, and student-centered learning tools.[1,2] In educational contexts, such systems hold considerable promise for enhancing instructional delivery, personalizing learning pathways, and fostering active learner engagement.[3]

In the context of vocational high schools in Indonesia, the potential impact of AI-NLP assistants is particularly significant. Indonesian vocational students are required to master technical and mechanical skills—such as robotic design, microcontroller programming, and automated control systems—that demand both theoretical understanding and extensive practical application.[4] However, the vocational education system in Indonesia continues to face persistent challenges, including limited teacher availability, insufficient personalization of learning materials, and difficulties students encounter when grappling with complex, abstract, or technical concepts.[5] These barriers are further compounded by resource-constrained environments, such as uneven access to digital infrastructure, connectivity issues, and disparities in school facilities across regions. Such contextual factors not only affect the pace and quality of learning but also underscore the urgent need for innovative, scalable solutions tailored to Indonesia's vocational education system.

AI-NLP assistants offer an innovative pathway to address these challenges by adapting instructional content to individual learners' comprehension levels, providing real-time feedback on programming and design tasks, and facilitating interactive simulations. Such features can accelerate skill acquisition, foster learner autonomy, and encourage creativity and independent problem-solving—qualities essential for success in programming-intensive domains where iterative practice is critical.[6]

Despite their potential, the integration of AI-NLP assistants into vocational high schools remains underexplored. Previous research has widely examined the use of artificial intelligence (AI) in general education contexts, particularly for adaptive feedback, automated assessment, and content personalization.[7] However, relatively few studies have focused on vocational curricula, where learning involves a complex interplay of cognitive, psychomotor, and creative skills, making the integration of AI potentially more challenging and distinctive. Moreover, the development of effective AI-based learning tools requires large, domain-specific datasets to ensure accuracy, contextual relevance, and cultural appropriateness. Additional challenges include the need for teacher training in integrating AI tools into instructional practice, safeguarding student data privacy, and ensuring that such technologies complement rather than replace the human elements of teaching.[8]

The present study addresses these gaps by developing an AI-NLP assistant specifically tailored for vocational high school contexts, employing the 4D instructional design model (Define, Design, Develop, Disseminate). The system is designed to support student learning in robotics, programming, and control systems through pedagogically sound, technologically robust, and contextually relevant features. Theoretically, this work contributes to adaptive learning and constructivist frameworks by operationalizing NLP-driven personalization in skill-based education. Practically, it offers a scalable solution to enhance instructional quality and student engagement in environments with limited access to specialized educators. Accordingly, the general objective of this study is to design, implement, and evaluate an AI-NLP assistant for Indonesian vocational education, with a focus on examining its usability, learning gains, and impact on student engagement.

Literature Review

AI technologies have increasingly created pathways for interactive, adaptive, and student-centered pedagogy. Among these, Natural Language Processing (NLP) is particularly significant for enabling language-based interaction between learners and instructional systems. Through NLP, digital assistants can analyze

student queries, generate context-aware responses, and deliver tailored learning experiences.[9,10,11] In general education, such systems have been applied to provide adaptive feedback, automate assessments, and personalize instructional pathways, thereby reducing cognitive load and supporting learner autonomy.[12,13,14]

In vocational education, however, the integration of AI remains limited despite its potential relevance. Vocational students are required to master both conceptual and hands-on technical competencies, such as robotics, microcontroller programming, and automated control systems, which demand extensive workshop practice and iterative problem-solving. While prior research on AI in education has demonstrated benefits for cognitive learning, little is known about its role in supporting psychomotor and creative skill development in laboratory or workshop settings. For example, only a small number of studies have examined how intelligent systems can analyze student programming projects, detect mechanical or coding errors, and provide targeted feedback in real time. This lack of domain-specific evidence highlights a gap between what is known in general education and what is required for vocational contexts, where practice-based and applied learning are central.

At the same time, critical challenges hinder the effective adoption of AI-powered learning assistants in vocational settings. One such challenge is the availability of robust, domain-specific datasets. In Indonesia, for instance, NLP-driven systems often rely on English-dominated or non-contextual datasets, which can lead to algorithmic bias and produce feedback misaligned with local technical practices or culturally diverse solutions.[15] Beyond bias, interpretability is also a pressing issue: teachers and students may struggle to understand why an AI assistant provides a particular recommendation, which risks eroding trust and limiting pedagogical integration. Ethical concerns such as safeguarding student data privacy and ensuring equitable access further complicate implementation, especially in resource-constrained schools.[16]

As emphasized by prior research, technological advancement alone is insufficient; successful integration requires alignment with pedagogical principles and policy frameworks that embed ethical safeguards and usability in practice.[17] Within this context, there remains a scarcity of empirical research on NLP-powered assistants specifically designed for vocational education. In particular, little is known about their usability, pedagogical effectiveness, and capacity to enhance both conceptual understanding and technical proficiency in programming-intensive and workshop-based domains. This gap justifies the need for empirical studies tailored to vocational education in Indonesia, where AI-NLP assistants could address challenges of personalization, feedback, and engagement in resource-limited environments while preparing students for technology-driven industrial demands.

Accordingly, this research is guided by the following questions:

- RQ1: How can an AI-NLP assistant be designed using the 4D model to support vocational high school learning?
- RQ2: What are the effects of this AI-NLP assistant on students' comprehension, engagement, and skill development in vocational subjects?
- RQ3: How do students and teachers perceive the usability and effectiveness of the developed assistant?

By addressing these questions, this study aims to advance both scholarly understanding and practical applications of AI in vocational high schools. The findings are expected to inform the design of future AI-NLP educational tools, ensuring they are pedagogically aligned, ethically responsible, and tailored to the specific needs of vocational learners.

METHOD

Research Design

This study employed a Research and Development (R&D) approach using the 4D instructional design model (Define, Design, Develop, Disseminate).[18] The 4D model was selected for its systematic process of iterative refinement, which is particularly suited for developing and evaluating technology-based educational tools.[19]

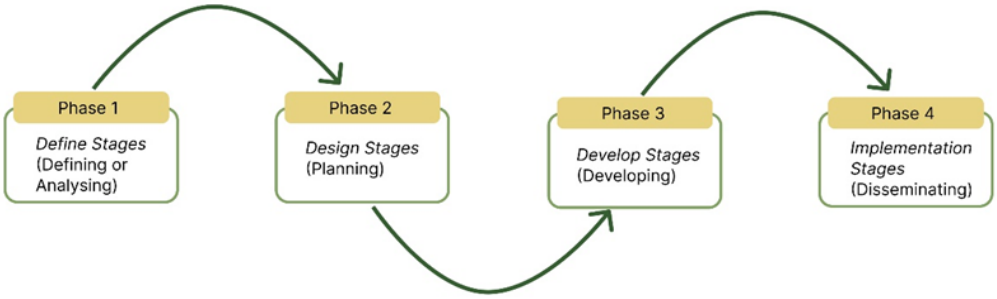

Figure 1. 4D Model

Sampling and Participants

A convenience sample of 100 vocational high school students was recruited from programming and automation courses. Inclusion criteria included active enrollment in robotics, microcontroller programming, or automation classes and voluntary consent to participate. Demographic data (age, gender, prior experience with digital tools) were collected to identify potential confounding factors. Additionally, fifteen vocational teachers with at least five years of teaching experience participated in classroom implementation after receiving standardized training on the AI-NLP system. The reliance on a convenience sample is recognized as a limitation of this study, potentially reducing the generalizability of findings.

System Development

The AI-NLP digital assistant was developed as a web-based application following the 4D stages:

- Define: Learning needs were identified through classroom observations (five sessions per class), semi-structured interviews with 15 teachers and 30 students, and curriculum analysis.
- Design: Dialogue structures and system workflows were modeled using UML diagrams. A curriculum-aligned knowledge base was created covering programming, robotics, and automation topics. Wireframes were designed to ensure a user-friendly interface.
- Develop: The system was implemented using Python (Flask framework) for the backend and ReactJS for the frontend. NLP functionality was based on spaCy and NLTK for text preprocessing (tokenization, lemmatization), while sentence-transformers (BERT embeddings) were used for semantic similarity. Curriculum content was indexed using FAISS for efficient query matching. Responses were generated through a retrieval-based approach combined with template-based feedback. System validation included white-box testing, debugging, and simulation of frequently asked questions.
- Disseminate: The prototype was piloted in two vocational classes (100 students) under the guidance of trained teachers. Feedback from teachers and students was collected to refine usability and pedagogical integration.

The system processes natural-language input through tokenization and embedding, matches it with the curriculum database, and generates contextual responses. It also adapts feedback complexity to student levels and includes FAQ modules to address common queries. The final output is delivered via an intuitive user interface in figure 2, providing real-time support and enhancing problem-solving in vocational subjects.

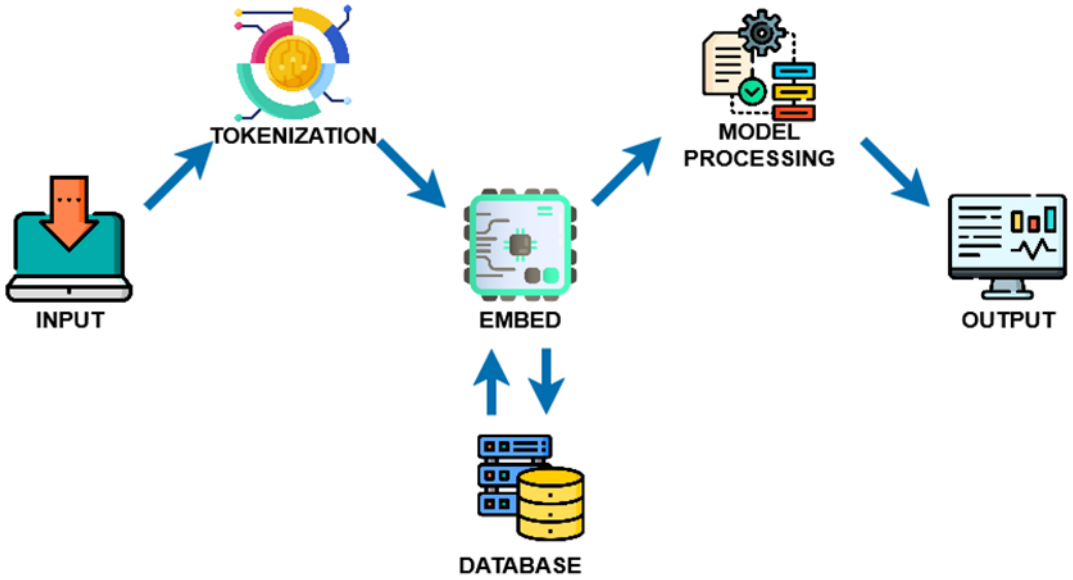

Figure 2. Digital Assistant for Vocational School

Data Collection Instruments

- Learning Outcomes: Pre-test and post-test assessments (theoretical + practical) were designed in alignment with the vocational curriculum to measure programming, control systems, and robotics competencies.
- System Usability: Measured using the System Usability Scale (SUS), a validated ten-item instrument.
- Student Engagement: Measured with a five-item questionnaire adapted from Schaufeli et al.'s Student Engagement Scale, with content validated by three vocational education experts and internal

consistency confirmed (Cronbach's α > 0,80).

- Perceived Response Clarity & Usefulness: Evaluated using a five-item instrument developed for this study, focusing on clarity, relevance, and usefulness of system feedback. Content validity was established through expert review, and pilot testing confirmed reliability (Cronbach's α > 0,78).
- Qualitative Feedback: Open-ended survey items and teacher reflection notes were collected to capture perceptions, challenges, and suggestions.

Data Analysis

Data analysis followed three steps:

- Learning Outcomes (RQ2): Pre- and post-test scores were compared using paired-sample t-tests to assess learning gains.
- Relationships among Variables (RQ2): Pearson correlation analyses examined associations between learning outcomes, engagement, perceived clarity, and usability.
- Student Perceptions (RQ3): Questionnaire data were analyzed using descriptive statistics (mean, SD, percentages). Open-ended responses were thematically analyzed to identify patterns in student and teacher perceptions of system usefulness and challenges.

RESULTS

The result of this study is the development and implementation of a digital assistant based on NLP, specifically designed to support learning at vocational school. This assistant aims to help students comprehend complex concepts in the field of programming, including design, programming code, control systems, and automation.

System Implementation

The developed model has been realized in the form of a web-based digital assistant application, equipped with integrated NLP technology and machine learning algorithms. In figure 2 The model developed in this study is an AI-based digital assistant system specifically designed to support the learning process at vocational school. The system integrates NLP technology to interpret student queries or commands expressed in natural language (Input Tokenization). Following tokenization, the data undergoes an embedding process, in which vector representations of the input text are generated and matched against a customized vocational school curriculum database (Embed Database).

Advanced Data Analysis

The correlation results in table 1 show consistently strong and positive relationships among system usefulness, engagement, perceived benefits, and learning outcomes (r = 0,80–0,92). This suggests that students who perceive the digital assistant as useful are generally more engaged, report higher perceived benefits, and achieve better academic results.

Table 1. Pearson Correlation Between Variables

Variable	Usefulness	Engagement	Perceived Usefulness	Learning Outcomes
Usefulness	1,00	0,85	0,88	0,80
Engagement	0,85	1,00	0,92	0,89
Perceived Usefulness	0,88	0,92	1,00	0,91
Learning Outcomes	0,80	0,89	0,91	1,00

However, the SEM analysis in figure 3 reveals a more nuanced pattern. While usefulness is positively associated with perceived benefits and learning outcomes, its direct effect on engagement is negative (path coefficient = –0,38). This indicates that when students perceive the system as highly useful, they may rely on it excessively, which could reduce their active participation in learning activities. In other words, the assistant supports comprehension and outcomes, but may unintentionally foster passivity if students overdepend on automated guidance.

On the other hand, system usefulness has a positive effect on the clarity and perceived usefulness of the system's responses (Y), with a coefficient of 0,18, suggesting that a system perceived as easy to use is also regarded as providing clear and beneficial responses. Meanwhile, student engagement (X) has a minimal effect on the perception of response clarity (Y), with a path coefficient of only 0,02. This implies that even when students are actively engaged, it does not necessarily enhance their perception of the system's response clarity. Furthermore, learning outcomes (Z) exhibit slightly negative relationships with all three other variables—system usefulness (W), student engagement (X), and response clarity (Y) with path coefficients of -0,14, -0,06, and -0,02, respectively. These results suggest that students' perceptions of learning outcomes do not significantly

influence how they evaluate the system's features.

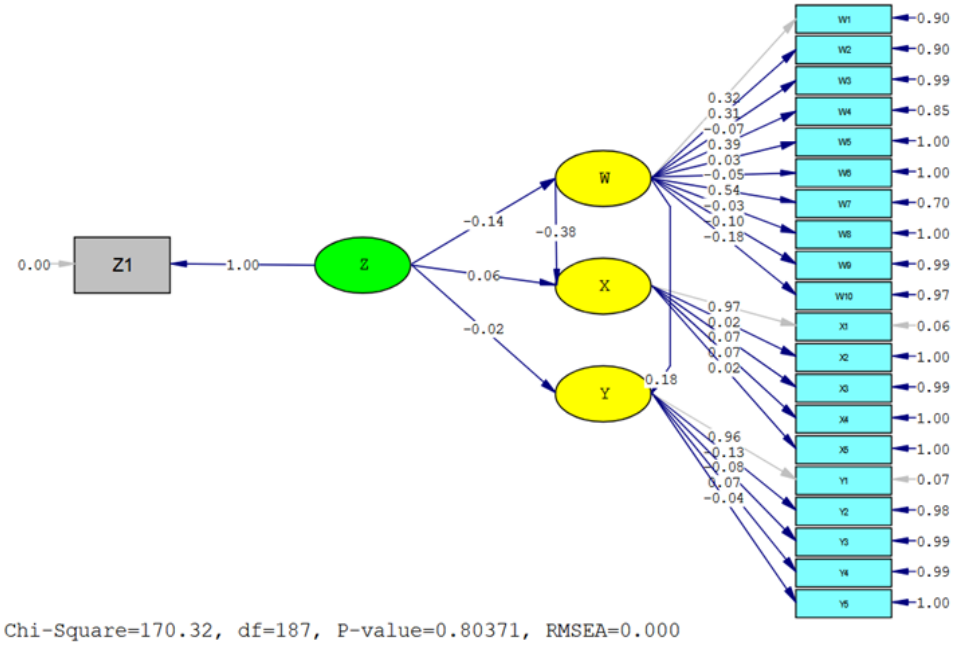

Figure 3. Path Diagram of the Structural Equation Model Evaluating the Impact of System Usability on Learning Outcomes through Student Engagement and System Response Clarity

Overall, the model demonstrates excellent fit, as evidenced by the Chi-Square value (x^2 = 170,32, df = 187), yielding a x^2/df ratio of 0,91. This value is below the commonly accepted threshold of 2,0, indicating a good model fit. Additionally, the p-value (P = 0,80371) exceeds 0,05, suggesting that the model does not significantly differ from the observed data, thereby supporting its validity. The RMSEA value of 0,000 further confirms the model's near-perfect approximation, reflecting an exceptionally low error level.

To evaluate the effectiveness and usability of the developed digital assistant, a field trial was conducted involving 100 students from vocational school. This evaluation utilized real user data and encompassed four main components.

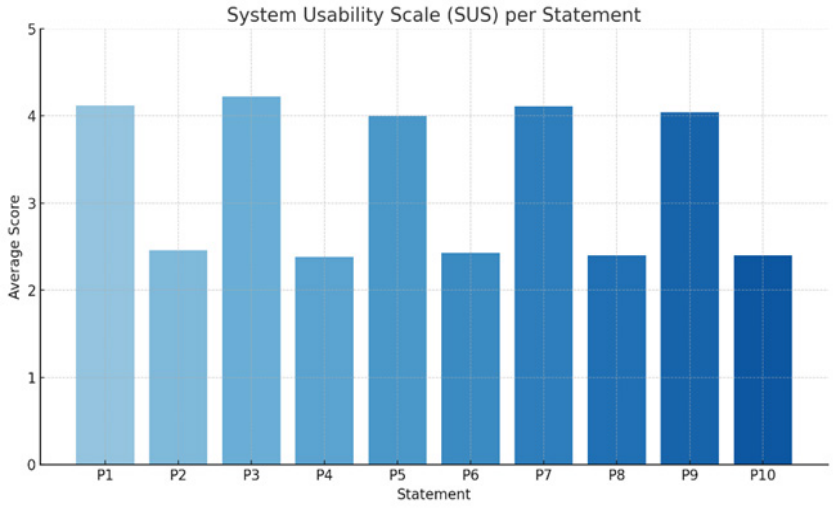

Figure 4. System Usability Scale

The evaluation was conducted using 10 statements assessed on a 5-point Likert scale. Each statement was rated by users, and the average scores are presented in figure 4. Referring to the figure, the majority of statements (e.g., P1, P3, P5, P7, and P9) received average scores above 4, reflecting a positive user response toward the system. Meanwhile, several other statements (e.g., P2, P4, P6, P8, and P10) received relatively lower scores, though still within an acceptable range. Based on the overall data, the System Usability Scale (SUS) score achieved was 71,05, indicating that the system is considered easy to use and has been well accepted

by users, as it surpasses the standard threshold of 68.

Table 2. Student Engagement with the Digital Assistant

No	Statement	Questionnaire Results (Score)					Total	Item Score
		1	2	3	4	5		
1	My motivation increased when using the digital assistant.	1	4	20	35	40	100	410
2	I felt more active in following the learning material.	2	5	23	40	30	100	400
3	I became more confident in completing robotics assignments.	1	3	20	35	41	100	420
4	The system helped me understand the material more easily.	0	2	18	35	45	100	430
5	I want to continue using this system in my learning process.	1	4	20	36	39	100	410
	Total							414

Student engagement was assessed using five questionnaire items as illustrated in table 2. The results show consistently high scores across all items, with total item scores ranging from 400 to 430. The highest score was observed for the item "The system helped me understand the material more easily" (430), while the lowest was for "I felt more active in following the learning material" (400). The overall average engagement score was 414, indicating that students generally reported high levels of motivation, confidence, and willingness to continue using the system.

Table 3. Clarity and Usefulness of System Responses

No	Statement	Questionnaire Results (Score)					Total	Item Score
		1	2	3	4	5		
1	The digital assistant's answers are clear and easy to understand.	0	2	20	35	43	100	422
2	The system provides accurate and relevant answers.	0	2	18	34	46	100	430
3	The system's answers help me complete robotics assignments.	1	3	21	35	40	100	415
4	The system is capable of answering various questions well.	2	5	22	40	31	100	400
5	I feel assisted by the presence of this system in my learning.	0	3	19	34	44	100	423
	Total							418

The evaluation was conducted using five statements aimed at measuring students' perceptions of the clarity, relevance, and usefulness of the system's responses. As illustrated in table 3, all statements received consistently high total scores. The overall average score reached 418, which falls into the "very satisfactory" category. These results indicate that the system is capable of providing clear, relevant, and helpful responses that assist students in understanding the material and completing tasks, particularly in the context of technology-enhanced learning.

Table 4. Learning Outcomes

Type of Test	Maximum Score	Average Score	Standard Deviation	Median	Min	Max
Pre-Test	100	56,7	12,4	57	30	80
Post-Test	100	78,9	10,2	79	55	95

The learning module demonstrated a significant improvement in student learning outcomes, as shown in table 4. The average pre-test score was 56,7, while the average post-test score increased to 78,9. The median score also rose from 57 to 78,9, and the standard deviation decreased from 12,4 to 10,2, indicating a more consistent distribution of scores following the learning intervention. Learning outcomes increased significantly,

with the average post-test score reaching 78,9 compared to the pre-test score of 56,7 ($p < 0,001$).

DISCUSSION

The findings of this study demonstrate the potential of an NLP-based digital assistant to support vocational learning by promoting interactivity, personalization, and adaptive feedback. Previous studies have highlighted similar benefits of AI integration in education, particularly in providing automated assessment, scaffolding, and tailored feedback.[20] In line with these works, the current research shows that such systems can foster higher motivation and confidence among students in technical fields such as programming, robotics, and automation. Teachers also valued the system for its role in supporting individualized learning and reducing instructional load, which aligns with findings.[21] that AI-based tools can enhance teachers' capacity for differentiation.

An important contribution of this study lies in the discovery of an unexpected relationship: while system usefulness was generally rated positively, Structural Equation Modeling revealed a negative path coefficient (-0,38) between perceived usefulness and student engagement. This suggests that when students view the system as highly convenient and reliable, they may become passive, relying on it excessively instead of engaging actively with the material. A similar concern was raised, who cautioned that AI in education should be designed to stimulate active learning rather than replace learners' cognitive effort. Our interpretation is that the system's efficiency must be carefully balanced with pedagogical strategies that encourage inquiry, collaboration, and critical thinking.

Another aspect worth noting is that students' subjective perceptions of usefulness and clarity did not always align with actual learning outcomes. While this mismatch has been reported in earlier studies.[22] it underscores the importance of triangulating self-reported data with objective performance measures when evaluating AI-based interventions in education. From the authors' perspective, these findings emphasize the dual role of AI-based assistants in vocational education: on one hand, they can enhance efficiency, personalization, and motivation; on the other, they risk encouraging passivity if not embedded in a carefully designed instructional framework. We argue that technology should serve as a facilitator of active and experiential learning, not as a substitute for student engagement. Future development should therefore focus on integrating features that promote problem-solving, peer collaboration, and reflective practices to counterbalance the potential for over-reliance on AI.

Overall, this study contributes to the growing body of research on AI in education by offering empirical evidence from the vocational school context in Indonesia. While the results affirm the benefits of NLP-based systems, they also highlight challenges that must be addressed to ensure sustainable and pedagogically meaningful integration.[23]

CONCLUSIONS

This study demonstrates the potential of integrating an AI-based digital assistant with NLP technology into vocational education. The system fosters adaptive and interactive learning, improves students' conceptual understanding, and enhances motivation and confidence in completing practical tasks. More importantly, it highlights how AI can be positioned as a facilitator of meaningful learning experiences aligned with the hands-on nature of vocational training. Despite these promising outcomes, sustainable implementation requires attention to several challenges, including the availability of domain-specific datasets, teachers' readiness to incorporate AI into pedagogy, and safeguards for student data privacy. Addressing these issues will be essential to ensure that AI contributes not only to efficiency but also to the quality and equity of education. Ultimately, this research provides a foundation for advancing the digital transformation of vocational education in Indonesia. Future studies should explore long-term impacts, investigate broader pedagogical strategies for integrating AI, and examine how such systems can be scaled to different educational contexts while maintaining personalization and learner engagement.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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