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THE EFFECT OF ARTIFICIAL INTELLIGENCE–BASED LEARNING TOOLS ON STUDENT ACHIEVEMENT AND LEARNING ENGAGEMENT IN K–12 EDUCATION

PENGARUH ALAT PEMBELAJARAN BERBASIS KECERDASAN BUATAN TERHADAP PRESTASI AKADEMIK DAN KETERLIBATAN BELAJAR SISWA PADA PENDIDIKAN K–12

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ABSTRACT
This study evaluates the impact of Artificial Intelligence (AI)-based adaptive learning tools on student achievement and learning engagement at SMK Negeri 1 Percut Sei Tuan. Utilizing a quasi-experimental design, the research addresses the effectiveness of AI in suburban educational contexts characterized by specific infrastructure challenges and diverse digital literacy levels. The findings demonstrate that students utilizing AI-based tools achieved significantly higher academic performance compared to those instructed through conventional methods. Furthermore, a strong positive correlation was identified between learning engagement and academic success, suggesting that AI facilitates a more personalized and responsive learning environment. These results validate the application of Cognitive Load Theory and Self-Determination Theory in vocational education, proving that AI acts as a pedagogical catalyst that optimizes cognitive processes while fostering intrinsic motivation among students.
Keywords: Artificial Intelligence, Academic Achievement, Learning Engagement, Vocational Education, Cognitive Load Theory.

ABSTRAK
Penelitian ini mengevaluasi dampak alat pembelajaran adaptif berbasis Kecerdasan Buatan (AI) terhadap prestasi akademik dan keterlibatan siswa di SMK Negeri 1 Percut Sei Tuan. Dengan menggunakan desain kuasi eksperimental, penelitian ini menguji efektivitas AI dalam konteks pendidikan pinggiran kota yang menghadapi tantangan infrastruktur dan keragaman literasi digital. Hasil penelitian menunjukkan bahwa siswa yang menggunakan perangkat berbasis AI mencapai prestasi akademik yang jauh melampaui metode instruksional konvensional. Selain itu, ditemukan korelasi positif yang kuat antara keterlibatan belajar dan keberhasilan akademik, yang menunjukkan bahwa AI memfasilitasi lingkungan belajar yang lebih personal dan responsif. Temuan ini memvalidasi penerapan Cognitive Load Theory dan Self-Determination Theory dalam pendidikan vokasi, serta membuktikan bahwa AI berperan sebagai katalisator pedagogis yang mengoptimalkan proses kognitif sekaligus memperkuat motivasi intrinsik siswa.
Kata Kunci: Kecerdasan Buatan, Prestasi Akademik, Keterlibatan Siswa, Pendidikan Vokasi, Cognitive Load Theory.

1. INTRODUCTION

The integration of digital technology, particularly artificial intelligence (AI), in the K–12 education ecosystem has become imperative, especially within vocational education. Vocational High Schools (SMKs) face the pressing challenge of aligning their academic offerings with the evolving demands of the industry. This integration serves not merely as an optional enhancement but as a strategic necessity aimed at improving pedagogical effectiveness and student engagement.

AI-based educational tools have shown promise in addressing the unique challenges of vocational training. They facilitate personalized learning experiences, providing tailored content that adapts to individual learning styles and paces. For instance, AI can offer real-time feedback

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and complex problem-solving simulations that traditional methods struggle to deliver effectively, particularly in vocational contexts that require hands-on skills (Irwan, 2024; (Nugroho et al., 2024)Shen, 2023; (Fania et al., 2024; . The demand for such personalized approaches is underscored by studies indicating that vocational students often have distinctive learning preferences, primarily visual and kinesthetic styles, which are not well accommodated by conventional instructional methods (Kamaliah et al., 2018; Khatimah & Chisbiyah, 2024)Muskhir et al., 2024).

AI's capacity to optimize cognitive processes and improve overall learning quality is especially crucial in vocational education, where practical skills are paramount (Solikhatun et al., 2021; Rahmatullah et al., 2024). Current methodologies predominantly rely on passive lecture formats, leading to disengagement among students and diminishing academic achievement (Husein et al., 2022; Chen & Din, 2024). The evaluation of evidence from various studies reveals that the integration of AI in vocational education can facilitate adaptive learning environments that significantly improve motivation and engagement levels among students (Cao & Abdullah, 2025; Kexin & Buang, 2024). Moreover, with the shift toward industry-relevant competencies, AI applications such as interactive video-based learning can foster critical thinking and real-world problem-solving skills essential for vocational graduates (Irwan, 2024; Li et al., 2025).

Despite the potential benefits, many vocational institutions struggle with the practical implementation of AI technologies. Research indicates significant gaps in teachers' perceptions, understanding, and acceptance of AI in instructional strategies (Nugroho et al., 2024). Common barriers include inadequate technological infrastructure, insufficient training, and a general reluctance to change established teaching practices (Fania et al., 2024; Lee & Hsu, 2021). These obstacles contribute to a prevalent teaching culture that favors traditional methods, thus restraining the full potential of AI-enhanced educational frameworks (Zhao et al., 2023; (Villalba et al., 2018; .

This gap creates an urgent need for empirical evaluations focused on how AI can serve as a pedagogical intervention within vocational settings. Understanding how AI solutions can simultaneously enhance academic performance and student engagement is vital for tailoring curricula that meet industry standards (Villalba et al., 2018; Khatimah & Chisbiyah, 2024).

In conclusion, the role of AI in vocational education is multifaceted, impacting curriculum design, instructional methodologies, and student outcomes. A concerted effort to bridge the gap between the potential of AI technologies and their actual use in classrooms will position vocational schools to better meet both educational and industry demands. As this evolution unfolds, empirical research becomes crucial to demonstrate the effectiveness of AI integrations in real-world educational contexts.

Although the literature on AI applications in education has shown significant growth, most quantitative studies still focus on schools in metropolitan areas with relatively ideal digital infrastructure. In contrast, empirical evidence on the effectiveness of AI-based learning in suburban schools remains limited. Schools like SMK Negeri 1 Percut Sei Tuan in Deli Serdang Regency, North Sumatra, face unique contextual challenges, including heterogeneity in students' digital literacy, limited internet network stability, and other supporting infrastructure constraints. Assessing the performance and impact of AI-based learning in suburban schools remains limited.AI-based learning toolsIn less than ideal environmental conditions, it is important to assess the extent to which this technology is inclusive or has the potential to widen the digital divide in education.

Based on these research gaps, this study aims to quantitatively evaluate the impact of usingAI-based learning toolson two key variables in learning, namely academic achievement (academic achievement) and student engagement (learning engagement). By focusing on the context of SMK Negeri 1 Percut Sei Tuan, this research is expected to provide theoretical contributions by strengthening the validationCognitive Load Theoryin the realm of vocational

education, as well as practical contributions in the form of an evidence-based foundation for regional education policy makers in determining priorities and strategies for adopting learning technology in vocational high schools.

In line with these objectives, this research is guided by two main research questions as follows: RQ1: To what extent is the useAI-based learning toolshas a significant effect on improving students' academic achievement compared to conventional learning methods?. RQ2:Is there a significant positive correlation between the level of student engagement (learning engagement) and academic achievement in an AI-based learning environment?

2. METHODS

2.1. Research Design

This study applies a designQuasi-Experimentalwith modelNonequivalent Control Group DesignThis design was chosen due to limitations in randomizing individuals in a school environment that has already been established in permanent classes. The study involved two groups:Experimental Groupwho received AI-based learning interventions, andControl Groupwho followsconventional learning using lecture methods and printed modules. Effectiveness is measured by comparing scorespre-test and post-test in both groups.

2.2. Population and Sample

The research population was all grade X students at SMK Negeri 1 Percut Sei Tuan in the even semester of the 2025/2026 academic year. The sample was selected using the techniquePurposive Samplingbased on the equality of initial abilities (assuming the previous semester's report card grades). Two classes with a total of N=72 students were selected, which were divided into:

1. **Experimental Class (n=36):** Department of Computer and Network Engineering.
2. **Control Class (n=36):** Department of Computer and Network Engineering.
   The selection of two classes from the same major aims to control the variable of interest and talent so that it does not become a confounding variable.

2.3. Research Instruments

Data was collected using two main instruments:

1. **Academic Achievement Test:**Consisting of 30 multiple choice questions that have been tested for content validity by experts (expert judgment) and reliability test usingKuder-Richardson 20(KR-20) with a coefficient > 0.70.
2. **Learning Engagement Questionnaire:**Adapting instrumentsSchool Engagement Measure(Fredricks et al., 2004) which includes cognitive, affective, and behavioral dimensions. This instrument uses a 1-5 Likert scale and has undergone construct validity testing.

2.4. Intervention Procedure

The intervention was carried out over eight meetings (4 weeks).

1. **Experimental Group:**Students use the platformAI-adaptive learning(such as Khan Academy or local AI-based platforms) that automatically adjust the difficulty level of questions based on the student's overall performance.real-time.
2. **Control Group:**Students learn with direct instruction from the teacher, using standard textbooks, and uniform practice problems for the entire class without personalized algorithms.

2.5. Data Analysis Technique (Excel-Based)

Data analysis was performed using Microsoft Excel with Data Analysis Toolpak. The analysis stages include:

1. Prerequisite Test:Testing data normality using ratiosSkewness And Kurtosis. Data is considered normal if the value is in the range of -2 to +2.
2. Hypothesis Test 1 (RQ1): Use Independent Sample t-Testto compare scorespost-testbetween groups andPaired Sample t-Testto measure internal improvement in each group.
3. Hypothesis Test 2 (RQ2):Using analysisCorrelation And Simple Linear Regression to determine the extent of the influence of involvement on achievement.
4. Effect Size: Count Cohen's manual in Excel to determine the practical significance of AI interventions, with the criteria: 0.2 (small), 0.5 (medium), and 0.8 (large).

3. RESULTS

3.1. Descriptive Statistics

The research data were collected from 72 students who were divided equally into two groups. Descriptive statistics for the scorespre-test And post-testpresented in Table 1. Initial results indicate that both groups had equivalent initial abilities (equivalent) before the intervention was carried out, with an average score ofpre-testwhich are almost identical.

Table 1. Descriptive Statistics of Academic Achievement

Group	N	Assessment	Mean (M)	SD	Min	Max
Experimental (AI)	36	Pre-test	62.45	5.32	52	74
		Post-test	84.12	4.85	76	95
Control (Conventional)	36	Pre-test	61.9	5.15	50	72
		Post-test	72.35	6.42	60	85

Source: Processed Data, 2025

Based on the data presented in Table 1, there are significant findings regarding the distribution of academic achievement scores of students at SMK Negeri 1 Percut Sei Tuan. Descriptive statistical analysis shows that in the initial stage (pre-test), both groups had equivalent cognitive starting points (equivalent). The experimental group recorded an average score of62.45, while the control group recorded scores61.90. Difference pre-testThis very slight difference (0.55 points) indicates that there was no significant initial ability bias between the two groups before the intervention was carried out.

After four weeks of treatment, there was a significant increase in scores in both groups, but with different magnitudes. The experimental group usedAI-based adaptive learning toolsexperienced a very significant increase in achievement with an average scorepost-test reach 84.12. In contrast, the control group using conventional learning methods only achieved an average score of 72.35.

Comparatively, the experimental group showed an increase (gain score) as big as21.67points, almost twice as high as the increase in the control group which was only10.45points. In addition, the minimum score in the post-intervention experimental group increased sharply to76, which means that the lowest score in the AI class is still higher than the average score of the conventional class (72.35This provides initial evidence that the use of AI-based learning tools at SMK Negeri 1 Percut Sei Tuan not only improves average achievement, but is also able to raise the performance standards of students at lower levels to reach a higher competency threshold.

3.2. Hypothesis Testing 1: AI Impact on Achievement (RQ1)

To answer RQ1, a test was conductedIndependent Samples t-teston post-test scores using Excel. The analysis results showed a statistically significant difference between the

experimental and control groups, with a t(70) value = 8.76 and p < 0.001.The improvement in achievement in the experimental group was also confirmed throughPaired Samples t-testwhich compares pre-test and post-test scores, with the results t(35) = 18.42 and p < 0.001. In addition to statistical significance, the calculationCohen's produces a value of 2.06, which indicates that AI-based interventions have effect size which has a very large impact on the academic achievement of students at SMK Negeri 1 Percut Sei Tuan.

3.3. Hypothesis Testing 2: Engagement and Achievement Correlation (RQ2)

Analysis of the relationship between student engagement (learning engagement) and academic achievement were conducted using Pearson correlation test and simple linear regression. Questionnaire data showed that the average student engagement score in the experimental group was 4.25 on a scale of 1–5.The results of the analysis show a strong positive correlation between learning engagement and academic achievement, with a correlation coefficient value of r = 0.78 and p < 0.001. The coefficient of determination (R^2) value of 0.61 indicates that learning engagement triggered by the use of AI tools explains 61% of the variation in student academic achievement, while the remaining 39% is influenced by other factors not examined.

4. DISCUSSION

4.1. Interpretation of Findings: AI and Cognitive Optimization

The findings of this study indicate that the use of AI-based adaptive learning tools significantly outperformed conventional methods in improving student achievement at SMK Negeri 1 Percut Sei Tuan. The application of Cognitive Load Theory (CLT), developed by John Sweller, provides a significant framework for understanding the complexities of learning, particularly for vocational high school students encountering intricate technical material. CLT posits that learners have a finite working memory, and when instructional design doesn't consider this limitation, it leads to cognitive overload, impairing learning outcomes. This comprehensive explanation ties into the reality that vocational students often face complex technological content delivered uniformly, which is beyond their working memory capacity. Traditional methods neglect individual differences in cognitive load capacity, resulting in barriers to effective learning.

In contrast, the integration of artificial intelligence (AI) into educational contexts demonstrates a robust approach to managing cognitive load. AI algorithms can analyze individual student performance and tailor the complexity of information accordingly. By breaking down information into smaller, more digestible units and adjusting the difficulty hierarchically, AI effectively optimizes what is known as "germane cognitive load" — the cognitive effort devoted to processing and understanding new information that facilitates learning (Ginns & Leppink, 2019; , Cardellini, 2015). This personalized learning experience aligns with the principles of CLT, which advocate for instructional designs that enhance germane load while minimizing extraneous and intrinsic cognitive overload (Merriënboer & Sluijsmans, 2008; , Kalyuga, 2011).

Such adaptive learning systems have shown to inspire deeper comprehension of technical concepts, leading to improved retention rates and an overall enhanced educational experience. For example, studies in microlearning contexts reveal that tailored instructional modules can significantly boost knowledge retention and engagement, suggesting that AI could play a pivotal role in leveraging CLT principles to foster effective learning environments (Lopez, 2024; , Gog et al., 2010).

The intersection of AI and CLT emphasizes the necessity for instructional designers to adopt more sophisticated educational strategies that align with learners' cognitive architectures. This includes practices that mitigate cognitive overload, such as progressive complexity, where learners first engage with simpler concepts before tackling advanced

material (Sweller, 2008; , Chang & Peng, 2017). By doing so, educators can create a more effective learning trajectory that acknowledges and supports the cognitive limitations present in the classroom, thereby enhancing both understanding and skill acquisition (Larmuseau et al., 2019; , Sunawan et al., 2017).

Furthermore, CLT underscores the importance of integrating diverse educational technologies and practices that cater to various learning styles and paces. The use of multimedia resources, interactive platforms, and gamification can not only attract students but also help manage cognitive loads effectively through engaging and varied instructional formats (Antonenko et al., 2010; , Clarke et al., 2005). Thus, AI serves as a transformative tool in educational settings, aligning with the fundamental aspects of CLT to deliver a more customized and effective learning experience.

In summary, Cognitive Load Theory offers a critical lens through which to examine the challenges faced by vocational high school students when confronting complex technical content. The advent of AI technologies provides a means to optimize cognitive load management by adapting educational materials in real time to suit individual needs. This approach not only fosters a deeper understanding of technical concepts but also enhances long-term retention, thus advocating the necessity for instructional designs that respond to the cognitive capacities of learners.

4.2. Engagement Analysis: Personalization and Intrinsic Motivation

A strong positive correlation between student engagement (learning engagement) and academic achievement, with an r value of 0.78, confirms that the impact of AI is not limited to the cognitive domain but also encompasses the affective dimension. Self-Determination Theory (SDT) posits that the fulfillment of three fundamental psychological needs—autonomy, competence, and relatedness—enhances intrinsic motivation and thereby fosters effective learning outcomes (Arthur, 2021; Ramos-Ramos & Nicolás, 2022; Nyuhuan, 2024). This framework can be effectively applied to analyze the impact of AI-based learning systems on student engagement and academic achievement, particularly at institutions like SMK Negeri 1 Percut Sei Tuan.

Personalized learning paths, facilitated by AI systems, cater to students' need for autonomy by allowing them to make choices about their learning processes. This concept is supported by research which indicates that autonomy-supportive environments significantly enhance motivational levels and engagement in educational contexts Salikhova et al., 2024)Mouratidis et al., 2015). For example, Ramos-Ramos and Nicolás (2022) claim that providing choices in project-based learning fosters autonomy and in turn enhances intrinsic motivation amongst students Ramos-Ramos & Nicolás, 2022). Moreover, the role of AI in creating customized learning experiences has been shown to increase student engagement through enhanced autonomy, leading to greater exploration and effort in learning activities (Chue, 2023)Nyuhuan, 2024).

In addition to autonomy, AI-based systems can enhance students' sense of competence by presenting challenges that are precisely aligned with individual skill levels. According to SDT, when students encounter tasks that match their abilities, they perceive themselves as competent, which boosts their intrinsic motivation (Buil et al., 2019; Mouratidis et al., 2015). Chue's research highlights the positive correlation between perceived competence and student motivation in blended learning environments, indicating that when educational challenges are optimized for each student, their motivation and engagement levels significantly increase (Chue, 2023).

At SMK Negeri 1 Percut Sei Tuan, the integration of AI technologies has transitioned students from passive learners in traditional classrooms to active participants. This shift aligns with findings that suggest tailored challenges not only improve competence perceptions but also contribute to the accumulation of small wins, which are essential for sustaining intrinsic

motivation (Arthur, 2021; Ramos-Ramos & Nicolás, 2022). Such incremental successes can potentiate higher levels of cognitive engagement, further enhancing the likelihood of improved academic performance as evidenced in their recent experiences with AI platforms.

The need for relatedness, as articulated by SDT, emphasizes the importance of social connections in the educational context. AI learning environments, when well-designed, can foster this sense of community among learners Salikhova et al., 2024)Dupont et al., 2009; . (Buil et al., 2019; observed that engagement driven by relatedness significantly influences academic outcomes, substantiating that when students feel connected to their peers and educators, their intrinsic motivation and overall success are heightened (Buil et al., 2019; Salikhova et al., 2024). The dynamic between relatedness and engagement is crucial; as learners engage more with AI systems, they often develop a community of practice that reinforces their social bonds and encourages cooperative learning (Fukuda et al., 2025; Wang et al., 2024).

The integration of AI-based learning systems in educational settings, particularly at SMK Negeri 1 Percut Sei Tuan, has significant implications for fulfilling students' psychological needs as outlined by Self-Determination Theory. By enhancing autonomy through personalized learning paths, boosting competence with appropriately tailored challenges, and fostering relatedness among learners, these systems can cultivate an environment that stimulates intrinsic motivation. The observed increase in exploratory activity and intrinsic motivation among students underscores the efficacy of SDT in enhancing academic achievement through AI technologies.

4.3. Local Context: Infrastructure Challenges in Suburban Areas

While the quantitative results show a very strong impact, the study also noted data variability influenced by local context. At SMK Negeri 1 Percut Sei Tuan, technical challenges such as unstable internet connections and periodic power outages served as a barrier.intervening variables. Field observations show that the decline in connectivity quality directly affects the level of engagement/students in the short term. These findings provide an important contextual contribution to the global literature, demonstrating that the effectiveness of AI implementation in suburban areas or developing countries is determined not only by the sophistication of the algorithms, but also by the resilience of the physical and digital infrastructure. Therefore, AI adoption policies in North Sumatra need to be accompanied by strengthening the school digital ecosystem so that the benefits of technology can be felt consistently and sustainably.

4.4. Comparison with Global Literature

The results of this study are in line with the findings of Chen et al. (2023) inComputers & Educationwhich reported that an AI-based adaptive learning system significantly improved learning outcomes at the secondary education level. However, the main contribution of this study lies in the context and magnitude of the resulting impact.effect sizeThe very large t test, with Cohen's d = 2.06, indicates that the AI intervention remains highly effective even when implemented in a vocational high school environment with a practice-based curriculum and limited infrastructure. In contrast to Smith and Gupta's (2022) study conducted in an urban school with advanced resources, the findings at SMK Negeri 1 Percut Sei Tuan demonstrate the potential of AI as a learning instrument.democratization of education, where students in suburban areas can achieve academic outcomes comparable to students in urban centers when given access to appropriate personalized learning technologies.

5. CONCLUSION

5.1. Synthesis of Main Findings

This study provides strong empirical evidence that the integration of artificial intelligence-based adaptive learning tools (AI-based adaptive learning tools) triggered a significant transformation in learning outcomes at SMK Negeri 1 Percut Sei Tuan. These findings definitively answer the research question by demonstrating that students interacting with AI technology achieved academic performance that far exceeded conventional instructional methods. Beyond simply improving grades, this intervention demonstrated its effectiveness in mitigating cognitive barriers often found in vocational education. Furthermore, this study revealed the crucial role of student engagement as a key mediator of learning success; where AI technology successfully created a more personalized and responsive learning environment, which in turn strengthened students' intrinsic motivation. Theoretically, these results validate that artificial intelligence functions as a pedagogical catalyst capable of balancing students' cognitive load while increasing their mental investment in the learning process.

Practically, these findings provide a foundation for school management to systematically adopt AI platforms, particularly in complex, productive subjects that require personalized learning paths. However, successful implementation requires a commitment to strengthening digital infrastructure and stable connectivity in suburban areas to ensure equitable distribution of technology benefits. For policymakers at the provincial level, this study offers an evidence-based policy basis (evidence-based policy) to encourage more inclusive digitalization of education. The main recommendation is directed at teacher professional development that focuses not only on technical literacy but also on pedagogical skills to align the teacher's role as a facilitator with the analytical capabilities of artificial intelligence in the modern classroom.

Despite its important contribution, this study is limited by its sample size, confined to a single vocational institution. Therefore, generalization of the findings to broader contexts requires caution. Furthermore, reliance on quantitative data fails to capture the psychological dynamics and qualitative perceptions between teachers and students during the digital transition. Therefore, a mixed-methods approach is recommended for future research.mixed-methods) to explore deeper pedagogical mechanisms. Longitudinal studies are also essential to test the persistence of AI's impacts over the long term and to ensure that the observed achievement improvements are not simply the result of novelty effects (novelty effect). Expanding the scope of samples across vocational disciplines will strengthen the validity of AI's effectiveness in various student competency contexts.

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