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The effect of Moodle-based adaptive e-learning on self-regulated learning and cognitive learning outcomes

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ABSTRACT

This study aims to develop a Moodle-based adaptive e-learning system and examine its effectiveness in improving students' self-regulated learning and cognitive learning outcomes. This study employed a Research and Development method using the Alessi and Trollip model, which includes the stages of planning, design, and development. The research subjects were eleventh-grade students, divided into experimental and control groups. The research instruments included a self-regulated learning questionnaire adapted from the SRL-O, cognitive achievement tests, and expert validation. Data were analyzed using MANOVA and univariate tests. The results indicate that the developed adaptive e-learning system is highly feasible, with average scores of 4.78 from content experts and 4.82 from media experts. Meanwhile, user evaluations yielded scores of 4.34 and 4.27, both categorized as feasible. Empirically, the MANOVA results showed a significant difference between the experimental and control groups. These findings were supported by univariate tests, which revealed a large effect on self-regulated learning and a moderate effect on cognitive learning outcomes. This study recommends the implementation of Moodle-based adaptive e-learning to support differentiated instruction and enhance students' independent learning.

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INTRODUCTION

The rapid advancement of digital technology has transformed education by supporting 21st-century learning, which emphasizes critical thinking, creativity, collaboration, communication, and self-directed learning (van Laar et al., 2017). This transformation has shifted educational practices from teacher-centered toward student-centered learning, requiring learners to take greater responsibility for managing their own learning processes (Adnan, 2020; Fajri et al., 2021). Consequently, educational technology is expected not only to facilitate knowledge acquisition but also to promote lifelong learning competencies that enable students to adapt to continuously changing learning environments.

Personalized learning has become an important approach for addressing differences in students' needs, abilities, and learning progress (Naseer et al., 2024). Through technology-supported learning environments, students can access learning resources flexibly while receiving learning experiences that better match their individual characteristics (Bashir & Lapshun, 2025; Chukwuemeka-Nworu et al., 2024). Recent evidence also indicates that digital learning enhances accessibility, engagement, and personalization, although its effectiveness depends on adequate

technological infrastructure and digital connectivity (Zou et al., 2025; Bendo & Alviar, 2026). Therefore, the integration of adaptive digital technologies should be accompanied by instructional design that actively supports students' learning processes.

Despite these developments, classroom instruction in many schools continues to rely on teacher-centered approaches that provide limited opportunities for students to actively regulate their own learning (Fitriasari & Sari, 2018; Shemshack & Spector, 2020). Such learning environments often position students as passive recipients of information rather than active participants in constructing knowledge, limiting the development of learning independence. As a result, students' self-regulated learning (SRL) remains insufficiently developed.

Self-regulated learning refers to learners' ability to plan, monitor, and evaluate their own learning activities to achieve academic goals (Zimmerman, 2002). According to Zimmerman, SRL develops through three cyclical phases: forethought, performance, and self-reflection. Therefore, effective digital learning environments should not only provide learning materials but also facilitate goal setting, continuous monitoring, timely feedback, and reflection to support these self-regulatory processes.

E-learning has been widely adopted as a digital learning solution in schools. However, many existing implementations primarily function as repositories for learning materials without providing adaptive learning pathways or personalized feedback (Nguyen & Nguyen, 2023). Consequently, the potential of e-learning to facilitate self-regulated learning has not been fully realized. Adaptive e-learning addresses this limitation by dynamically adjusting learning content, sequencing, and feedback according to learners' characteristics and performance, thereby providing more individualized learning experiences (Olusegun & Brighwood, 2024).

An Adaptive Learning System (ALS) enables this personalization through the interaction of three core components: the learner model, content model, and adaptation model (Vagale et al., 2020). The learner model represents students' characteristics and learning progress, the content model organizes instructional resources, while the adaptation model determines how learning materials, navigation, and feedback are dynamically delivered according to learner needs (Martin et al., 2020). Such mechanisms allow adaptive e-learning to function not only as a content delivery platform but also as an instructional support system for self-regulated learning.

Previous studies consistently demonstrate that adaptive e-learning improves learning outcomes, learning engagement, and motivation compared with conventional e-learning (El-Sabagh, 2021; Ristić et al., 2023). Research has reported positive findings in mathematics learning (Awang et al., 2024), adaptive feedback systems (Mejeh et al., 2024), AI-based adaptive learning environments (Lin et al., 2025), and structured Moodle learning environments that support SRL (Bellhauser et al., 2022; Satriani et al., 2024; Núñez et al., 2011). Other studies have also shown that SRL-oriented e-learning improves learning outcomes despite the absence of adaptive mechanisms (Arifin & Marini, 2022; Wahyuni et al., 2020). Collectively, these findings suggest that adaptive learning and SRL are closely related; however, they have generally been investigated separately or implemented on specialized platforms rather than learning management systems commonly used in schools.

Accordingly, an important research gap remains. Few studies have integrated adaptive learning mechanisms within Moodle specifically to facilitate SRL among senior high school students while simultaneously examining their effects on both self-regulated learning and cognitive learning outcomes. As a result, empirical evidence regarding the effectiveness of adaptive Moodle-based learning in supporting students' learning independence within authentic school contexts remains limited.

To address this gap, this study develops a Moodle-based adaptive e-learning system utilizing the conditional activities feature to generate remedial, reinforcement, and enrichment learning pathways based on students' formative assessment results (Jusuf & Andriani, 2025). The system is designed to support the phases of self-regulated learning while remaining consistent with the differentiated learning principles of the Kurikulum Merdeka. Accordingly, this study contributes in three ways: (1) integrating Moodle-based adaptive e-learning with an SRL-oriented instructional design; (2) implementing automatic adaptive learning pathways based on formative assessment

performance; and (3) evaluating the effects of the developed system on both self-regulated learning and cognitive learning outcomes among senior high school students using MANOVA.

METODE

This study employed a research and development (R&D) approach adapted from the instructional design model of Alessi & Trollip (2001), which consists of five stages: planning, design, development, implementation, and evaluation. The study was conducted at Turi 1 Senior High School, Sleman Regency, Special Region of Yogyakarta, Indonesia, from September 2025 to February 2026. The research involved two subject-matter experts, two media experts, 10 students participating in the limited trial (Beta I), and 36 students in the experimental class during the implementation stage (Beta II).

The subject-matter experts consisted of one mathematics lecturer from the Faculty of Mathematics and Natural Sciences, Yogyakarta State University, and one senior mathematics teacher from Turi 1 Senior High School. The media experts consisted of one Professor of Educational Technology from Yogyakarta State University and one educational technology developer specializing in digital learning media. These experts evaluated the accuracy of the learning content, instructional design, media quality, usability, and the adaptive learning mechanism before implementation.

Before the quasi-experimental implementation, the developed adaptive e-learning system underwent a limited trial (Beta I) involving 10 students. This pilot testing aimed to evaluate system functionality, readability of the learning materials and instruments, usability, and technical performance. Feedback obtained during this stage was used to improve both the adaptive learning system and the research instruments before implementation in the experimental class.

The adaptive mechanism was implemented using Moodle's Conditional Activities feature. The learning system consisted of three main instructional modules, each ending with a formative assessment. Students' formative assessment results automatically determined their subsequent learning pathway. Students obtaining scores of ≤ 60 were directed to the remedial pathway, those obtaining a score of 80 accessed the reinforcement pathway, and students achieving 100 proceeded to the enrichment pathway. After completing the assigned adaptive pathway, all students completed a reflection journal before continuing to the next instructional module. This adaptive sequence was repeated across all three modules, allowing learning pathways to dynamically adjust according to students' learning performance.

The self-regulated learning instrument was adapted from Broadbent et al., (2023), consisting of two higher-order factors and ten dimensions that measure students' self-regulated learning in online and blended learning environments. The instrument comprised 40 validated items and demonstrated high reliability with a Cronbach's Alpha coefficient of 0.939. Cognitive learning outcomes were measured using a 20-item multiple-choice test. The instrument was validated by the subject-matter experts and achieved a Cronbach's Alpha coefficient of 0.726, indicating high reliability.

The collected data were analyzed using descriptive quantitative techniques to determine the feasibility level of the developed adaptive e-learning system based on evaluations from subject-matter experts, media experts, and students. Feasibility scores were converted into percentages and interpreted according to Akbar (2013) feasibility criteria.

$$P = \frac{\Sigma X}{\Sigma X max} \times 100\%$$

Where P represents the feasibility percentage, ΣX is the total obtained score, and $\Sigma x max$ is the maximum possible score. The resulting percentages were interpreted based on the feasibility criteria proposed by Akbar (2013):

Table 1. Level of Validity

No.	Score Range (100%)	Category
1	81% - 100%	Very Good
2	61% - 80%	Good
3	41% - 60%	Sufficient
4	21% - 40%	Less
5	0% - 20%	Vey Less

The effectiveness of the adaptive e-learning system was examined using a quasi-experimental design involving one experimental class and one control class. Self-regulated learning and cognitive learning outcomes were analyzed simultaneously using Multivariate Analysis of Variance (MANOVA) at a significance level of 0.05. Follow-up univariate analyses (Tests of Between-Subjects Effects) were conducted to determine the treatment effect on each dependent variable and to measure effect sizes.

RESULT AND DISCUSSION

Results

The product developed in this study is a Moodle-based adaptive e-learning system for Grade XI trigonometry, specifically the sine and cosine rules. The development was informed by a student needs analysis, school educational report data, and interviews with teachers at Turi 1 Senior High School. The adaptive mechanism was implemented using Moodle's Conditional Activities feature, which automatically adjusts learning pathways according to students' formative assessment results. The interface of the developed system is presented in Figure 1 and Figure 2.

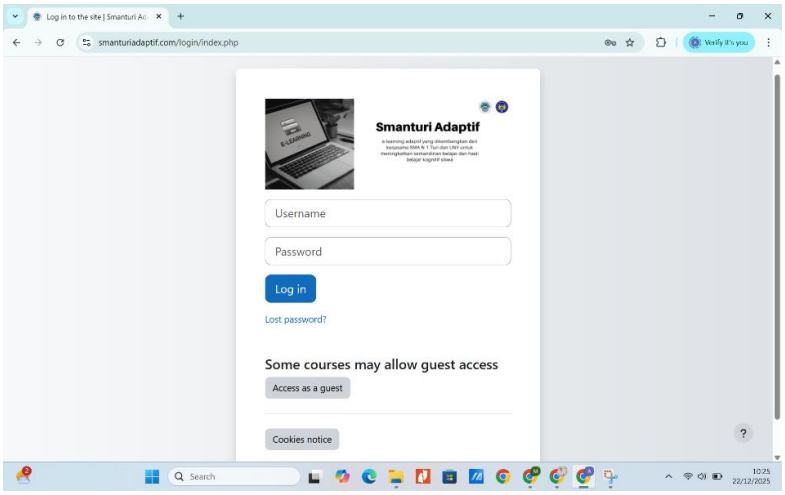

Figure 1. Adaptive E-Learning Login Page

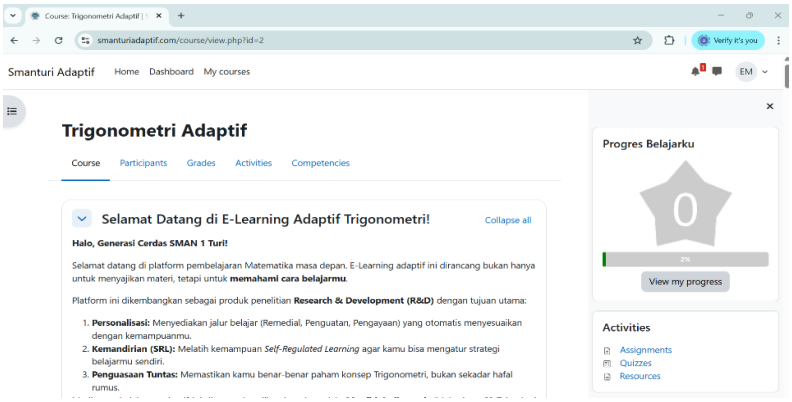

Figure 2. Trigonometry Course Interface on the Adaptive E-Learning Platform

The adaptive e-learning system provides three learning pathways: remedial, reinforcement, and enrichment, which are automatically assigned based on students' formative assessment performance. In addition, the system integrates self-regulated learning (SRL) support throughout the learning process. The *Target Belajarku* feature facilitates goal setting and learning planning, the *Progres Belajarku* dashboard enables students to monitor their learning progress, and the Jurnal Belajarku feature supports reflection upon completion of each learning module. The adaptive learning pathways are illustrated in Figure 3.

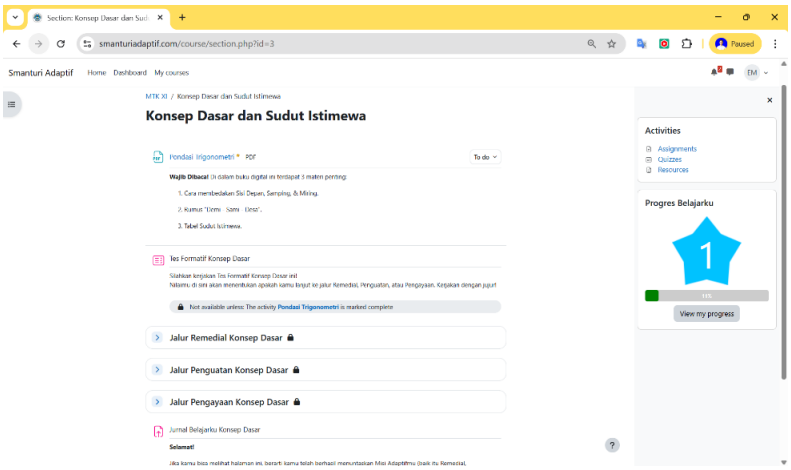

Figure 3. Adaptive Path in Adaptive E-learning

The developed product was evaluated through expert validation and user testing. The results of content validation, media validation, and student responses are summarized in Tables 2, 3, and 4, respectively.

Table 2. Results of Expert Validation on Content

No.	Aspect	Percentage	Category
1	Content Quality	96%	Very Good
2	Instructional Design	96%	Very Good
3	Adaptive Content	100%	Very Good
4	Support for SRL Content	94%	Very Good
5	Quality of Formative Test	96%	Very Good
6	Quality of Pretest and Posttest	92%	Very Good
Average		**95.6%**	**Very Good**

Table 3. Result of Expert Validation on Media

No.	Aspect	Percentage	Category
1	User Interface Design	98%	Very Good
2	User Experience	98%	Very Good
3	Adaptive Functionality	94%	Very Good
4	Support for SRL Features	96%	Very Good
5	Performance & Accessibility	96%	Very Good
Average		**96.4%**	**Very Good**

Table 4. Student Responses in Beta 1 and 2

No.	Aspect	Beta 1 (%)	Beta 2 (%)	Average (%)	Category
1	Ease of Access & Navigation	86.4%	84.8%	85.6%	Very Good
2	Quality of Content Presentation	84%	85.2%	84.6%	Very Good
3	Functionality of Adaptive Features	90.4%	86.4%	88.4%	Very Good
Average		**86.9%**	**85.5%**	**86.2%**	**Very Good**

Overall, the expert evaluations indicated that the developed adaptive e-learning achieved a very good level of feasibility across all assessed aspects, including content quality, instructional design, adaptive functionality, and support for self-regulated learning. Likewise, student responses from both Beta I and Beta II showed positive perceptions regarding accessibility, content presentation, and adaptive features, indicating that the system was appropriate for classroom implementation.

Following the feasibility evaluation, the adaptive e-learning system was implemented to examine its effectiveness in improving students' self-regulated learning and cognitive learning outcomes. The mean pretest, posttest, and gain scores for both variables are presented in Table 5.

Table 5. Mean Pretest and Posttest Scores for SRL and Cognitive Learning Outcomes

No.	Groups	SRL Pre	SRL Post	Gain SRL	Cognitive Pre	Cognitive Post	Cognitive Gain
1	Experimental	145.97	156.27	10.3	51.66	86.11	34.45
2	Control	145.44	147.91	2.47	52.97	76.76	2.79

Both groups demonstrated improvements in self-regulated learning and cognitive learning outcomes after the learning intervention. However, the experimental group consistently achieved higher gain scores than the control group for both variables, indicating greater learning improvement following the implementation of the adaptive e-learning system.

Table 6. Multivariate Analysis of Variance (MANOVA)

Effect	Multivariate Test	Value	F	Hypothesis df	Error df	p	Partial η^2
Group	Pillai's Trace	0.272	12.502	2	67	<0.001	0.0272

The multivariate analysis (MANOVA) revealed a statistically significant effect of the learning intervention on the combined dependent variables, namely self-regulated learning and cognitive learning outcomes (Pillai's Trace = 0.272, $F(2,67) = 12.502$, $p < 0.001$). The obtained Partial Eta Squared value of 0.272 indicates a large multivariate effect, suggesting that the adaptive e-learning intervention contributed substantially to the simultaneous improvement of both learning outcomes.

Table 7. Tests of Between-Subjects Effects

No.	Dependent Variable	F	p	Partial η^2	Effect Size
1	Self-Regulated Learning	16.380	<0.001	0.194	Large
2	Cognitive Learning Outcomes	4.791	0.032	0.066	Moderate

Effect size categories were interpreted based on Cohen (1988), where Partial $\eta^2 \geq 0.14$ indicates a large effect, 0.06–0.13 a moderate effect, and 0.01–0.05 a small effect. Follow-up univariate analyses confirmed significant treatment effects for both dependent variables (Table 7). The intervention produced a large effect on self-regulated learning (Partial $\eta^2 = 0.194$) and a moderate effect on cognitive learning outcomes (Partial $\eta^2 = 0.066$), indicating that the adaptive e-learning intervention had a stronger impact on students' self-regulated learning than on their cognitive learning outcomes.

Discussion

The findings demonstrate that integrating adaptive learning pathways into Moodle effectively supports both students' self-regulated learning and cognitive learning outcomes. Beyond improving academic performance, the adaptive learning environment appears to strengthen students' capacity to regulate their own learning through individualized learning pathways and continuous formative feedback. This finding suggests that adaptive learning is not merely a technological enhancement but also an instructional approach that promotes active learner engagement by providing learning experiences tailored to students' needs and performance. In this study, the automatic adjustment of remedial, reinforcement, and enrichment pathways encouraged students to participate in learning activities that matched their level of mastery, thereby creating opportunities for more meaningful and self-directed learning. Consequently, the developed adaptive e-learning system demonstrates the

potential of Moodle to support both personalized learning and the development of self-regulated learning within secondary school mathematics education.

Previous studies have consistently reported positive effects of Moodle-based learning environments on self-regulated learning and academic achievement (Núñez et al., 2011; Bellhäuser et al., 2022). The present study extends these findings by demonstrating that Moodle's built-in Conditional Activities feature can automatically generate differentiated learning pathways based on formative assessment results. Unlike previous studies that primarily evaluated general learning effectiveness (Ristić et al., 2023; Morze et al., 2021), this study simultaneously examined self-regulated learning and cognitive learning outcomes using MANOVA. These findings indicate that adaptive mechanisms embedded within widely used learning management systems can effectively operationalize personalized learning principles without requiring sophisticated AI-based platforms.

However, the effectiveness of adaptive learning environments is strongly influenced by instructional design rather than by the adaptive technology itself. Harati et al., (2024) reported a decline in students' self-regulated learning after using the ALEKS platform, which was associated with limited motivation, system complexity, low social presence, and the demanding nature of the learning environment. In contrast, the Moodle-based adaptive e-learning developed in this study employed a relatively simple adaptation mechanism using formative assessment results to provide remedial, reinforcement, and enrichment pathways. This approach allowed students to receive learning activities that matched their level of mastery without increasing the complexity of system navigation or learning tasks. These findings suggest that adaptive learning systems are more likely to support self-regulated learning when the adaptive mechanism is integrated with clear instructional guidance, manageable learning pathways, and continuous formative feedback that encourage students to regulate their own learning processes.

The stronger effect observed on self-regulated learning suggests that adaptive learning primarily influences students' learning behaviors before producing substantial improvements in academic achievement. This finding supports Zimmerman (2002) proposition that effective learning environments should first facilitate planning, monitoring, and reflection as the core processes of self-regulated learning. Similar tendencies have been reported in Moodle-based learning environments (Núñez et al., 2011; Bellhäuser et al., 2022) and AI-supported adaptive systems (Lin et al., 2025). In the present study, this stronger influence can be attributed to the integration of SRL-oriented features such as "*Target Belajarku*," "*Progres Belajarku*," and "*Jurnal Belajarku*," which explicitly support students in setting learning goals, monitoring progress, and reflecting on their learning experiences. Consequently, the adaptive e-learning environment not only personalizes content delivery but also encourages students to develop metacognitive strategies and independent learning behaviors.

In contrast, the moderate effect on cognitive learning outcomes suggests that improving conceptual understanding requires a more complex process. This aligns with Bellhäuser et al., (2022) and Huang et al., (2024), who found that SRL-based adaptive feedback has a greater impact on self-regulation than on cognitive performance directly. Studies by Awang et al., (2024) and Ristić et al. (2023) also reported improvements in learning outcomes through adaptive systems, but they did not examine the difference in effect strength between SRL and cognitive outcomes. Therefore, these findings extend previous research by suggesting that Moodle-based adaptive learning may strengthen students' self-regulation more substantially than cognitive learning outcomes during the intervention period. This finding implies that improvements in self-regulation may provide an important foundation for subsequent gains in cognitive learning, although this relationship requires further investigation. This also indicates that improvements in cognitive learning outcomes may require longer intervention durations or additional instructional strategies.

Further analysis of the SRL dimensions showed that the most prominent increases occurred in the forethought and performance phases. The greater improvement observed in the forethought and performance phases suggests that the adaptive learning design was particularly effective in supporting students' goal setting, learning management, persistence, and monitoring throughout the learning process. These competencies represent the initial stages of Zimmerman (2002) self-regulated learning cycle and provide an essential foundation for successful independent learning. Consistent with Mejeh et al., (2024) and Wahyuni et al., (2020), the present findings indicate that

integrating SRL-oriented learning activities with adaptive learning pathways can strengthen students' regulatory behaviors. The inclusion of real-time adaptive feedback further extends previous studies by providing personalized learning support within a widely used learning management system.

Meanwhile, the self-reflection phase showed relatively smaller improvement than the forethought and performance phases. This finding suggests that, although the adaptive e-learning system effectively supported students in planning, monitoring, and managing their learning activities, additional instructional support may be needed to strengthen reflective learning processes. This result is consistent with Huang et al., (2024), who reported that adaptive feedback tends to have a stronger influence on the earlier phases of self-regulated learning than on the reflection phase.

From a practical perspective, this study offers important implications for educational technology, particularly in the implementation of differentiated learning within the Merdeka Curriculum, which can be carried out automatically through the system. Adaptive e-learning enables teachers to manage diverse student abilities more efficiently without having to perform manual differentiation. In addition, from the perspective of educational management, these results indicate that the integration of adaptive technology in learning can serve as an effective strategy for improving data-driven instructional quality.

Despite these contributions, several limitations should be acknowledged when interpreting the findings. First, the study was conducted in only one senior high school with one experimental class and one control class, limiting the generalizability of the results beyond the present context. Second, self-regulated learning was measured using a self-report instrument, which may not fully capture students' actual learning behaviors during the intervention. Third, the relatively short implementation period may have limited the extent of improvement in cognitive learning outcomes. Accordingly, future research is encouraged to involve more diverse educational settings, larger participant groups, and longer intervention periods. Future studies may also integrate learning analytics derived from Moodle activity logs and develop more comprehensive reflection features or AI-supported adaptive mechanisms to further enhance personalized learning and self-regulated learning.

CONCLUSION

This study concludes that the Moodle-based adaptive e-learning system developed in this research was effective in improving self-regulated learning and cognitive learning outcomes among Grade XI students at SMA Negeri 1 Turi. The findings indicate that the integration of adaptive learning pathways through remedial, reinforcement, and enrichment activities, together with SRL-oriented features such as Target Belajarku, Progres Belajarku, and Jurnal Belajarku, supported students in planning, monitoring, and reflecting on their learning processes. Within the context of this study, the adaptive learning approach demonstrated a stronger effect on self-regulated learning than on cognitive learning outcomes, suggesting that adaptive instructional support may first strengthen students' learning regulation before producing broader academic gains.

From a practical perspective, the findings suggest that Moodle's built-in adaptive features can support the implementation of differentiated instruction in secondary school classrooms without requiring additional adaptive platforms. However, these findings should be interpreted within the context of a single-school implementation involving one experimental class and one control class over a relatively short intervention period. Therefore, caution should be exercised when generalizing the results to other educational settings.

Future studies are encouraged to examine the effectiveness of Moodle-based adaptive e-learning across multiple schools, larger and more diverse participant groups, and longer implementation periods to improve the external validity of the findings. In addition, future research may integrate learning analytics derived from LMS activity logs and explore more advanced adaptive technologies to further strengthen personalized learning and self-regulated learning support.

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