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Innovative E-Learning Strategies in Mathematics Education: Enhancing Self-Directed Learning and Student Motivation

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Abstract: *This study employs the ADDIE model (Analysis, Design, Development, Implementation, Evaluation) within a Research and Development (R&D) framework to develop a Moodle-based e-learning platform for enhancing mathematics learning motivation and self-directed among 9th-grade students at SMPN 1 Kota Bima. The research addresses two key issues: (1) Indonesia's low math competency (PISA score: 366) and (2) local findings showing 60% of target students scoring below minimum standards with observed low learning autonomy.Using the ADDIE model, the platform was developed with interactive features (structured materials, automated quizzes, discussion forums, and progress dashboards). Evaluation instruments included pre-post motivation questionnaires (Likert scale), self-regulated learning rubrics, and math achievement tests. Validation by material and media experts confirmed high feasibility (88% and 82%, respectively). Quantitative analysis revealed statistically significant improvements in the experimental class: motivation increased by 13.83 points (paired t-test, $p < 0.01$, $g = 0.72$ [high]), and self-directed learning by 17.66 points ($p < 0.01$, $g = 0.64$ [moderate]), surpassing the control class. The results demonstrate Moodle's efficacy in fostering 21st-century skills (4C) through hybrid learning, aligned with Vygotsky's constructivism (social interaction scaffolding) and Keller's ARCS theory (attention-relevance-confidence-satisfaction). The study contributes actionable insights for technology-mediated math education, emphasizing structured, feedback-driven, and student-centered design.*

Keywords*: e-learning, Moodle, mathematics education, self-directed learning, motivation*

Abstrak: Penelitian ini menggunakan model ADDIE (Analysis, Design, Development, Implementation, Evaluation) dalam kerangka Research and Development (R&D) untuk mengembangkan platform e-learning berbasis Moodle guna meningkatkan motivasi belajar matematika dan kemandirian belajar siswa kelas 9 di SMPN 1 Kota Bima. Penelitian ini mengangkat dua permasalahan utama, yaitu (1) rendahnya kompetensi matematika Indonesia (skor PISA: 366) dan (2) temuan lokal yang menunjukkan 60% siswa target memperoleh skor di bawah standar minimum dengan tingkat kemandirian belajar yang rendah. Dengan menggunakan model ADDIE, platform dikembangkan dengan fitur interaktif seperti materi terstruktur, kuis otomatis, forum diskusi, dan dashboard kemajuan belajar. Instrumen evaluasi meliputi kuesioner motivasi sebelum dan sesudah perlakuan (skala Likert), rubrik pembelajaran mandiri, serta tes prestasi matematika. Validasi oleh ahli materi dan media menunjukkan kelayakan tinggi (masing-masing 88% dan 82%). Analisis kuantitatif menunjukkan peningkatan yang signifikan secara statistik pada kelas eksperimen, yaitu motivasi meningkat sebesar 13,83 poin (uji t berpasangan, $p < 0,01$, $g = 0,72$ [tinggi]) dan kemandirian belajar sebesar 17,66 poin ($p < 0,01$, $g = 0,64$ [sedang]), yang lebih tinggi dibandingkan kelas kontrol. Hasil ini menunjukkan efektivitas Moodle dalam mengembangkan keterampilan abad ke-21 (4C) melalui pembelajaran hybrid, yang selaras dengan konstruktivisme Vygotsky (penopang interaksi sosial) dan teori ARCS Keller (attention-relevance-confidence-satisfaction). Penelitian ini memberikan kontribusi wawasan praktis untuk pendidikan matematika berbasis teknologi dengan menekankan desain yang terstruktur, berbasis umpan balik, dan berpusat pada siswa.

Kata kunci: e-learning, Moodle, pendidikan matematika, pembelajaran mandiri, motivasi

INTRODUCTION

Education plays a crucial role in enhancing and developing human quality across various aspects. To keep pace with modern advancements, the government must improve

the existing education system (Dini, 2021). One way to enhance human quality is through mathematics education in schools. A teacher must not only possess adequate qualifications but also be able to design creative and innovative learning processes, especially in teaching mathematics, which serves as the foundation for various other disciplines (Duha & Harefa, 2024; Sulistyaningsih et al., 2025). Learning mathematics helps students develop systematic, precise, and meticulous thinking. Mastering basic mathematical concepts such as arithmetic calculations, solving equations, and understanding geometry is essential for students to grasp more complex material at higher levels. Therefore, a thorough understanding of mathematics is imperative for every student.

According to the 2022 PISA (Program for International Student Assessment) results, released on December 5, 2023, Indonesian students' mathematical proficiency remains low compared to other countries. Indonesia's average mathematics score was only 366, while the global average was 472. This placed Indonesia 71st out of 81 participating countries (Kemendikbudristek, 2023). Additionally, the survey revealed that teachers in Indonesia face various challenges in the learning process, including a lack of digital tools such as computers or laptops, internet access, learning management systems (LMS), and educational platforms in schools (Aditia, 2024).

Mathematics plays a significant role in equipping students with the skills needed to face 21st-century challenges (Dwi Rahma Putri et al., 2022).To address these challenges, 21st-century skills such as critical thinking, problem-solving, creativity, communication, and collaboration (popularly known as 4C) are essential (Partnership for 21st Century Learning, 2015). As a key component of formal education, mathematics learning in schools often faces numerous obstacles. One major difficulty lies in understanding abstract and complex mathematical concepts. Additionally, classroom learning is often suboptimal due to limited time allocation and varying levels of student comprehension. Another common challenge is students' low motivation and lack of independence in learning, even though these aspects are vital for achieving optimal learning outcomes (Syaifuddin et al., 2023).

Based on interviews with mathematics teachers and students at SMPN 1 Kota Bima, it was found that many students still rely on parents, teachers, or peers when struggling with mathematics. The field data reveals two critical issues: (1) 60% of students do not meet the minimum competency standards in mathematics, and (2) teacher observations indicate a dominant tendency of learning dependence (low learning autonomy) among this group of students. They often require intensive guidance and show little initiative in solving problems independently. Rahayu & Aini (2021) state that independent learning is characterized by a student's ability to manage their own learning process and view obstacles as challenges to overcome. This dependence indicates low learning independence, partly due to weak foundational math skills. When students lack a solid grasp of basic mathematical concepts, they struggle with new material or problem solving, leading to reliance on external help.

Several studies have proven that e-learning implementation can enhance students'

motivation and learning independence. Gumilar & Hermawan (2021) found that e-learning fosters independent learning. Similarly, Aurora & Effendi (2019) demonstrated increased motivation when e-learning is used as a learning medium. Recent research by Cahyani (2023) further supports these findings, showing the effectiveness of e-learning in improving both motivation and learning independence.

To address these educational gaps, Indonesia has increasingly adopted e-learning platforms such as Moodle (Modular Object-Oriented Dynamic Learning Environment). Its open-source flexibility offers valuable tools for mathematics education, including equation editors, interactive quizzes, and progress tracking systems. Research by Dethan et al., (2024) demonstrates significant positive correlations between Moodle-based learning and the development of metacognitive skills among 11th-grade students in applied mathematics, particularly emphasizing how self-directed learning enhances higher-order thinking skills.

However, implementation challenges persist. Teachers face substantial difficulties in adapting Moodle's functionalities to teach abstract mathematical concepts (e.g., geometry or algebra) that require dynamic visualizations - a challenge compounded by insufficient training and limited access to specialized tools like MathType (Judijanto, 2025). Furthermore, equity issues are particularly evident in programs like the 13-Year Compulsory Education Initiative, where infrastructural disparities across Indonesia's archipelagic regions result in underutilized Moodle offline capabilities due to persistent device shortages.

Current research on Moodle's efficacy in Indonesian mathematics education, while still emerging, reveals several critical findings. Teacher readiness remains a fundamental barrier, with recent studies indicating only 60% of Indonesian teachers meet minimum competency standards, significantly limiting their ability to employ Moodle for developing 4C skills (collaboration, critical thinking) through problem-based learning approaches (Wijayanto et al., 2024). These researchers further identified that teachers limited conceptual understanding and professional capacity constitute primary obstacles to effective 4C skills integration in mathematics instruction.

The post-pandemic hybrid learning environment has exacerbated these systemic disparities. Urban schools with superior internet infrastructure reported significantly higher algebra N-gain scores (0.5-0.7) compared to rural institutions (0.2-0.3), clearly demonstrating how technological inequities directly affect learning outcomes (Aletheiani, 2021).These findings underscore the urgent need for comprehensive solutions addressing both technological access and pedagogical competence in Indonesia's mathematics education reform efforts.

This study is expected to produce a high-quality, ready-to-use e-learning platform for mathematics educators and students in Indonesia. Furthermore, this research aims to: (1) contribute significantly to the advancement of national educational technology, and (2) strengthen the competitiveness of Indonesian youth in an increasingly dynamic global landscape.

METHOD

This study adopts a Research and Development (R&D) approach (Sugiyono, 2018) aimed at creating and evaluating an educational product specifically, a Moodle-based e-learning platform for mathematics instruction. Conducted at SMP Negeri 1 Kota Bima with ninth-grade students and math teachers as participants, the research gathered data through questionnaires, interviews, and classroom observations to assess learning needs, motivation, and self-directed learning in Two-Variable Linear Equation Systems (SPLDV).

The development process in this study followed the systematic ADDIE model (Dick, 1996), which consists of five structured phases: Analysis, Design, Development, Implementation, and Evaluation. In the Analysis phase, needs assessments were conducted to identify learning objectives, learner characteristics, and technological requirements. The Design phase involved creating detailed instructional strategies, content outlines, and multimedia storyboards, which were reviewed by subject-matter experts (SMEs) to ensure alignment with pedagogical goals. During the Development phase, the e-learning materials were produced, incorporating feedback from media experts to enhance usability and engagement. The Implementation phase included pilot testing with both students and teachers to assess functionality and instructional effectiveness in a real-world setting. Finally, the Evaluation phase employed formative and summative assessments to measure learning outcomes and identify areas for improvement. Each phase was rigorously validated through expert reviews and iterative testing, ensuring the final product was both pedagogically sound and empirically validated. While the ADDIE framework provided a clear structure, a more detailed description of task-specific activities, challenges encountered, and adaptations made during each stage would further strengthen the transparency and replicability of the study's methodology.The ADDIE framework was selected for its systematic approach, which aligns with the study's goal of producing a validated, pedagogically sound e-learning solution.

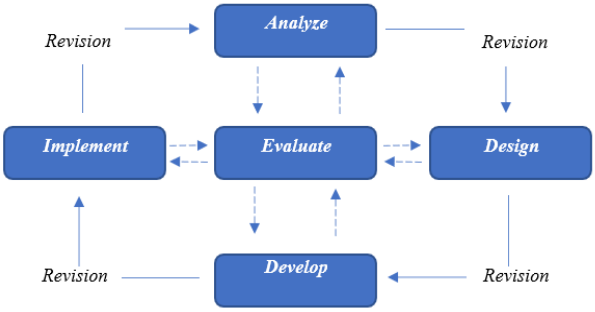


Figure 1. *Stages of the ADDIE Model Development*

The research employed three complementary data collection instruments to ensure comprehensive results. Observation sheets were used to systematically assess both learning activities and academic outcomes in the classroom setting. Structured interviews

provided valuable insights into participants' teaching and learning experiences, their levels of motivation, and their utilization of e-learning resources. Additionally, e-learning feasibility questionnaires, evaluated by subject matter experts, contributed crucial technical and pedagogical perspectives. Together, these methods generated robust, multi-dimensional data that informed the development of the Moodle-based e-learning platform at SMPN 1 Kota Bima, addressing both theoretical and practical aspects of the implementation.

The validation results were analyzed using a formula adapted from Sudijono (2009) as follows:

Formula:

$$P = \frac{f}{N} \times 100\%$$

Where:

P = Percentage score

f = Total score obtained

N = Maximum possible score

The validation questionnaire used a 1-4 Likert scale for scoring. The resulting percentage scores were then interpreted based on predetermined feasibility criteria for the learning media, as follows:

Table 1. Feasibility Assessment Criteria

Percentage Range (%)	Feasibility Level
82% ≤ P < 100%	Highly Feasible
63% ≤ P ≤ 82%	Feasible
44% ≤ P < 63%	Moderately Feasible
P < 44%	Not Feasible

After data collection, the raw scores were input and converted according to predetermined scoring intervals. The data was then qualitatively categorized using a Likert scale to facilitate clear interpretation when determining the feasibility of the developed e-learning product. To calculate scores for each component, the following formula was applied:

$$\bar{X} = \frac{\sum x}{n}$$

Descriptions:

$\bar{X}$: mean/ Average

$\sum x$: Total of all individual scores

n : Number of observations/participants

After performing calculations using the aforementioned formula, the next step involved determining the assessment category by converting the total scores into standardized values. These values were then classified using a 1-4 rating scale based on Wagiran, (2014).

The motivation and self-directed learning data were analyzed using N-gain score to evaluate test results. The calculation follows this equation:

$$\text{gain } \langle g \rangle = \frac{xpost\ tets - x\ pretest}{x - xpretest}$$

$X_{posttest}$: Mean posttest score
$X_{pretest}$: Mean pretest score
X : Maximum possible score

Table 2. N-Gain Score Change Criteria

N-Gain Range	Criteria
$0.7 \leq g \leq 1$	High Improvement
$0.3 \leq g < 0.7$	Moderate Improvement
$0 < g < 0.3$	Low Improvement
$g = 0$	No Change
$-1.0 \leq g < 0$	Decline

RESULTS & DISCUSSION

RESULTS

This research and development study has successfully produced a Moodle-based e-learning platform specifically designed to enhance motivation and self-directed learning in mathematics for ninth-grade students at SMPN 1 Kota Bima. The platform, accessible at http://elearningsmpn1bima.site/, features systematically developed instructional materials on Two-Variable Linear Equation Systems, incorporating structured pedagogical approaches. The study employed the ADDIE model (Analysis, Design, Development, Implementation, Evaluation) developed by Dick (1996) as its methodological framework. The instructional media development process commenced with:

Analysis

This e-learning development research began with a needs analysis phase consisting of field studies and literature review. The field study was conducted on June 11, 2024, through classroom observations and interviews with stakeholders at SMPN 1 Kota Bima, which identified several key challenges in mathematics learning, including: (1) students' difficulties in comprehending abstract concepts such as algebra and geometry due to limited teaching aids and LCD facilities, (2) low learning motivation levels, and (3) suboptimal self-directed learning among students. These findings indicated the necessity for developing a Moodle-based e-learning platform that provides interactive digital learning materials with high accessibility. For the literature review aspect, researchers analyzed the Merdeka Curriculum documents, syllabi, Lesson Plans (Rencana Pelaksanaan Pembelajaran/RPP), and Grade IX mathematics textbooks published by Kemendikbudristek in 2022 as the foundation for developing Two-Variable Linear Equation Systems content, with particular emphasis on graphical methods. This approach

ensures the product's alignment with both learning needs and current curriculum standards.

Design

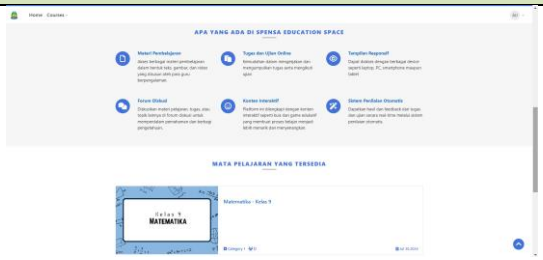
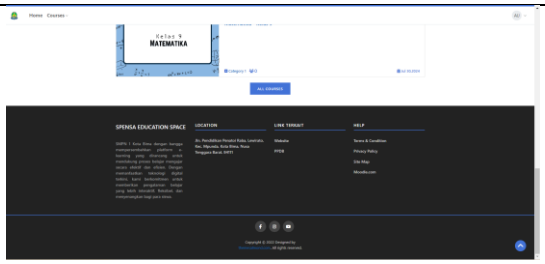
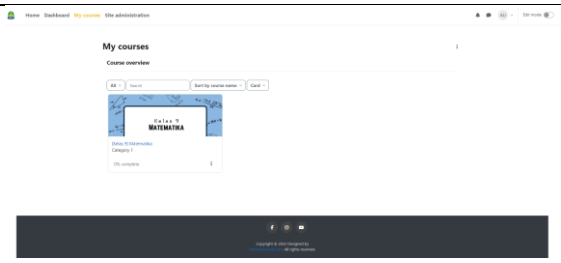
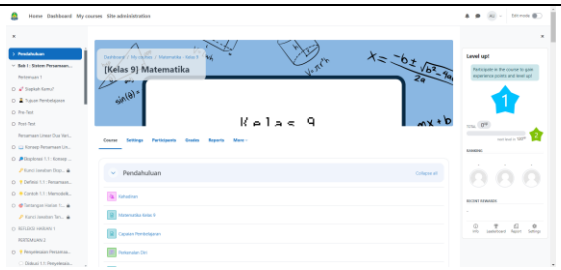
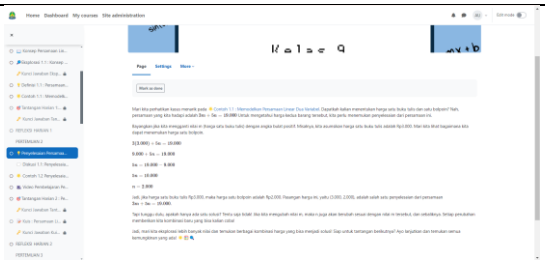
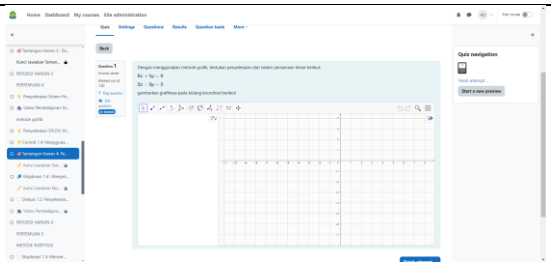
The design phase established a comprehensive Moodle-based e-learning framework specifically targeting Two-Variable Linear Equation Systems (SPLDV), with particular emphasis on graphical visualization to overcome students' difficulties with abstract mathematical concepts. Aligned with the Grade IX Merdeka Curriculum, the platform's learning objectives were carefully structured to encompass three key areas: (1) conceptual understanding of SPLDV, (2) mastery of solution methods including graphical, substitution, elimination and mixed approaches, and (3) practical application to real-world problems. The platform's design integrates diverse interactive elements including multimedia content (textual explanations, illustrative images, and instructional videos) combined with varied assessment tools such as multiple-choice quizzes, short-answer questions, and GeoGebra-embedded problem-solving activities. This pedagogical approach systematically incorporates three foundational learning theories: behaviorist principles through scaffolded exercises with immediate feedback and reward mechanisms; constructivist strategies enabling exploratory learning through diverse resources; and cognitive theory applications via carefully structured information presentation to optimize knowledge processing. By implementing this theoretically-grounded, multimodal design, the e-learning solution directly addresses previously identified learning challenges while simultaneously fostering self-directed learning skills and active student engagement through its comprehensive and interactive features.

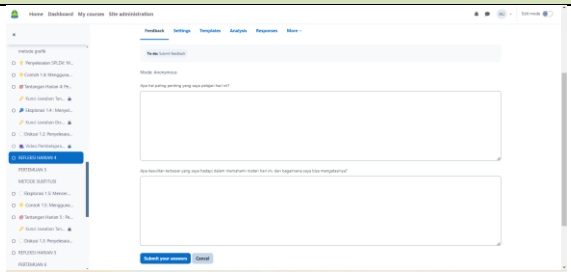
Development

This stage involved the actual development of the Moodle-based e-learning platform according to the previously established design specifications. The completed digital learning environment, now fully functional, is publicly accessible at https://elearningsmpn1bima.site/. Below are screenshots demonstrating the key interface elements and features of the implemented e-learning system:

Tabel 3. E-Learning Platform Interface

Interface Display	Functional Description
	Homepage display/screen

Interface Display	Functional Description
	My Courses page display
	Grade 9 Mathematics course page
	Learning materials section
	Sample quiz interface
	Daily reflection module
	Homepage display/screen

Interface Display	Functional Description
	My Courses page display

Subject Matter Expert Validation

The product validation involved four experts, comprising two content specialists and two media specialists. The evaluation utilized a 4-point Likert scale questionnaire with the following criteria: 4 = Strongly Agree, 3 = Agree, 2 = Disagree, and 1 = Strongly Disagree. This comprehensive assessment ensured rigorous evaluation of both pedagogical content and technical implementation aspects.

This material validation assessment evaluated both content and pedagogical aspects. The following are the evaluation results from subject matter experts:

Table 4. Material Expert Validation Results

No	Aspect	Total Score	Average Score
1	Content	116	3,63
2	Pedagogy	48	3,43
Total		164	
Overall Average		3,53	
Overall Percentage		88%	
Overall Quality Criteria		**High feasibility**	

Source: Data Processed by the Researcher (2025)

Based on assessments from two content experts, the developed e-learning platform achieved an " High feasibility " rating overall, confirming its readiness for research implementation pending these specific refinements: (1) fixing non-displayed images, (2) correcting textual typos, (3) incorporating parking lot examples for linear equations, (4) adding measurement units in Exploration 1.1 problems, (5) standardizing bold formatting for image captions, (6) aligning competencies with the latest 2022 standards (No. 033), (7) reviewing learning objectives 4-8, (8) revising two-variable equation symbols (using images if curly brackets prove problematic), and (9) enhancing answer feedback with motivational phrases. These targeted improvements address both technical functionality and pedagogical effectiveness while maintaining the platform's validated quality standards.

Table 5. Media Expert Validation Results

No	Aspect	Total Score	Average Score
1.	Visual Theme Appropriateness	14	3.50
2.	Layout/Composition	17	2.80
3.	Text Quality	18	3.00
4.	Image/Audio/Video Quality	42	3.50
5.	Navigation Functionality	13	3.25

6.	Usability	14	3.50
Total		118	
Overall Average		3,26	
Overall Percentage		82%	
Overall Quality Criteria		**High feasibility**	

Source: Data Processed by the Researcher (2025)

The media experts' evaluation yielded an overall "Feasible" rating for the e-learning platform, indicating its suitability for research use pending several improvements: (1) reorganizing layout elements with consistent section naming conventions, (2) adding clearer navigation instructions, (3) implementing reflection sections for each learning session, (4) adjusting image color contrast for better text visibility, and (5) increasing visual information representation while reducing text density. These recommended enhancements focus on optimizing user experience and interface design while maintaining the platform's core functionality.

Implementation

The implementation phase was carried out through two trials: a small-scale trial (August 31, 2024) involving six students (of high, medium, and low ability levels) to evaluate the practicality of the Moodle-based e-learning platform based on teacher and student response questionnaires, and a large-scale trial in class IX-1 (32 students) over four sessions to measure the effectiveness of the e-learning system in enhancing motivation and self-directed learning through pre-tests, interactive lessons, and post-tests. The results of both trials were used to refine the product before wider implementation.

Small-Scale Trial

The practicality assessment of this e-learning platform was conducted by a ninth-grade mathematics teacher at SMPN 1 Kota Bima, covering aspects of usability and functionality, with 19 statements evaluated using a 1-4 rating scale. The converted data from the teacher's responses in the small-scale trial are presented as follows.

Table 6. Teacher's Practicality Scale Results in the Small-Scale Trial

No.	Aspect	Teacher's Score	Category
1	Usage	31	Very Practical
2	Function	35	Very Practical

Source: Data Processed by the Researcher (2025)

The practicality evaluation of this e-learning product was conducted by 6 ninth-grade students at SMPN 1 Kota Bima. The assessment covered aspects of usability and functionality, with 20 statements evaluated using a 1-4 rating scale. The converted data from the teacher's responses in the small-scale trial are presented as follows:

Table 7. Student’s Practicality Scale Results in the Small-Scale Trial

No.	Aspect	Student’s Score	Category
1	Media Usability	48	Very Practical
2	Media Quality	21	Very Practical

Source: Data Processed by the Researcher (2025)

Large-Scale Trial

1) Learning Motivation Assessment Results

The evaluation of students' learning motivation was conducted using a questionnaire instrument comprising 20 items across eight assessment aspects. This assessment was administered to both the control and experimental groups. The objective was to measure changes in students' motivation levels toward mathematics learning before and after the implementation of the e-learning platform. The pre-test and post-test data on students' mathematics learning motivation are presented in the following table.

Table 8. N-gain Score Learning Motivation

No.	Class	Average Score		Gain	Category
		Pre-test	Post-test		
1	Control	57,91	60,44	0,11	Low
2	Experiment	61	74,83	0,72	High

Source: Data Processed by the Researcher (2025)

The results of the motivation assessment showed that the average pre-test score in the control class was 57.91. In the following session, learning was conducted conventionally without using e-learning, and the learning motivation assessment questionnaire was administered again, resulting in an average score of 60.44. The comparison between pre-test and post-test scores indicated an increase of 2.53 with a gain score of 0.11, which falls into the low category. In the experimental class, the motivation assessment showed an average pre-test score of 61. In the next session, learning was conducted using e-learning, and the learning motivation assessment questionnaire was administered again, resulting in an average score of 74.83. The comparison between the pre-test and post-test scores indicated an increase of 13.83 with a gain score of 0.72, which falls into the high category. The results of the comparative diagram of pre-test and post-test scores for the control and experimental groups are presented in the figure below.

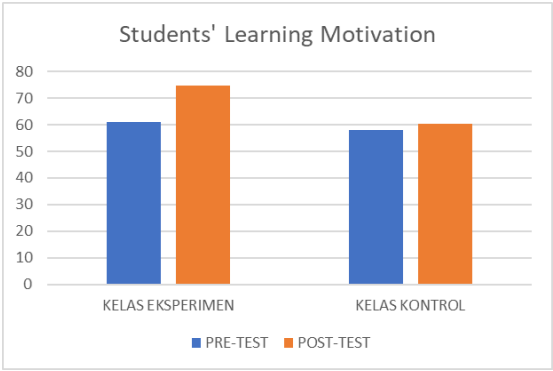


Figure 2. Graph of Students' Learning Motivation

The diagram above demonstrates that both the control and experimental classes showed improvement in their post-test average scores compared to their pre-test results. However, the experimental class exhibited significantly greater score

enhancement than the control group. These findings confirm that the Moodle-based e-learning platform effectively enhances learning motivation in mathematics education.

Self-Directed Learning Assessment Results

The evaluation of students' autonomous learning capabilities was conducted using a 24-item questionnaire measuring nine distinct assessment dimensions. This comparative study administered parallel pre-test and post-test measurements to both control and experimental groups, aiming to quantitatively analyze the impact of e-learning implementation on mathematics students' self-regulated learning competencies. The resulting data set, presented in Table 8, demonstrates longitudinal changes in learner autonomy indicators across both instructional modalities.

Table 9. N-gain Score Self-Directed Learning

No.	Class	Average Score		Gain	Category
		Pre-test	Post-test		
1	Control	65,59	68,91	0,12	Low
2	Experiment	68,24	85,90	0,64	High

Source: Data Processed by the Researcher (2025)

The assessment of students' learning independence showed that the average pre-test score in the control class was 65.59. In the following session, after the implementation of conventional learning without the use of e-learning, the learning independence assessment questionnaire was administered again, resulting in an average score of 68.91. The comparison between the pre-test and post-test scores indicated an increase of 3.32 with a gain value of 0.12, which falls into the low category. Meanwhile, in the experimental class, the average pre-test score for learning independence was recorded at 68.24. After the learning process using e-learning was conducted, the questionnaire was administered again, and the average score rose to 85.90. The comparison between the pre-test and post-test scores in the experimental class showed an increase of 17.66 with a gain value of 0.64, classified as moderate. A diagram comparing the pre-test and post-test scores of the control and experimental groups is presented in the following figure 3.

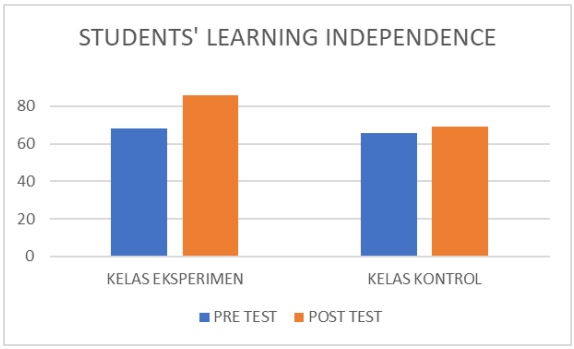


Figure 3. Graph of Students' Learning Independence

The diagram above shows that the average post-test scores in both the control and experimental classes increased compared to the average pre-test scores. However, the increase in post-test scores in the experimental class was more significant than in the control class. Based on these findings, the use of Moodle-based e-learning has proven to be effective in enhancing students' learning independence in mathematics instruction.

The normality test for the data on motivation and self-regulated learning assessments of grade IX students at SMPN 1 was conducted using SPSS 29 with the Kolmogorov-Smirnov and Shapiro-Wilk methods. The decision rule for the normality test was based on the significance value (sig.), where if the sig. value ≥ 0.05, the data was considered normally distributed. The results of the normality test for the experimental class group and the control class group are presented in the following table.

Table 10. Results of the Normality Test for Motivation and Self-Directed Learning Data

Tests of Normality

	Class Group	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Learning Motivation	Experiment	.104	29	.200*	.978	29	.796
	Control	.121	32	.200*	.977	32	.706
Self-Directed Learning	Experiment n	.134	29	.197	.943	29	.122
	Control	.131	32	.175	.971	32	.539

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Based on the results of the normality test for motivation and self-regulated learning assessment data in both the control and experimental groups, the significance values (sig.) were found to be greater than 0.05. This indicates that the data for both variables learning motivation and self-directed learning follow a normal distribution in each group. The findings confirm that the parametric statistical assumptions are met, allowing for further analysis using tests such as t-tests or ANOVA, which require normally distributed data. These results provide a solid foundation for subsequent comparative studies between the two groups, ensuring the reliability of the conclusions drawn regarding the effectiveness of the applied learning interventions.

Evaluation

The evaluation stage is the final phase of this research. In this stage, improvements are made to the developed product. These improvements are based on suggestions and feedback from subject matter experts and media experts during the validation phase.

DISCUSSION

This research implements the development of a Moodle-based e-learning platform specifically designed to enhance the motivation and self-directed learning of mathematics among ninth-grade students at SMPN 1 Kota Bima. The study was conducted over two months, from August to September 2024. The platform is equipped with innovative features such as structured learning materials aligned with the curriculum, interactive exercises with automatic feedback, collaborative discussion forums, and a learning progress monitoring dashboard. The uniqueness of this research lies in its emphasis on synchronous (real-time) interaction to maintain active student engagement while retaining the flexibility of asynchronous access. This hybrid approach distinguishes it from similar studies that typically focus solely on asynchronous learning.

Validation results by subject matter experts reached 88%, while media experts scored it 82%, indicating a high level of feasibility. These findings align with the research of Wahyuaji & Taram, (2018), which reported validation scores above 80% for a similar platform development, as well as Priyasmara et al., (2022), which achieved a 92.3% score in media validation for a Moodle-based e-learning platform for vocational high school students.

Theoretically, these findings are strongly supported by Vygotsky's Constructivism Theory, where collaborative features such as discussion forums and automatic feedback serve as scaffolding to facilitate students' knowledge construction (Shan Jayasinghe, 2024). This is reinforced by the research of Kurniasih et al., (2020), which demonstrated that Android-based learning with high interactivity enhances self-directed learning in mathematics through immediate feedback mechanisms. The development of this Moodle-based e-learning platform is grounded in three key theoretical frameworks that directly shape its core functionalities to enhance motivation and self-regulated learning. Vygotsky's Constructivism theory informs the platform's collaborative design through several innovative applications. The integration of discussion forums and real-time collaborative workspaces operationalizes Vygotsky's concept of social scaffolding, facilitating peer-to-peer knowledge co-construction among learners. A particularly innovative implementation involves the platform's automated feedback system, which has been carefully designed to provide incremental hints aligned with the Zone of Proximal Development (ZPD) principle. This system intelligently adapts to learner progress by gradually reducing scaffolding support as students demonstrate increasing competence, thereby supporting their transition to independent problem-solving. These constructivist elements work synergistically to create a dynamic learning environment that mirrors Vygotsky's emphasis on social interaction and guided learning within educational contexts.

Meanwhile, Knowles' Self-Directed Learning Theory is reflected in students' ability to manage independent learning through progress monitoring features. The platform's design incorporates Knowles' Self-Directed Learning Theory to foster user autonomy through carefully implemented features. Self-monitoring tools such as interactive progress trackers and visual competency heatmaps enable learners to set personal goals

and monitor their development, while modular learning paths provide the flexibility to curate content according to individual needs and preferences - core principles of Knowles' andragogical approach. These autonomous learning features are further enhanced by embedded learning analytics that process user performance data to generate personalized recommendations, creating a dynamic feedback loop that empowers learners to adapt their strategies and optimize their learning journey. This comprehensive implementation of self-directed learning mechanisms not only supports learner independence but also facilitates the development of crucial metacognitive skills through continuous self-assessment and strategy adjustment. These findings are consistent with Munandar et al., (2022) study on Moodle-based e-learning for trigonometry, where 87.23% of students responded positively to the platform's ease of use. Additionally, Keller's ARCS Motivation Theory explains how varied content (videos, text, animations) and reward systems (badges) in Moodle successfully enhance students' attention, relevance, and confidence. Empirical support also comes from (Lubis & Ikhsan, 2015), whose research showed a significant improvement in student motivation and cognitive achievement through Android-based chemistry learning media.

Practically, this research has significant implications for education. Teachers can utilize Moodle features such as interactive quizzes and learning analytics to monitor student progress in real time, as implemented in Indonesia's School Mobilization Program (Havrilova & Beskorsa, 2021). However, challenges such as students' digital literacy gaps must be addressed through pre-implementation training (Siregar et al., 2024). For future research, exploring the integration of the STEAM (Science, Technology, Engineering, Arts, Math) approach is recommended to enrich the creative dimensions of mathematics learning, as proposed by Silva-Hormazábal & Alsina (2023) in the context of STEM approaches.

Overall, the development of this Moodle-based e-learning platform not only reinforces previous empirical findings on improving motivation and self-directed learning but also introduces innovation through the integration of synchronous-asynchronous interaction and self-monitoring features. These findings are theoretically supported by Vygotsky's constructivism. Knowles' self-directed learning theory Munandar et al., (2022) and Keller's ARCS motivation theory, collectively affirming Moodle as an effective learning platform. Moving forward, development recommendations include refining the hybrid (synchronous-asynchronous) model with a more structured approach, referencing recent studies on blended learning (Mendoza & Venables, 2023), integrating interdisciplinary approaches such as STEAM, as proposed in recent mathematics education research (Chen et al., 2019), and conducting further research to test the scalability of this model in various learning contexts, particularly within the framework of post-pandemic education, which demands greater flexibility (Unisco, 2023).

CONCLUSION

This research concludes that the implementation of Moodle-based e-learning effectively enhanced students' learning autonomy in mathematics at SMPN 1 Kota Bima.

This was evidenced by a significant increase in the learning autonomy scores of the experimental group using Moodle compared to the control group. The developed Moodle platform, featuring interactive elements and progress monitoring, was deemed highly feasible by material experts (88%) and media experts (82%), aligning with Vygotsky's Constructivism, Knowles' Self-Directed Learning, and Keller's ARCS Motivation theories. Practically, the study recommends adopting Moodle to improve student interactivity and monitoring, although digital literacy challenges need to be addressed through training. Further development is suggested to integrate the STEAM approach and explore hybrid learning models, allowing this research to contribute to more flexible educational practices in the post-pandemic era. The practicality of this platform was rated as excellent by both teachers and students in small-scale trials. Furthermore, the results of large-scale trials demonstrated a significant increase in the learning autonomy of the experimental group (N-gain 0.64, moderate category) compared to the control group (N-gain 0.12, low category), as well as a considerably higher increase in learning motivation in the experimental group (N-gain 0.72, high category) compared to the control group (N-gain 0.11, low category). Consequently, this study recommends the adoption of Moodle as an effective tool for improving students' autonomy and motivation in mathematics learning, although digital literacy challenges should be taken into account.

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