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MOODLE-INTEGRATED FLIPPED CLASSROOM DESIGN TO ENHANCE STUDENTS' MATHEMATICAL CONCEPTUAL UNDERSTANDING

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ABSTRACT Mathematical conceptual understanding is an essential ability that enables students to interpret, connect, represent, and apply mathematical ideas. However, students still experience difficulties in developing this ability, partly due to procedural and teacher-centered learning practices. This study aimed to design and develop a Moodle-integrated Flipped Classroom and evaluate its validity, practicality, and effectiveness in enhancing students' mathematical conceptual understanding on geometric transformation material. This study employed a Research and Development approach using the Plomp model, consisting of preliminary research, prototyping, and assessment phases. The participants were 32 eighth-grade students at one state junior high school in Medan, North Sumatra. Data were collected through expert validation sheets, teacher and student practicality questionnaires, Moodle log activity data, and pre-test and post-test instruments. The results showed that the Moodle-integrated Flipped Classroom was very valid with a score of 90.6%, very practical with a score of 86.3%, and effective based on the predetermined effectiveness criterion, as indicated by a moderate N-Gain score of 0.51. Learning analytics data showed high student engagement, including a 90.6% video completion rate, an 89.6% quiz completion rate, and 288 forum interactions with a 1.8:1 reply-to-post ratio. The highest improvements occurred in connecting mathematical concepts and applying concepts in new situations. These findings indicate that a systematically designed Moodle-integrated Flipped Classroom can support students' mathematical conceptual understanding through structured independent learning, interactive activities, and collaborative discussion.

Keywords: flipped classroom, learning analytics, mathematical conceptual understanding, moodle, student engagement

ABSTRAK Kemampuan pemahaman konsep matematis merupakan kemampuan penting yang memungkinkan siswa menafsirkan, menghubungkan, merepresentasikan, dan menerapkan ide-ide matematika. Namun, siswa masih mengalami kesulitan dalam mengembangkan kemampuan ini, salah satunya disebabkan oleh praktik pembelajaran yang prosedural dan berpusat pada guru. Penelitian ini bertujuan untuk merancang dan mengembangkan Moodle-integrated Flipped Classroom serta mengevaluasi validitas, praktikalitas, dan efektivitasnya dalam meningkatkan pemahaman konsep matematis siswa pada materi transformasi geometri. Penelitian ini menggunakan pendekatan Research and Development dengan model Plomp yang terdiri atas fase preliminary research, prototyping, dan assessment. Subjek penelitian adalah 32 siswa kelas VIII pada salah satu SMP Negeri di Medan, Sumatera Utara. Data dikumpulkan melalui lembar validasi ahli, angket praktikalitas guru dan siswa, data log aktivitas Moodle, serta instrumen pre-test dan post-test. Hasil penelitian menunjukkan bahwa Moodle-integrated Flipped Classroom berada pada kategori sangat valid dengan skor 90,6%, sangat praktis dengan skor 86,3%, dan efektif berdasarkan kriteria efektivitas yang telah ditentukan, sebagaimana ditunjukkan oleh skor N-Gain sedang sebesar 0,51. Data learning analytics menunjukkan keterlibatan siswa yang tinggi, meliputi video completion rate sebesar 90,6%, quiz completion rate sebesar 89,6%, dan 288 interaksi forum dengan rasio reply-to-post sebesar 1,8:1. Peningkatan tertinggi terjadi pada indikator menghubungkan konsep matematis dan menerapkan konsep dalam situasi baru. Temuan ini menunjukkan bahwa Moodle-integrated Flipped Classroom yang dirancang secara sistematis dapat mendukung pemahaman konsep matematis siswa melalui pembelajaran mandiri yang terstruktur, aktivitas interaktif, dan diskusi kolaboratif.

Kata-kata kunci: flipped classroom, keterlibatan siswa, learning analytics, moodle, pemahaman konsep matematis

INTRODUCTION

Mathematical conceptual understanding is a fundamental ability that enables students to interpret mathematical ideas, connect concepts, use multiple representations, and apply concepts in problem-solving situations. It is not limited to remembering formulas or procedures, but involves understanding the meaning, relationships, and structure underlying mathematical concepts (NCTM, 2000; Rittle-Johnson & Schneider, 2015). However, Indonesian students continue to face difficulties in developing this ability. The PISA 2022 results placed Indonesia 67th out of 81 countries, with an average mathematics score of 366, far below the OECD average of 472 (OECD, 2023). In addition, Setiawan et al. (2023) found that students' mathematical conceptual understanding in geometry remained low, with an average score of 62.65. The 2023 National Assessment also indicated that only 28.7% of lower secondary students achieved proficiency in numeracy, reflecting broader weaknesses in mathematical understanding as a foundation for mathematical literacy (Kemendikbudristek, 2023).

One of the factors contributing to students' low mathematical conceptual understanding is the dominance of procedural learning, which emphasizes memorizing formulas and imitating examples rather than constructing conceptual meaning (Rittle-Johnson & Alibali, 1999; Schoenfeld, 2016). Mathematics learning in Indonesia is still frequently dominated by teacher-centered instruction, where students mainly receive information and have limited opportunities for active engagement, meaningful exploration, collaborative discussion, and independent learning (Rahmania et al., 2023; Trisandi & Saragih, 2024). Haya et al. (2025) further reported that only 32.4% of eighth-grade students in one lower secondary school met the minimum achievement criteria in mathematics, indicating persistent difficulties in understanding and applying mathematical concepts. This condition is also evident in North Sumatra, where Minarni et al. (2016) found that students' mathematical understanding abilities in several public junior high schools were categorized as low and that conventional approaches remained dominant in classroom practice. These findings indicate the need for instructional innovation that can shift learning from teacher-centered explanation toward active, student-centered conceptual construction.

The flipped classroom model offers a relevant alternative to address this issue by shifting initial content learning to the pre-class phase and using classroom time for active learning activities (Li et al., 2024). In a flipped classroom, students first study instructional videos and online learning materials before class, while face-to-face sessions are used for guided problem-solving, discussion, collaboration, and conceptual exploration. This learning structure provides students with more opportunities to process mathematical ideas, ask questions, and construct understanding through interaction. Previous studies have shown that flipped classroom implementation has a positive effect on students' mathematics learning. Purnomo et al. (2022), for example, reported that the flipped classroom model significantly improved students' mathematical abilities. Similarly, Li et al. (2024), through a three-level meta-analysis of K–12 studies, found that flipped classroom designs had positive effects on students' overall performance, cognitive outcomes, and affective outcomes. These findings suggest that flipped classroom learning can be a promising approach for strengthening students' mathematical conceptual understanding.

The successful implementation of the flipped classroom depends not only on the learning model itself, but also on the availability of a digital platform that can systematically support its three learning phases: pre-class, in-class, and post-class activities. An effective platform should be able to host instructional videos, organize learning materials, facilitate discussion, provide quizzes and feedback, manage student access, and track students' learning activities. Moodle, as an open-source Learning Management System (LMS), provides these features and has been widely used in technology-enhanced learning. Gamage et al. (2022), in a systematic review of Moodle use in STEM education, found that Moodle can support student performance, satisfaction, and engagement. Saygili and Çetin (2021) also reported that LMS use in mathematics learning had a positive effect on students' mathematics achievement. In the context of flipped classroom learning, Moodle offers relevant features such as H5P Interactive Video, quiz modules with automatic feedback, discussion forums, activity completion tracking, and conditional activities, all of which can support structured and sequential learning processes (Aldiab et al., 2019; Raspopovic et al., 2017). Yorganci (2025) further showed that online flipped learning integrated with Moodle improved student engagement and self-regulation.

Despite the growing number of studies on flipped classroom learning and Moodle integration, several research gaps remain. First, many flipped classroom studies still focus on general academic achievement and do not specifically examine students' mathematical conceptual understanding based on clear indicators, such as restating concepts, classifying objects, representing concepts, connecting mathematical ideas, and applying concepts in new situations (Akçayır & Akçayır, 2018; NCTM, 2000). Second, many studies have not sufficiently utilized system log data or learning analytics to describe how students actually engage in digital learning environments. Learning analytics can provide empirical information about video completion, quiz completion, forum participation, login frequency, and time spent on learning activities. Algayres and Triantafyllou (2020) noted that learning analytics in flipped classrooms has strong potential to predict learning outcomes and support adaptive learning, yet many studies remain limited to general correlations between engagement and performance. Doo and Park (2024) also emphasized the importance of analyzing students' pre-class video-watching behavior to better understand engagement in flipped classroom learning. Third, Moodle-based learning is often implemented merely as a repository for videos and materials, rather than being systematically designed according to the syntax of flipped classroom learning. Previous Moodle-based flipped learning studies have reported improvements in learning outcomes and engagement (Mursyidah et al., 2021; Yorganci, 2025), but they have not fully integrated systematic Moodle design, conceptual understanding indicators, and learning analytics data within a single research and development framework.

Based on these gaps, this study aims to design and develop a Moodle-integrated flipped classroom and evaluate its validity, practicality, and effectiveness in enhancing students' mathematical conceptual understanding. The design was systematically structured into three phases: pre-class, in-class, and post-class activities. This study focuses on geometric transformation material, which requires spatial visualization and conceptual connections and is therefore suitable for technology-enhanced learning environments (Kandaga et al., 2022; Medina Herrera et al., 2024). By integrating Moodle features, flipped classroom syntax, conceptual understanding indicators, and learning analytics, this study is expected to provide both a validated learning design and empirical evidence of how students engage with digital learning activities in relation to the development of mathematical conceptual understanding.

METHODS

This study employed a Research and Development (R&D) approach using the Plomp model (Plomp & Nieveen, 2013), which consists of three main phases: (1) Preliminary Research, (2) Prototyping Phase, and (3) Assessment Phase. This model was chosen because it is research-oriented and provides a systematic framework for developing educational technology products while simultaneously evaluating their validity, practicality, and effectiveness.

Preliminary Research. This phase involved needs analysis through observations and interviews with mathematics teachers and students at junior high schools in North Sumatra, as well as a literature review on Flipped Classroom, Moodle, and mathematical conceptual understanding. The analysis identified that students struggled with abstract mathematical concepts and that teachers needed digital platforms that could support independent learning, collaboration, and activity tracking. Content analysis determined that geometric transformation material was suitable for Moodle-integrated Flipped Classroom implementation due to its visual and interactive nature.

Prototyping Phase. This phase involved designing and developing Moodle version 4.1, which was systematically structured according to Flipped Classroom syntax. The platform integrated key features, including H5P Interactive Video for pre-class learning, Quiz Module for diagnostic assessment, Forum Discussion for collaborative learning, and Activity Completion Tracking with Conditional Activities to ensure structured learning pathways. The prototype was developed for three topics: (1) symmetry in geometric patterns, (2) geometric transformations, and (3) plane figures. The prototype was evaluated by three experts, namely a media expert, an instructional design expert, and a mathematics content expert, and was revised based on their feedback until it was deemed ready for implementation.

Assessment Phase. This phase evaluated the Moodle-integrated Flipped Classroom in terms of validity, practicality, and effectiveness. The research subjects were 32 eighth-grade students at a junior high school in North Sumatra, selected through purposive sampling based on internet access availability and technological readiness. Implementation was conducted over three weeks with five meetings: three core material meetings, one review session, and one post-test session.

Research Subject. The research subjects consisted of 32 eighth-grade students at one state junior high school in Medan, North Sumatra, Indonesia. The subjects were selected using purposive sampling based on the following criteria: (1) the school had adequate technological infrastructure, including internet access and computer laboratory facilities, (2) the mathematics teacher was willing to participate in the implementation of the Moodle-integrated Flipped Classroom, and (3) the students had not previously experienced flipped classroom instruction. The subjects were involved in the Assessment Phase of the Plomp model, which included pre-test administration, three weeks of Moodle-integrated Flipped Classroom implementation, and post-test administration.

Data Collection. Four types of data were collected in this study. First, expert validation data were obtained using validation sheets consisting of 25 items with a five-point Likert scale to assess media design, instructional design, content quality, and feature suitability. Second, practicality data were collected through questionnaires for teachers and students, each consisting of 20 items using a five-point Likert scale to measure ease of use, interface attractiveness, time efficiency, and learning motivation. Both questionnaires were validated by the same three experts prior to use to ensure that the items accurately reflected the measured constructs and were clearly worded. Revisions were made based on expert suggestions before the questionnaires were administered. Third, system log activity data were automatically recorded by Moodle, including video completion rate, quiz completion rate, forum participation, average time spent per session, and login frequency. Fourth, mathematical conceptual understanding data were collected through tests consisting of 10 essay questions based on the five NCTM (2000) indicators, administered as pre-test and post-test. Prior to implementation, the instrument was validated by three experts: one mathematics education lecturer, one language lecturer, and one mathematics teacher. Validation covered three aspects: content validity, construct validity, and language clarity. All items were reviewed, and necessary revisions were made based on expert feedback before the instrument was used in data collection.

Data Analysis. Validity and practicality were analyzed using the following percentage formula:

$$V = (\text{Total obtained score} / \text{Maximum score}) \times 100\%$$

The interpretation criteria are presented in Table 1.

Table 1. Validity and Practicality Criteria

Percentage (%)	Validity Category	Practicality Category
85–100	Very Valid	Very Practical
70–84	Valid	Practical
55–69	Fairly Valid	Fairly Practical
<55	Less Valid	Less Practical

Effectiveness was measured using the N-Gain formula (Hake, 1998):

$$\text{N-Gain} = (\text{Post-test score} - \text{Pre-test score}) / (\text{Maximum score} - \text{Pre-test score})$$

The N-Gain score criteria are presented in Table 2.

Table 2. N-Gain Score Criteria

N-Gain Score	Category
$g \geq 0.70$	High Improvement
$0.30 \leq g < 0.70$	Moderate Improvement
$g < 0.30$	Low Improvement

N-Gain was calculated for each of the five NCTM indicators to provide detailed insights into mathematical conceptual understanding improvement. In this study, effectiveness was evaluated within the framework of Research and Development

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rather than experimental research. Consistent with the Plomp model and prior R&D studies in mathematics education (Plomp & Nieveen, 2013; Mursyidah et al., 2021), the effectiveness criterion refers to the extent to which the intervention produces the desired learning outcomes as indicated by pre-test to post-test improvement. A minimum N-Gain of 0.30, or the moderate category, was set as the criterion for the product to be considered effective. Learning analytics data from Moodle system logs were analyzed descriptively to document student engagement patterns across meetings, including video completion rates, quiz completion rates, forum participation, average time spent, and login frequency.

FINDING AND DISCUSSION

Moodle Design for Flipped Classroom

The final Moodle design was structured systematically according to the three phases of Flipped Classroom learning. Each of the three topics (symmetry in geometric patterns, geometric transformations, and plane figures) contained: (1) H5P Interactive Video (8–12 minutes) presenting mathematical concepts through visual and interactive elements, (2) diagnostic quizzes consisting of 10 multiple-choice questions to assess students' initial understanding, (3) discussion forums for reflective and collaborative learning, (4) digital worksheets that could be downloaded for in-class activities, and (5) activity completion tracking that ensured students completed pre-class activities before accessing subsequent materials. Teachers could monitor student activities in real time through the Activity Completion Report feature, which displayed completion rates, access frequency, and forum participation for each student.

Validity of Moodle-integrated Flipped Classroom

In the Assessment Phase of the Plomp model, the validity of the Moodle-integrated Flipped Classroom was evaluated through expert judgment. The platform achieved a very valid status (90.6%), indicating that the product developed during the Prototyping Phase had met the required standards of content quality, instructional design, and feature suitability. The Moodle prototype was validated by three experts using validation sheets consisting of 25 items with a five-point Likert scale. Table 3 presents the validation results from the three experts.

Table 3. Expert Validation Results

Aspect	Media Expert (%)	Learning Design Expert (%)	Content Expert (%)	Mean (%)	Category
Interface Design	92.0	88.0	-	90.0	Very Valid
Flipped Classroom Model	-	93.3	90.0	91.7	Very Valid

Aspect	Media Expert (%)	Learning Design Expert (%)	Content Expert (%)	Mean (%)	Category
Video Content Quality	90.0	85.0	95.0	90.0	Very Valid
Mathematics Content	-	86.7	93.3	90.0	Very Valid
Feature Suitability	90.0	95.0	90.0	91.7	Very Valid
Overall Validity	**90.8**	**89.6**	**92.0**	**90.7**	**Very Valid**

Table 3 shows that the Moodle-integrated Flipped Classroom obtained an average validity percentage of 90.7%, categorized as very valid. The aspect with the highest assessment was conformity with the Flipped Classroom model (91.7%), indicating that the Moodle design was appropriately structured according to Flipped Classroom syntax. Interface design, video content quality, and mathematics content quality each received 90.0%, demonstrating that both the content and platform design met the expected quality standards.

Practicality of Moodle-integrated Flipped Classroom

Still within the Assessment Phase, practicality was evaluated through teacher and student questionnaires following implementation. The very practical status (86.3%) suggests that the Moodle-integrated Flipped Classroom designed in the Prototyping Phase was well received by users in terms of ease of use, interface attractiveness, and learning support. Practicality testing was conducted through questionnaires given to teachers and students after the implementation of learning. Table 4 presents the practicality results from both teacher and student perspectives.

Table 4. Practicality Results from Teachers and Students

Aspect	Teacher (%)	Students (%)	Mean (%)
Ease of use	89.0	84.0	86.5
Interface attractiveness	85.0	87.0	86.0
Content clarity	88.0	83.0	85.5
Time efficiency	86.0	85.0	85.5
Feature completeness	90.0	-	90.0
Suitability with FC needs	88.0	-	88.0
Increased learning motivation	-	86.0	86.0
Helped understanding concepts	-	87.0	87.0
Overall Practicality	**87.0**	**85.6**	**86.3**

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Table 4 shows that the Moodle-integrated Flipped Classroom received a very practical category from both teachers (87.0%) and students (85.6%), with an overall average of 86.3%. Teachers gave the highest ratings for feature completeness (90%) and ease of use (89%), indicating that Moodle facilitated the management of the pre-class phase and supported student readiness before face-to-face learning. Students gave the highest ratings for interface attractiveness and the extent to which the platform helped them understand concepts (87%), indicating that the videos and Moodle features supported contextual understanding of mathematical concepts. These practicality results indicate that the Moodle-integrated Flipped Classroom is easy to use, attractive, and practical for supporting mathematics learning in the study context.

Student Engagement Patterns Based on Log Activity Data

To understand the level of student involvement in Moodle-integrated Flipped Classroom learning, an analysis was conducted on log activity data automatically recorded by the system. This log data provides empirical evidence of how students engaged with the digital learning platform and how their engagement patterns evolved throughout the implementation. Table 5 presents student activity data across three main meetings.

Table 5. Student Engagement Patterns from Moodle Log Activity Data

Metric	Meeting 1	Meeting 2	Meeting 3	Average
Video Completion Rate (%)	87.5	90.6	93.8	90.6
Quiz Completion Rate (%)	84.4	90.6	93.8	89.6
Forum Posts (total)	68	82	91	80.3
Initial posts	27	29	31	29.0
Replies/comments	41	53	60	51.3
Average Time Spent (minutes)	22.3	26.7	28.5	25.8
Average Login Frequency	2.1	2.4	2.6	2.4
Total Forum Interactions	-	-	-	288*

Total cumulative forum interactions across all meetings: three main meetings and one review session.

Table 5 reveals several important patterns of student engagement. First, the video completion rate showed a consistent increase from 87.5% in Meeting 1 to 93.8% in Meeting 3, with an average of 90.6%. This high completion rate indicates that nearly all students watched the videos to completion, suggesting that the video content was engaging and relevant. The progressive increase across meetings also indicates that students became increasingly accustomed to following the pre-class phase.

Second, the quiz completion rate also showed improvement from 84.4% in Meeting 1 to 93.8% in Meeting 3, with an average of 89.6%. This high quiz completion rate indicates that students actively tested their initial understanding before face-to-face learning, in line with the Flipped Classroom principle that emphasizes student readiness in the pre-class phase. The Conditional Activities feature, which required students to complete pre-class activities before accessing subsequent materials, helped ensure systematic learning progression.

Third, forum participation demonstrated a positive trend. Total forum interactions increased from 68 posts in Meeting 1 to 91 posts in Meeting 3, with an average interaction per student reaching 2.5 times per meeting. More importantly, the ratio of replies/comments (51.3 on average) to initial posts (29.0 on average) was approximately 1.8:1, indicating that the discussion forum was not merely used as a space for individual reflection but also as a collaborative space where students engaged in dialogue, helped each other explain concepts, and negotiated meaning. The total of 288 forum interactions across the entire implementation demonstrates high social engagement and knowledge construction through peer interaction.

Fourth, average time spent on the Moodle platform increased from 22.3 minutes in Meeting 1 to 28.5 minutes in Meeting 3, with an overall average of 25.8 minutes per session. This increase indicates that students became more engaged in exploring learning materials over time, rather than merely accessing content superficially. Combined with the increasing login frequency from 2.1 to 2.6 times, this pattern shows sustained and repeated engagement, which is important for supporting mathematical conceptual understanding.

These engagement patterns provide empirical evidence that students were actively involved in the digital learning process. The high and increasing engagement metrics distinguish this study from previous research that focused mainly on system design or learning outcomes without sufficiently analyzing actual usage patterns and their pedagogical implications.

Improvement in Mathematical Conceptual Understanding

The effectiveness evaluation, also conducted in the Assessment Phase, revealed a moderate N-Gain score of 0.51, indicating that the product met the predetermined effectiveness criterion in improving students' mathematical conceptual understanding. This finding is consistent with the goal of the Assessment Phase in the Plomp model, which aims to demonstrate that the developed product produces the expected learning outcomes. The effectiveness of the Moodle-integrated Flipped Classroom in improving students' mathematical conceptual understanding was measured through pre-test and post-test consisting of 10 essay questions based on the five NCTM (2000) indicators. Table 6 presents the results of pre-test, post-test, and N-Gain for each indicator.

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Table 6. Pre-test, Post-test, and N-Gain Results for Mathematical Conceptual Understanding

NCTM Indicator	Pre-test	Post-test	N-Gain	Category
Restating a concept	56.3	78.1	0.50	Moderate
Classifying objects based on properties	52.8	76.4	0.50	Moderate
Presenting concepts in various representations	51.6	75.3	0.49	Moderate
Connecting mathematical concepts	49.7	77.8	0.56	Moderate
Applying concepts in new situations	50.2	76.9	0.54	Moderate
Average	52.1	76.9	0.51	Moderate

Table 6 shows that there was an improvement in students' mathematical conceptual understanding scores across all five NCTM indicators. The average pre-test score of 52.1 increased to 76.9 in the post-test, representing an improvement of 24.8 points. N-Gain analysis yielded an average value of 0.51, categorized as moderate improvement, indicating that learning using the Moodle-integrated Flipped Classroom met the effectiveness criterion in improving students' mathematical conceptual understanding.

The indicator with the highest improvement was "connecting mathematical concepts" with an N-Gain of 0.56, followed by "applying concepts in new situations" with an N-Gain of 0.54. These results are particularly noteworthy because they represent higher-order aspects of conceptual understanding. The ability to connect concepts requires students to see relationships between different mathematical ideas, while the ability to apply concepts in new situations demonstrates flexible understanding that can be transferred to unfamiliar contexts. The improvement in these two indicators suggests that the Moodle-integrated Flipped Classroom approach, particularly through interactive videos in the pre-class phase and collaborative discussions in forums, helped students build relational understanding rather than merely instrumental understanding.

The other three indicators, restating concepts (N-Gain = 0.50), classifying objects based on properties (N-Gain = 0.50), and presenting concepts in various representations (N-Gain = 0.49)—also showed moderate improvement, although slightly lower. This pattern indicates that the Moodle-integrated Flipped Classroom supported students' conceptual understanding across multiple dimensions. Overall, all indicators showed positive and meaningful improvement, demonstrating that the developed learning design was effective based on the predetermined effectiveness criterion.

This study demonstrates that the Moodle-integrated Flipped Classroom was valid (90.7%), practical (86.3%), and effective in improving students' mathematical conceptual understanding based on the predetermined effectiveness criterion (N-Gain = 0.51). The most significant contribution of this study lies in the integration of learning analytics data, which provides empirical evidence of actual student engagement. High video completion rates (90.6%), quiz completion rates (89.6%), and extensive forum interactions (288 total interactions with a 1.8:1 reply-to-post ratio) demonstrate that the platform facilitated active learning rather than passive content consumption. This engagement pattern was aligned with improvements in higher-order indicators such as connecting concepts (N-Gain = 0.56) and applying concepts in new situations (N-Gain = 0.54).

The effectiveness of the Moodle-integrated Flipped Classroom can be understood through Vygotsky's (1978) Zone of Proximal Development theory. The discussion forum created a space where students negotiated meaning through social interaction, with the high reply-to-post ratio indicating active peer scaffolding. This peer-mediated learning may help explain why "connecting concepts" and "applying concepts in new situations" showed the highest improvement. In addition, Bruner's (1966) enactive-iconic-symbolic theory helps explain the role of H5P Interactive Video, where visual representations bridged concrete experiences and abstract mathematical symbols, while interactive elements promoted active processing and deeper conceptual understanding.

The moderate improvement found in this study (N-Gain = 0.51) is consistent with Cheng et al. (2019), who found that the Flipped Classroom had greater effects on conceptual understanding than procedural knowledge. The increasing engagement patterns are also in line with Wei et al. (2020), who found improvements in performance, engagement, and self-regulated learning through flipped classroom implementation. The practicality results are consistent with Mursyidah et al. (2021), while the validity results align with Gamage et al. (2022), confirming that well-designed Moodle-based learning can meet educational technology standards and support student engagement.

Unlike previous studies that mainly reported learning outcomes (Akçayır & Akçayır, 2018), this study provides more detailed learning analytics showing how students engaged with the platform. This responds to the need for more attention to student engagement patterns in Moodle-integrated flipped learning (Yorganci, 2025). While Giannakos et al. (2015) found that video completion rates often decrease significantly, this study showed consistently high rates (90.6%) and progressive increases across meetings. This result may be related to the use of H5P Interactive Video and Conditional Activities, which transformed video watching into an integral part of the learning pathway rather than an optional activity.

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Theoretically, this study demonstrates how learning analytics integration can provide deeper insights into learning processes by showing how students participate in digital learning activities. The systematic LMS design using Conditional Activities, H5P Interactive Video, and structured forums coherently supported each phase of the Flipped Classroom, addressing the need for more structured flipped classroom implementation as noted by Bishop and Verleger (2013). Practically, the specific design features, short videos of 8–12 minutes, embedded quizzes, conditional access, and structured forum prompts, offer adaptable templates for mathematics teachers. The learning analytics approach also enables evidence-based improvement through real-time monitoring and timely intervention.

Despite these contributions, this study has several limitations. The sample size was limited to 32 students from one school, and the implementation was conducted over a relatively short period of three weeks. In addition, this study did not use inferential statistics to examine the relationship between engagement data and learning outcomes, did not involve a comparison group, and focused only on one mathematical topic at one grade level. Future research should involve larger multi-site studies, longer implementation periods, comparative designs, more sophisticated learning analytics techniques, and qualitative explorations of user experiences across different mathematical topics and grade levels.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results and discussion, it can be concluded that the Moodle-integrated Flipped Classroom designed according to three learning phases, pre-class, in-class, and post-class, was valid, practical, and effective in enhancing students' mathematical conceptual understanding based on the predetermined effectiveness criterion. The product achieved a very valid category with an average score of 90.7%, a very practical category with an average score of 86.3%, and a moderate N-Gain score of 0.51. These results indicate that the developed Moodle design met the quality criteria of an educational development product. In addition, Moodle log activity data showed high student engagement, as reflected in the video completion rate, quiz completion rate, forum interactions, time spent on the platform, and login frequency. The highest improvements were found in the indicators of connecting mathematical concepts and applying concepts in new situations, suggesting that the integration of interactive videos, structured activities, and collaborative forums supported students' conceptual learning processes.

Based on these findings, mathematics teachers may consider using Moodle-integrated Flipped Classroom as an alternative learning design, especially for topics that require visualization, representation, and conceptual connections. The use of short interactive videos, diagnostic quizzes, conditional access, and structured discussion forums can help organize students' independent and collaborative learning activities more systematically. Schools are also encouraged to provide sufficient technological support and teacher training focused not only on technical

LMS operation but also on pedagogical design. For future research, broader implementation involving larger samples, longer learning periods, different mathematical topics, and comparative designs is recommended to strengthen the evidence regarding the effectiveness of Moodle-integrated Flipped Classroom in supporting students' mathematical conceptual understanding.

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