Jupiter: Jurnal Pendidikan Terapan
Homepage : https://journal.diginus.id/jupiter/index
Email: jurnalpendidikanterapan@gmail.com.

p-ISSN : 2985-3214; e-ISSN : 2964-3171
Jupiter, Vol. 4, No. 3, July 2026
Page 529-543

Artificial Intelligence and Gamification-Integrated Analytic Geometry Instruction: Design and Implementation in Higher Education

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ARTICLE INFO
Article history:
Submitted: May, 21 2026
Final Revised: June, 19 2026
Accepted: June, 28 2026
Published: July, 31 2026
Keywords:
Analytic Geometry; Artificial Intelligence; Gamification; Higher Education; Mathematics Education.

ABSTRACT
Purpose: This study aims to: (1) design an Analytical Geometry learning model that integrates Artificial Intelligence (AI) and gamification, and (2) identify the strengths and limitations of AI in supporting mathematics learning, particularly within Analytical Geometry lectures in higher education. **Methods:** The study employed a qualitative Design-Based Research (DBR) approach that began from a classroom phenomenon and tested the design empirically in an authentic course. Participants were 20 undergraduate students from mathematics education study program. Data were collected through documentation, observation notes, and AI-generated outputs, then analyzed using descriptive, content and thematic analysis. **Findings:** The developed learning design includes three stages: Introduction, Main Points, and Closing. Gamification elements are embedded in all stages, while AI integration occurs primarily in the Main Points stage to support conceptual explanation of Wordwall-generated problems. AI proved effective in providing step-by-step problem-solving explanations but demonstrated limitations in geometric visual representation and mathematical notation accuracy. Wordwall served effectively as an assessment tool capable of identifying students' learning difficulties. **Research Implications:** The findings suggest that integrating AI and gamification into Analytical Geometry learning is associated with improved instructional clarity and student engagement, although careful instructional planning is required to address AI's limitations in visual and symbolic mathematical representation. **Originality:** This study contributes novelty by presenting a practical, systematically designed model for integrating AI and gamification into Analytical Geometry learning using DBR, documenting how lecturer can implement it in real classrooms and offering empirical insights into the capabilities and constrains of AI in higher-level mathematics instruction.

Doi: https://doi.org/10.61255/jupiter.v4i3.1196

INTRODUCTION

Analytical Geometry is a fundamental undergraduate course in the Mathematics Education Study Program in Indonesia, combining geometric concepts with algebra, requiring advanced critical thinking and mathematical communication skills. Prospective teacher students must not only master mathematical concepts but also be able to communicate mathematical ideas clearly and logically (National Council of Teachers of Mathematics, 2024). However, conventional Analytical Geometry instruction faces various challenges. Research shows that students often struggle to visualize abstract concepts, connect algebraic representations with geometry, and communicate their mathematical thinking processes systematically (Sunzuma & Maharaj, 2019).

Developments in educational technology, particularly Artificial Intelligence (AI) and gamification, offer innovative solutions to address these challenges. AI such as ChatGPT and Gemini have demonstrated potential in providing structured mathematical explanations and accessible learning support (Pepin et al., 2025; Wardat et al., 2023). Meanwhile, gamification platforms like Wordwall can increase student engagement and provide comprehensive learning analytics data (Ndraha et al., 2024). In Indonesia, although students are increasingly familiar with ChatGPT and other AI tools, systematic and planned pedagogical integration remains rare (Habibi et al., 2024)

The literature review revealed several significant gaps in research on the integration of AI and gamification in mathematics learning. First, there is a lack of concrete documentation of learning designs. Many studies use AI or gamification, but few document how the learning designs were developed, including specific components, time allocation, and sequence of activities (Buchholtz et al., 2024). Second, there is a lack of description of teacher actions. Research tends to focus on student outcomes but rarely documents teacher actions that facilitate technology integration (Almarashdi et al., 2024). Third, there is a lack of reflection on implementation challenges. The literature often presents idealized versions without candid discussion of the challenges faced and how to overcome them. Fourth, there is a separate integration of AI and gamification. Most studies focus on either AI or gamification, but rarely explore the synergistic integration of both. Fifth, the Indonesian context is underexplored. Most studies on AI integration are conducted in Western or East Asian countries, while implementation in the Indonesian context, with its distinct institutional and cultural characteristics, is still minimally documented.

Based on these gaps, this study aims to: (1) design Analytical Geometry learning that systematically integrates AI (ChatGPT and Gemini) and gamification using the Wordwall platform, (2) document the implementation of the design, especially teacher actions and instructional decisions, and (3) identify the strengths and limitations of AI in supporting geometry learning. This study makes important contributions in several aspects. The practical contribution is providing a concrete learning design model that can be adapted by mathematics lecturers to integrate AI and gamification in lectures, including specific pedagogical strategies and detailed teacher actions. The methodological contribution is using a Design-Based Research approach that emphasizes iteration and refinement, resulting in evidence-based and contextually grounded design principles. The contribution to teacher education is preparing prospective mathematics teachers not only as competent AI users, but also as future educators who can integrate AI pedagogically sound in their classrooms.

AI in Mathematics Education

The development of Large Language Models (LLMs) such as ChatGPT, Gemini, and Claude has ushered in a new paradigm in mathematics learning. A scoping survey by Pepin et al. (2025) identified ChatGPT as having potential in assisting mathematical concept understanding, lesson planning, assessment design, and personalized learning. However, the same survey also emphasized the importance of human oversight and ethical considerations in leveraging ChatGPT for mathematics education.

Research by Wardat et al. (2023) found ChatGPT effective in solving basic mathematical problems and providing structured, step-by-step explanations. However, the same study also identified a significant limitation: ChatGPT struggled with complex geometric concepts, particularly those involving spatial visualization and geometric construction. This finding was confirmed by Wei (2024), who reported that ChatGPT-4 and ChatGPT-4o performed worse on geometry and measurement problems than on algebra problems.

In the context of pre-service mathematics and geometry teachers, Buchholtz et al. (2024) conducted an exploratory study on the use of ChatGPT for constructing mathematical proofs in geometry. The results showed that although students had limited prior experience with LLMs and mostly demonstrated superficial knowledge of the technology, they were able to use ChatGPT with structured guidance to support geometric proving. This study emphasized the importance of instrumental genesis, the process by which students develop schemes of utilization for technology tools. Similarly, Yoon et al. (2024), in an exploratory study of undergraduate students using AI to prove mathematical statements, found that productive use depends on student's conceptions of proof and of AI, and concluded that students need explicit guidance to engage critically with AI outputs rather than accept them passively.

A systematic review by Almarashdi et al. (2024) of ChatGPT in transforming mathematics teaching and learning found that ChatGPT offers diversified responses that facilitate lesson planning and student support. However, this review also identified that ChatGPT struggles to answer complicated or difficult mathematical questions, indicating limitations in specific topics such as spatial geometry. This indicates that AI should be used as a complement to, rather than a replacement for, traditional instruction. More recent studies reinforce this picture, ChatGPT can support explanation and problem-solving in mathematics teaching, yet its effective use depends on careful pedagogical framing (Dasari et al., 2024; Taani & Alabidi, 2025)

Studies on Gemini AI in mathematics education are still relatively limited. Olivares Funes et al. (2024) conducted research on the integration of GeoGebra applets and Gemini AI for differential equations and found that Gemini AI complements GeoGebra by providing a personalized, adaptive learning experience. This combination of tools represents a significant advancement in educational technology integration for mathematics learning in higher education.

Gamification in Mathematics Learning

Gamification in education refers to the use of game design elements in non-game contexts to increase motivation and engagement (Deterding et al., 2011). A systematic literature review by Jutin and Maat (2024) confirmed that gamification consistently improves students' motivation, retention, and mathematical performance while reducing math anxiety. This review analyzed various gamification elements such as leader boards, points, and badges and found that when implemented effectively, these elements positively impact motivation and engagement. In higher education specifically, gamified designs have been shown to support engagement and motivation (Panis et al., 2020), and generative-AI-supported activities show comparable engagement potential (Au et al., 2025).

In the Indonesian context, Ndraha et al. (2024) developed mathematics learning media using Wordwall with the ADDIE instructional design framework. The results showed that the media was valid in terms of content, language, and visual design; highly practical with positive responses from more than 90 percent of students and teachers; and effective in improving learning interest with an average increase of 25 percent and learning outcomes with an N-gain of 0.62 in the medium-high category. The novelty of this study lies in positioning Wordwall not merely as a gamification tool, but as an interactive learning medium systematically integrated within the instructional design framework.

Rezeki and Amelia (2025) evaluated the effectiveness of Wordwall in enhancing senior high school students' cognitive abilities in mathematics learning (Phase E). Through quasi-experimental research with a pre- and post-test group design, the study found statistically significant differences indicating Wordwall's effectiveness in improving mathematics learning outcomes. This study expands the evidence base on Wordwall effectiveness from elementary and junior high school to senior high school and potentially higher education contexts.

Recent research by Mudrika et al. (2024), examining a Wordwall-assisted problem-based learning model, found that Wordwall-assisted gamification supported students' higher-order thinking skills, particularly critical thinking and mathematical problem-solving. These findings indicate that gamification, when designed thoughtfully, can enchace higher-order thinking rather than merely boost engagement. Alt (2023) compared four conditions of mathematics learning activities and found that problem-based digital gamification was most beneficial for game experience and motivation. This indicates that gamification is most effective when integrated with problem-based learning approaches, not simply as a superficial addition to game elements.

AI and Critical Thinking

Critical thinking, broadly understood as reflective and reasonable judgement about what to believe or do (Ennis, 2011) and as purposeful, self-regulatory evaluation and inference (Facione,1990), is a central goal of mathematics education. There are two contrasting views in the literature on the relationship between AI and critical thinking. The pessimistic perspective, articulated by Essel et al. (2024) in a systematic review of the impact of AI-based Chabot on higher education learning, warns that over-reliance on AI can weaken analytical thinking and problem-solving skills. This review identifies concerns that students will adopt AI answers uncritically, reducing their cognitive engagement in the learning process. This concern is particularly relevant in mathematics education, where the development of reasoning skills is a central learning objective.

Conversely, the optimistic perspective argues that AI, when used with appropriate pedagogical design, can actually enhance critical thinking. Melisa et al. (2025) in a systematic review of critical thinking in the age of AI found that ChatGPT can stimulate further exploration through quick and diverse responses, encouraging students to delve deeper into complex topics. Crucially, students who use ChatGPT to study texts, data, or arguments must critically assess AI outputs, which in turn trains their critical evaluation skills. This perspective views AI as a cognitive scaffolding tool that, with proper guidance, can enhance rather than diminish critical thinking capabilities. In mathematics specifically, Barana et al. (2023) showed that activities requiring students to solve problem with AI and then evaluate and correct the AI's solution paths can foster both problem solving and critical thinking, reinforcing the idea that AI can be integrated into learning and assessment rather than restricted.

Zhai et al. (2024), in a comprehensive review of AI in education from 2010 to 2020, provides a balanced perspective, identifying that the effectiveness of AI in supporting learning depends on how it is integrated into pedagogical practices. This review emphasizes the importance of teacher mediation in ensuring that AI tools are used to support meaningful learning rather than superficial task completion.

METHOD

This research uses a qualitative descriptive approach with a Design-Based Research (DBR) framework. The qualitative descriptive approach was chosen because this research aims to describe the learning design and its implementation process in depth and systematically, not to test hypotheses or measure effectiveness through experiments. The DBR framework was used because this research simultaneously develops instructional innovation (AI-gamification integrated instruction) and produces an understanding of implementation processes. This choice reflects the flexible yet systematic character of DBR (Bakker, 2018; Wang & Hannifin, 2005), rather than following the fixed, lengthy procedures of development R&D models or the controlled conditions of experiments, DBR allows the inquiry to begin from a real classroom phenomenon, that is, the challenge of integrating AI into Analytic Geometry instruction, and to test the researcher's design idea empirically in an authentic setting. The study thus embodies the pragmatic, grounded, flexible, integrative, and contextual characteristics of DBR, yielding an applicable instructional design together with transferable design principles.

The DBR cycle in this research consists of three phases: (1) Initial Design Development, which begin not from a formal needs analysis but from a phenomenon observed in the classroom, specifically the challenge of designing Analytic Geometry instruction that can be meaningfully integrated with AI, and then develops the instructional design based on literature review on AI integration, gamification, and Analytic Geometry instruction. (2) Implementation and Data Collection, which involves implementing the design in the actual Analytical Geometry course, collecting data on implementation processes, documenting teacher actions, student responses, and challenges; (3) Reflection and Refinement, which involves analysing implementation data, identifying what worked and what didn't, refining the design based on empirical evidence, and formulating implementation principles. Through this cycle, the study produces a complete instructional design as its final product, empirically testing the effectiveness of this design is positioned as the next step for subsequent research. The overall of DBR process from the initiating classroom phenomenon, trough the three phases is summarized in Figure 1.

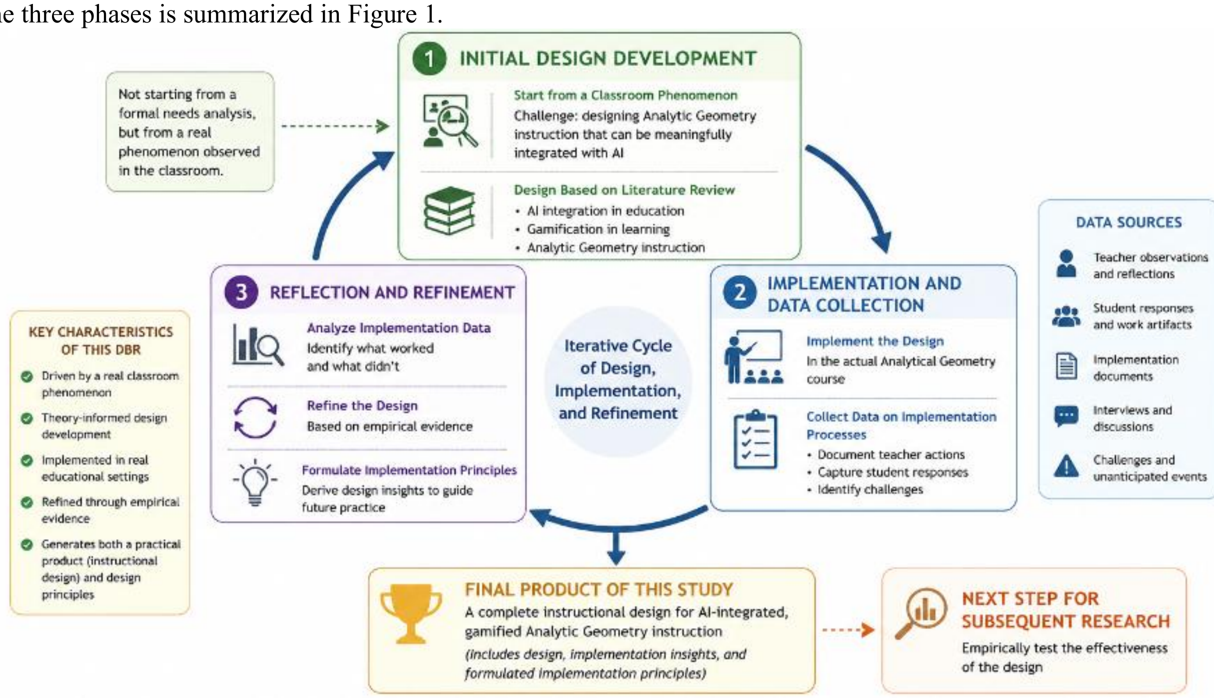

Figure 1. The Design-Based Research process of this study

The research was conducted in the Mathematics Education Study Program at the Islamic University of Malang (UNISMA), a university in East Java, Indonesia. The Analytical Geometry course carries 3 credits. The activity was carried out in the even semester of 2024/2025. Participants consisted of 23 fourth-semester undergraduate students who had completed prerequisite courses, namely Calculus I, Calculus II, and Euclidean Geometry. Of these, 20 students attended the three data collection sessions and are the participants whose interactions and responses were documented. Participant characteristics included having access to a smartphone or laptop with an internet connection; familiarity with the use of AI tools; based on a pre-survey, 95% of students had used ChatGPT to complete assignments, although mostly for non-mathematics-specific applications. Data collection spanned three consecutive 150-minutes sessions (3 x 50 minute credit hours) within this semester. Across these sessions, the researchers compiled the complete set of lesson-design documents, state-by-stage observation field notes and seven screenshot of students and AI interactions (three from ChatGPT and four from Gemini). Students accessed the AI tools on their own smartphones, some through the installed ChatGPT app and others through a web browser, so the collected screenshots are captures of their phone screens.

This study was conducted in accordance with institutional research ethics requirements. Approval was obtained from LPPM Universitas Islam Malang, and all 23 enrolled students provided informed consent prior of this study. Students were informed of purpose of the research, the voluntary nature of participation, and their right to withdraw at any time. Specific permission was obtained to collect and analyzed screenshots of their interactions with ChatGPT and Gemini, and all data were anonymized before analysis.

Learning Design

The learning design was developed through several systematic steps. Step 1: Needs Analysis, based on previous experience teaching Analytical Geometry, identified that students struggle with conceptual understanding, such as line equations. Traditional lectures are insufficient for diverse learner needs, there is limited time for individual feedback, and there is a need for efficient and engaging formative assessment. Step 2: Defining Learning Objectives, for the session on line equations, learning objectives include determining the equation of a line through two points, determining the equation of a line with a given gradient, determining the equation of a parallel or perpendicular line, using AI tools to support problem-solving, and critically evaluating AI-generated solutions. Step 3: Technology Selection and Rationale, where Wordwall was chosen for formative assessment because it provides immediate feedback for students, generates real-time analytics on class performance, has an engaging interface with gamification elements, and allows for easy creation and customization of questions. ChatGPT and Gemini were chosen for AI-assisted problem solving because they have free versions accessible to all students, are capable of explaining mathematical concepts step-by-step, support multimodal input in the form of text and images, and are widely used, increasing relevance for students' future professional practice. Step 4, Designing Instructional Sequence, developed with three design stages, stage 1 is Introduction (35 minutes) to set the stage, activate prior knowledge, prepare for technology usage; stage 2 is Main Points (100 minutes) to assess student understanding, identify difficulties, teach using AI, critically discuss; and stage 3 is Closing (15 minutes) to consolidate learning, assign independent practice.

Data Collection

Data was collected through several methods to ensure triangulation. First, learning design documentation included detailed lesson plans with time allocations, technology setup instructions, guiding questions and prompts, and rationales for each design decision. Second, implementation observation field notes included what actually happened (vs. what was planned), teacher actions at each stage, student responses and engagement levels, technical issues and how they were resolved, and spontaneous instructional decisions and rationales. Third, AI output documentation included screenshots of AI interactions from ChatGPT and Gemini (with student permission), which were then analyzed to identify patterns in AI responses, strengths, and limitations.

Data Analysis

Data analysis was conducted using three complementary approaches. First, descriptive analysis for the learning design, compiling comprehensive descriptions of the initial design (as planned), actual implementation (what happened), and deviations between planned and actual, along with explanations. This analysis focused on documenting design components, time allocations, activity sequences, and rationales for design decisions.

Second, content analysis for AI outputs, namely AI responses from ChatGPT and Gemini, was analysed deductively using predetermined categories: (a) Structural elements, presence of step-by-step explanations, use of mathematical notation, inclusion of visual representations; (b) Mathematical accuracy, correctness of solutions, appropriateness of methods used; (c) Pedagogical quality, clarity of explanations, accessibility of language, and support for conceptual understanding. This analysis aimed to identify the strengths and limitations of AI in supporting geometric reasoning.

Third, thematic analysis for implementation processes, field notes, and reflective journals was analysed inductively to identify recurring themes. Thematic analysis focuses on: (a) Teacher actions, specific actions taken at each stage to facilitate learning and technology integration; (b) Implementation challenges, technical, pedagogical, or organizational obstacles encountered; (c) Solutions employed how challenges were addressed in-the-moment; (d) Student engagement patterns observation of student responses, questions, and interactions with AI tools. Themes emerged through iterative reading and coding of field notes, with attention to both anticipated and unexpected occurrences.

RESULTS

Integrated Learning Design with AI and Gamification

The developed learning design consists of three stages with a total duration of 150 minutes (3 credits x 50 minutes). Each stages has clearly defined specific purposes, activities, teacher actions, and technology roles. The complete structure of the learning design is presented in Table 1.

Table 1. Learning Design Structure

Stage	Duration (minutes)	Objective	Main Activities	Technology Used
Introduction	35	Preparing students cognitively, affectively, and technically	Greeting and prayer; convey learning objectives; technology preparation (Wordwall)	Wordwall (preparation)
Main points	100	Assessment, teaching integrated with AI, critical discussion	Wordwall formative quiz (15 minutes); item analysis & conceptual review (20 minutes); AI-assisted problem solving (40 minutes); Critical analysis of AI outputs (25 minutes)	Wordwall, ChatGPT, Gemini and other AI tools
Closing	15	Consolidating learning and transfer knowledge	Synthesis and reflection; independent practice assignment; closing prayer	ChatGPT, Gemini homework: Wordwall, Visualization from GeoGebra

The Introductory Stage (35 minutes) begins with an opening ritual that includes greetings, a recitation of Sholawat Nuril Anwar, and an opening prayer. This ritual is important in the institutional context for establishing community, transitioning students from outside activities to learning mode, and creating a sense of continuity. Next, the lecturer explicitly communicates learning objectives, emphasizing that the use of AI and critical evaluation of AI outputs are integral to learning. Technology preparation includes sharing the Wordwall quiz link via QR code and WhatsApp group, ensuring all students can access the platform, and troubleshooting technical issues such as Wi-Fi connectivity or low battery life with solutions like password sharing and device pairing.

The Main points Stage (100 minutes) is the core of instruction where AI and gamification are most actively integrated. This stage begins with a 15-minute Wordwall formative quiz containing four multiple-choice questions about line equations. The lecturer provides clear instructions that AI should not be used during the quiz to obtain baseline data on student understanding. Following the quiz, item analysis is conducted with students (10 minutes), where the lecturer projects Wordwall analytics and identifies questions with the highest error rate. Transparency about data and instructional decisions promotes metacognition and data-driven teaching models. Conceptual review (10 minutes) is conducted through interactive questioning to activate relevant prior knowledge about the concepts of gradient, the equation of a line through two points, and perpendicular lines. This review is intentionally brief, merely a refresher, not a comprehensive teaching method, as depth will come in the AI-assisted problem-solving phase.

AI-assisted problem solving (40 minutes) is the heart of the lesson. The instructor provides explicit instruction on using AI: AI as a cognitive tool, not an answer generator, a screenshot demonstration of the method for uploading problems to ChatGPT or Gemini, and an emphasis on understanding the process, not just getting answers. Students work individually or in pairs, uploading screenshots of problems to their chosen AI tool, analysing AI outputs, and discussing them with peers or the instructor. Teacher actions during this stage include: circulating the classroom to observe screens and provide just-in-time support, asking probing questions such as 'What did the AI say?', 'Do you understand this step?', and facilitating a whole-class discussion about AI reasoning and comparing outputs from different models.

Critical analysis of AI outputs (25 minutes) uses structured guiding questions: Are the steps provided by the AI complete and logical? Does the AI explain using sketches or images? Is the mathematical notation used appropriate? What are the limitations of this AI output? Through this systematic analysis, students identify that the AI is strong in explanation and argumentation, but weak in visual representation and proper mathematical notation. Remember, when the AI doesn't provide a clear sketch, instructors can use other tools like GeoGebra to visualize the problem. Remember, after providing a sketch with GeoGebra, instructors should review with students how to draw their own sketches as a meaningful learning experience.

The closing stage (15 minutes) includes synthesis and reflection, where the lecturer facilitates a brief reflection on what was learned, both about the content and the process of using AI. Independent practice assignments are given, encouraging students to use AI but also verify and elaborate. Students are also asked to plot lines using GeoGebra to address AI's limitations in visual representation. This stage concludes with a final prayer. As a note, lecture is at the end of sub-material, at the closing stage a quiz can be given using Wordwall as an individual assignment. The overall flow with its tool-integration points is illustrated in Figure 2.

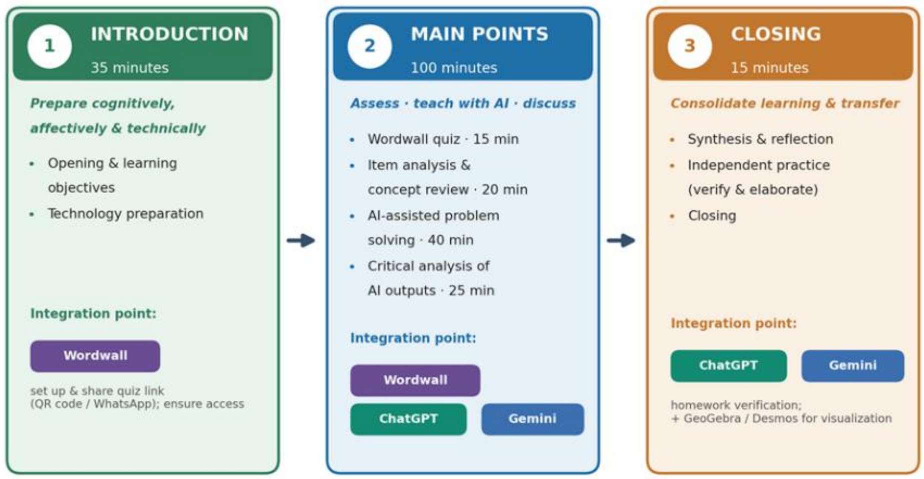

Figure 2. Three-stage instructional flow and the integration points

Teacher Actions in Implementation

Implementing learning design requires active and deliberate teacher actions at each stage. Table 2 provides a detailed breakdown of teacher actions per stages.

Table 2. Teacher Actions in Learning Implementation

Stage		Teacher Actions	Rationale
Introduction	Opening	Lead opening ritual with warm tone; present objectives clearly; circulate to assist technical issues; ensure all students access before proceed.	Build community; set expectations; ensure accessibility; prevent disruptions
	Wordwall Quiz	Share Wordwall link via multiple channels; Clarify rules (no AI during quiz); monitor real-time dashboard; observe student engagement; do not interrupt, allow independence	Obtain baseline data; diagnostic assessment; promote autonomy
Main Points	Item Analysis	Project analytics openly; identify difficult items transparently; explain instructional decisions; model data literacy	Data-driven instruction; professional modeling
	AI Introduction	Frame AI as cognitive tool; demonstrate screenshot method; emphasize critical stance; set expectations for evaluation	Establish proper AI-usage norms; reduce anxiety; promote critical thinking
	AI Problem Solving	Circulate classroom; ask probing questions; provide just-in-time support; facilitate whole-class discussion; compare multiple AI outputs	Active facilitation; scaffold learning; make thinking visible; promote peer learning
	Critical Analysis	Provide guiding questions; lead systematic analysis; validate diverse perspectives; synthesize insights about AI strengths or limitations	Develop evaluative skills; structured reflection; balanced perspective
Closing		Facilitate reflection; connect to future teacher identity; give clear assignment	Consolidate learning; professional identity; promote transfer

	guidelines; encourage multimodal tool use	

Based on Table 2, after giving a quiz with Wordwall, enter the main points stage on the item analysis by reviewing the students' answers, based on the results of the wordwall (see Table 5), namely the first discussion is question number 4 (see Figure 1). The lecturer determines that question number 4 will be discussed first. Entering the AI Introduction stage, the lecturer opens a dialogue with the class to jointly use AI to check the answer to number 4, presented in a dialogue excerpt that has been translated into English in Session I.

Lecturer: "Okay, before we discuss question number 4, have you ever used AI?"
Students: "Yes, ma'am..." (answers almost simultaneously)
Lecturer: "What AI do you use?"
Students: "Gemini,..."; (several answer simultaneously)
Students: "ChatGPT..."; (several answer simultaneously)
Lecturer: "Okay, it doesn't matter which AI you use. What we're looking at isn't the name of the AI, but how it answers, whether the concepts presented are correct, and whether you understand the AI's explanations." Now, try asking the AI you frequently use question number 4."

(The lecturer gives students time to ask the AI...)

(Session I)

Lecturers need to give the class time to ask questions to the AI they are using, which is also a break to enter the AI Problem Solving stage by using examples of trigger questions. Through these trigger questions, the lecturer invites students to criticize the AI's answers, which are presented in the dialogue excerpts in Session 2.

Lecturer: "Have you received an answer from the AI?"
Students: "Yes..."
Lecturer: "Now, look carefully and check the AI's solution steps. Do you understand them?"
(Several students murmur): Hmmm... not really...
Student A: "There are steps from Gemini, but I don't quite understand them. Can you explain them further?"
Lecturer: Okay, this is from the Gemini team, what about the ChatGPT team?
Several Students: Explain that too, ma'am...
Lecturer: Okay, one can display the answer from ChatGPT and the other can display the Gemini results.
(Lecturer explains the AI steps and concepts learned in Analytical Geometry)
Lecturer: "Next, is there anything else you don't understand?"
Student B: (raises finger) "Ma'am, there's a symbol do not understand has appeared in my results that I don't understand. (See Figure 4)
Lecture: (Asks Student A to show and share in the WhatsApp group)
"The symbol that appears in Student B's Gemini is an example of a LaTeX symbol, {frac}, which comes from the word fraction, which is written as 1/2."
Students: "Oh..."
Lecture: "Is there an AI that displays graph sketches?"
Students: "No, ma'am..."

(Session 2)

After ensuring there are no problems, the lecturer can continue the discussion to the next question or close the learning activity.

Strengths and Limitations of AI in Geometry Learning

An analysis of AI outputs from ChatGPT and Gemini reveals consistent patterns of AI's strengths and limitations in supporting geometric learning. In terms of strengths, both AI tools consistently provide structured, step-by-step explanations that students can follow. AI is able to break down complex problems into manageable steps, explaining mathematical reasoning at each step. For example, when given the problem of finding the equation of a line perpendicular to a given line through a point, AI systematically: (1) identifies the slope of the original line, (2) applies the perpendicular slope rule, multiplication the gradients of line are minus one, (3) uses point-slope form to construct a new equation, and (4) simplifies to standard form (Figure 3 and 4). This explanation structure is helpful for students who struggle with knowing where to start in problem-solving.

AI also demonstrates strong capability in mathematical reasoning and argumentation. Explanations typically include not just procedural steps but also rationales explaining why certain approaches are used. This is particularly valuable in developing students' understanding of mathematical thinking processes. Furthermore, the AI was responsive to follow-up questions, allowing students to request clarifications or additional examples, creating a personalized interactive learning experience.

However, the analysis also revealed significant limitations, summarize in Table 3. The most prominent limitation was the inability to generate proper geometric visualizations. Across the collected solutions, both ChatGPT and Gemini answered purely algebraically and produced no sketch of the line (Figure 3 and 4); neither tool offered to visualize the line, leaving its geometric representations entirely to the student. In class, the student. In class, the students later confirmed that none of the AI tools had produced a graph or sketch (classroom observation, Session 2). This is a critical limitation because geometric visualization is a fundamental component of geometric.

The second limitation is improper mathematical notation. In some responses the AI rendered fractions correctly, yet in others it displayed raw LaTeX-style markup such as '\frac{1}{2}' and 'm_1' instead of conventional symbols (Figure 4), at times even within the same response. While technically accurate, such markup can confuse students who are unfamiliar with LaTeX conventions and expect conventional mathematical notation. Several students were initially puzzled by such markup and needed the lecturer's help to interpret it, as the classroom exchange below illustrates.

The third limitation is variability in response quality depending on prompt specificity. When students upload screenshots without accompanying text prompts, AI sometimes provides overly brief responses or makes assumptions about what is being asked. This highlights the importance of teaching students effective prompting strategies, not just using AI, but using it well. Observations also reveal that although AI outputs are generally mathematically correct for problems at this level, occasional errors do occur, particularly in multi-step problems. This underscores the necessity of critical verification, students cannot simply accept AI outputs as authoritative but must develop the habit of checking and evaluating.

Table 3. Summary of Observed AI Limitations in Analytic Geometry Tasks

Category	Indicator	Illustrative observation	Evidence
Geometric visualization	No geometric figure produced	Solutions remained purely algebraic; no figure or sketch of the line was produced or offered	Figures 3–4
Mathematical notation	Inconsistent rendering of symbols	Some fractions rendered correctly, but raw LaTeX-style \frac{1}{2}, and m_1 appeared in others	Figure 4
Prompt sensitivity	Variable response quality	Screenshot-only prompts without text yielded overly brief or assumption-laden answers	Field notes (Session 2)

Note: each limitation is evidenced by screenshots of ChatGPT and Gemini outputs (Figures 3–4) together with observation field notes; no aggregate frequency count is reported because the analysis is illustrative rather than statistical.

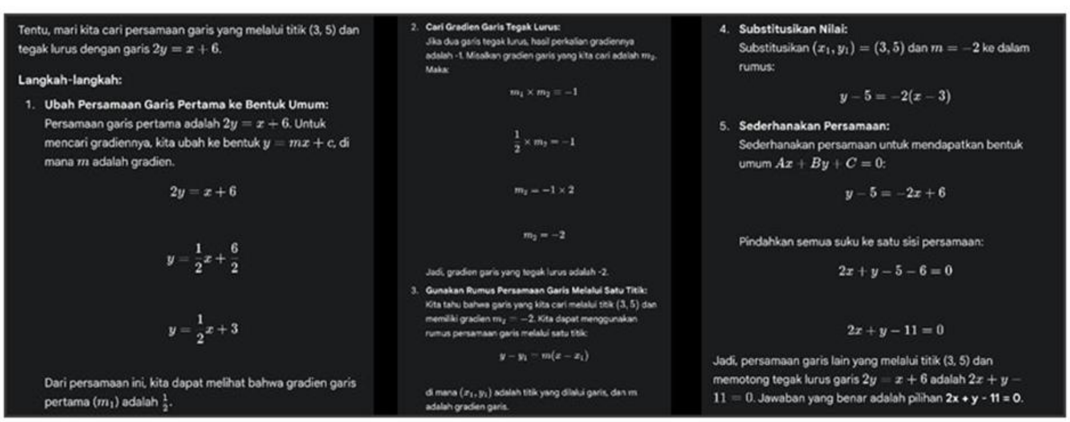

Figure 3. ChatGPT's capture

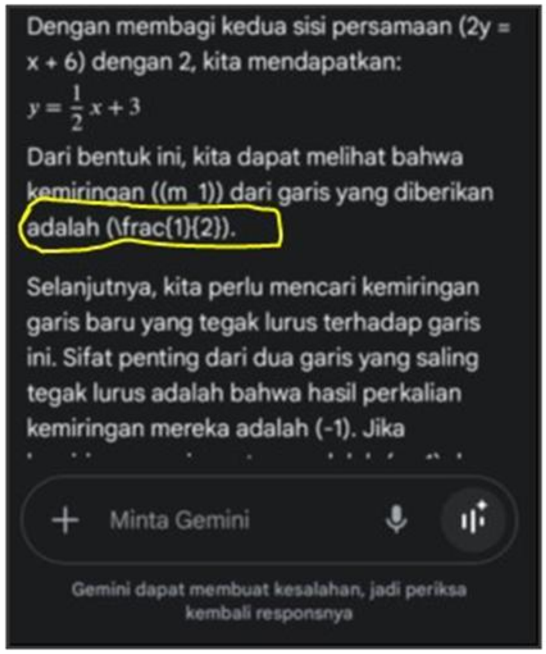

Figure 4. Ax Gemini response with displaying raw LaTeX-style

Based on direct evidence from the classroom (Session I and Session II), a classroom exchange during the review of AI answers illustrates how the critical-analysis phase unfolded (Session 2; translated from Indonesian). When the lecturer asked which AI tools the students had used, several answered at once, naming both Gemini and ChatGPT. The lecturer then redirected their attention from the choice of tool to the quality of reasoning: “It does not matter which AI you use; what we examine is not the name of the AI but how it answers, whether the concept it gives is correct, and whether you understand its explanation.” Shortly afterwards, one student raised her hand and said, “Ma'am, a symbol I do not understand has appeared in my result,” pointing to the raw ‘\frac’ mark (Figure 4). The lecturer asked her to display it and explained that ‘frac’ stands for ‘fraction’, so ‘\frac{1}{2}’ means one-half; the students then signalled their understanding. When the lecturer subsequently asked whether any AI tool had produced a graph or sketch, the students confirmed that none had. This exchange shows the lecturer explicitly orienting students toward evaluating the correctness and comprehensibility of AI output rather than its source, and it surfaced, in the students' own words, the notation and visualization limitations noted above.

A second exchange shows the lecturer bridging these limitations directly. After asking the students to look closely at the AI's steps and check whether they understood them, the lecturer was met with hesitation, and one student admitted, “There are steps from Gemini, but I cannot quite understand them, may they be explained again?” (Session 2). The lecturer responded by working through the solution again, clarifying that the term the AI had used, ‘kemiringan’, was simply the ‘gradien’ (gradient) the students were accustomed to, and to compensate for the AI's missing visualization sketching the graph of the resulting line, $2x + y - 11 = 0$, before re-explaining how the gradient can be read from the equation. Here the teacher actively bridged two frictions left by the AI, its unfamiliar terminology and its inability to provide a geometric representation.

DISCUSSION

AI in Geometry Learning

The results of this study indicate that AI can function effectively as a support for mathematical reasoning, in line with the perspective proposed by Zhai et al. (2024) on AI's role in supporting learning. AI's strengths in analysis, inference, and explanation mean that AI can help students understand how to break down a problem and construct step-by-step reasoning. For students who struggle with initial problem formulation or don't know where to begin, AI provides a crucial entry point, aligning with the Vygotskian notion of scaffolding as temporary support that helps learners operate in the Zone of Proximal Development.

However, consistent with the findings of Buchholtz et al. (2024) regarding pre-service teachers using ChatGPT for geometric proving, this study confirms that truly effective scaffolding must gradually fade and be accompanied by explicit critical engagement activities. Essel et al.'s (2024) concern that AI potentially weakens critical thinking is legitimate if AI usage is not accompanied by deliberate strategies to promote independent thinking and verification. The results of this study indicate that when students only receive AI outputs without being prompted to evaluate and reflect, opportunities to develop higher-order thinking skills may be missed.

The optimistic perspective of Melisa et al. (2025) that AI can enhance critical thinking when used with proper pedagogical design is confirmed in this study. Structured critical analysis activities using guiding questions proved effective in developing students' evaluative skills. Students learned not just to use AI, but to use it critically by questioning outputs, verifying steps, and identifying limitations. This represents an important shift from passive consumption of AI-generated content to active critical engagement with it.

Limitations of AI in Geometry

The inability of AI (both ChatGPT and Gemini) to generate accurate geometric visualizations, as found in the studies of Wei (2024) and Almarashdi et al. (2024), is a critical limitation that should not be ignored. Analytical geometry inherently relies on the interplay between algebraic representations and geometric visualizations. AI that is only strong in algebraic manipulation but not in visualization leaves a significant gap in supporting conceptual understanding. This reinforce the continuing value of dedicated dynamic-geometry tools such as Geogebra for visual reasoning in geometry (Batiibwe, 2024).

The finding of Gemini's limitations in geometric visualization is interesting considering recent advances in multimodal AI. The study by Olivares Funes et al. (2024) on Gemini integration with GeoGebra shows that Gemini can function effectively when paired with visualization tools. This suggests a promising direction: rather than expecting a single AI tool to address all learning needs, adopt a multimodal integration approach where different tools complement each other's strengths. AI's limitations in visualization underscore the importance of multiple representations in mathematical thinking. Over-reliance on AI that is only strong in symbolic representation can impoverish students' representational flexibility. Therefore, integrating visualization tools like GeoGebra is not optional but essential for comprehensive geometric learning.

Observations also reveal that although AI outputs are generally mathematically correct for problems at this level, occasional errors do occur, particularly in multi-step problems. This underscores the necessity of critical verification: students cannot simply accept AI outputs as authoritative but must develop the habit of checking and evaluating. Such occasional lapses are consistent with evaluations of GPT's uneven performance on mathematics assessment items (Korkmaz Guler et al., 2024).

Wordwall as a Gamified Assessment Tool

Although this study did not deeply analyze Wordwall item statistics (reserved for a future article), the implementation confirmed the value of Wordwall as a gamified assessment tool that generates actionable data in real time, in line with the findings of Ndraha et al. (2024) and Rezeki and Amelia (2025). The real value of Wordwall in this instructional design context is enabling assessment for learning (formative) rather than just assessment of learning (summative). As summarized in Table 4, Question 4 which asked students to find the line through (3,5) perpendicular to $2y = x + 6$ stood out as markedly the most difficult item, answered correctly by only 9 students, incorrectly by 8, and left unanswered by 3, whereas each of the first three items was answered correctly by 16 students. This pattern allowed the lecturer to target the AI-assisted problem-solving phase on precisely that problem, the same perpendicular-line task that ChatGPT and Gemini were later asked to solve (Figures 3 and 4). A deeper analysis of student learning and representational ability is reserved for a separate study.

Table 4. Item-level results of the Wordwall Quiz

Question	Correct	Incorrect	No answer
1	16	4	0
2	16	3	1
3	16	4	0
4	9	8	3

(Source: Wordwall result)

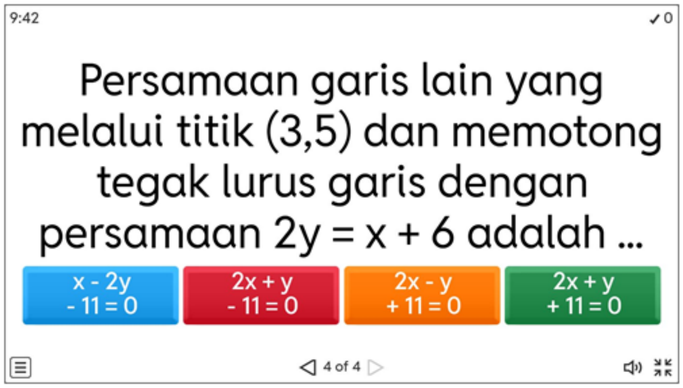

Figure 5. Question number 4 in Wordwall

Consistent with the findings of Jutin and Maat (2024) on gamification effectiveness and Mudrika et al. (2024) on Wordwall supporting higher-order thinking, the use of Wordwall in this study demonstrates how gamification, when thoughtfully integrated, can serve pedagogical purposes beyond mere engagement. Wordwall data immediately revealed areas of difficulty, allowing instructors to strategically allocate instructional time, this is an efficient use of limited class time and models data-driven decision-making for future teachers.

Teacher Actions as a Critical Success Factor

The results of this study strongly emphasize that technology integration depends heavily on teacher actions. Technology alone does not teach; rather, thoughtful teacher facilitation transforms technology into a learning tool. This aligns with the emphasis of Almarashdi et al. (2024) and Pepin et al. (2025) on the importance of human oversight in AI integration.

Teacher actions identified in this study include explicit framing of the AI role, modelling effective prompting, facilitating critical discussion, and adaptive teaching based on real-time observations, representing professional expertise that cannot be automated. Even with powerful AI tools available, the quality of the learning experience is determined by the quality of teacher decision-making and facilitation. Teacher actions bridge the limitations of AI in geometric visualization and encourage students to critique each step provided by the AI, verifying it with appropriate concepts. To address AI's shortcomings in visualization, lecturers encourage students to create visual representations based on the information in the problem, then linking it to the concepts needed to answer the problem and develop solutions. These actions were directly observed in the classroom (Session 2), the lecturer redirected students from the choice of AI tool toward evaluating whether the AI's concept was correct and understood, clarified the AI's mismatched terminology, and sketched the graph that the AI could not produce concrete instances of a teacher bridging AI's limitations in real time. Based on the findings and theoretical analysis, five design principles emerge, researcher summarized in Table 5.

Table 5. Design Principles, Their Empirical Basis, and Supporting Literature

No	Principle	Empirical basis in this study	Extends / supported by
1	Technology purpose must be explicit	Explicit framing of AI as a cognitive tool shaped how students engaged with it	Pepin et al. (2025); Almarashdi et al. (2024)
2	Scaffold technology use	Modelling the screenshot/prompting method enabled productive AI use	Buchholtz et al. (2024)
3	Critical engagement must be designed in	Structured guiding questions produced evaluative, not passive, AI use	Melisa et al. (2025); Barana et al. (2023); Yoon et al. (2024)
4	Multimodal integration	AI's visualization gap required pairing with GeoGebra	Olivares Funes et al. (2024)
5	Teacher actions are central	Real-time facilitation bridged AI limitations and prompted student verification	Zhai et al. (2024); Pepin et al. (2025)

AI in the Indonesian Context

This research was conducted in an Indonesian higher education context with prospective mathematics teacher students. Findings from Habibi et al. (2024) on ChatGPT acceptance and use among students in five Indonesian universities show a positive adoption trend but also highlight the need for systematic pedagogical integration. The results demonstrate that with thoughtful instructional design and active teacher facilitation, AI and gamification integration can be effectively implemented even in contexts with varying levels of technological infrastructure. Specifically for teacher education, students' dual roles as learners and future educators make this integration particularly valuable: students not only learn mathematical content and critical thinking skills but also experience firsthand what thoughtful technology integration looks like, which can inform their future practice as teachers.

Limitations

This study has several limitations. The single-case implementation was limited to one course with one cohort of students, limiting generalizability. Its short duration, focused on three lecture sessions, did not capture long-term effects. Limited in scope, this study focused on the design and its implementation process and did not measure learning outcomes quantitatively through pre-post assessments. Because the aim was to produce and document the instructional design itself, the effectiveness of the resulting design has not yet been empirically tested; evaluating its effect on student learning is therefore the most important next step. Promising future research directions include experimental or quasi-experimental evaluation of the design's effectiveness on mathematical understanding, critical thinking, and communication; comparative studies of different AI-gamification integration approaches; investigation of fading strategies; and testing design transferability across topics, institutions, and cultural contexts.

CONCLUSION

This study designed, implemented, and documented a three-stage Analytic Geometry lesson (35-minute Introduction, 100-minute Main Points, 15-minute Closing) integrating AI (ChatGPT and Gemini) with gamification (Wordwall) for undergraduate mathematics education students. AI supported step-by-step explanation and reasoning but was limited in geometric visualization and notation; Wordwall enabled data-driven formative assessment; and active teacher facilitation proved decisive. Because this study set out to produce and document the design rather than to measure its effects, these results are context-specific and the recommendations below are transferable design guidance whose effectiveness still needs to be tested empirically.

For practitioners, the study suggests: (1) design AI integration deliberately at specific points, using assessment data to time it (from the documented design and Wordwall-guided sequencing); (2) teach AI literacy and verification explicitly (from structured critical-analysis activities, not mere access, producing evaluative use); (3) pair AI with visualization tools such as GeoGebra (from AI's observed visualization gap); (4) invest in teacher facilitation skills (from facilitation bridging AI limitations); and (5) document and share designs and reflections (from this study's own documentation contribution). Ultimately, success depends not on adopting technology but on pedagogical integration that treats it as a means rather than an end.

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ACKNOWLEDGEMENT

The authors thank the students of the Analytic Geometry course at Universitas Islam Malang who participated in this study, as well as colleagues whose feedback strengthened the instructional design and analysis. This research was funded and ethically approved by the Institute for Research and Community Service (LPPM), Universitas Islam Malang.

AUTHOR CONTRIBUTION STATEMENT

TCW contributed to conceptualization, methodology, supervision, validation, writing – original draft, and writing review & editing. S and ZA contributed to methodology, formal analysis, investigation, resources, and writing, review & editing. Also contributed to data curation, investigation, project administration, and writing original draft. All authors have read and approved the final version of the manuscript.

AI DISCLOSURE STATEMENT

The authors used ChatGPT (OpenAI) during the preparation of this work for limited language editing and grammar improvement. After using the tool, the authors carefully reviewed and revised the manuscript and take full responsibility for the accuracy, integrity, and content of the publication.

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