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Edumath: ADDIE-Based Interactive Media for Improving Fifth-Grade Students' Critical Thinking in Plane Geometry

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ABSTRACT

Purpose: Edumath interactive media was developed to evaluate its validity, practicality, and effectiveness in improving fifth-grade students' critical thinking in plane geometry, addressing the limited empirical evidence on systematically developed and evaluated interactive media for elementary geometry learning. **Methods:** A Research and Development approach employed the ADDIE model and a quasi-experimental nonequivalent control group pretest–posttest design. Participants included 59 fifth-grade students (30 experimental and 29 control). Data were collected through expert validation sheets, teacher and student response questionnaires, and critical thinking tests. Subject-matter, media, and learning experts evaluated the product. Data were analyzed using descriptive statistics, reliability testing, *t*-tests, and normalized gain (N-gain). **Findings:** Edumath achieved an average validity score of 88.67%, based on evaluations from the subject-matter expert (89%), media expert (87%), and learning expert (90%), indicating high validity. Teacher and student responses reached 90% and 89%, respectively, demonstrating high practicality. The critical thinking instrument included eight valid essay items with a Cronbach's Alpha of 0.825. The experimental class improved from 18.17 to 26.67, significantly outperforming the control class ($t(57) = -8.388$, $p < .001$), and achieved a moderate N-gain (0.63) compared with 0.29 in the control class, confirming Edumath's effectiveness. **Research Implications:** Edumath provides a valid, practical, and effective digital resource for interactive geometry instruction that strengthens elementary students' critical thinking. **Originality:** Unlike previous studies examining digital mathematics media separately, ADDIE-based interactive media development was integrated with quasi-experimental evaluation while aligning instructional features with critical thinking indicators in fifth-grade plane geometry learning.

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INTRODUCTION

Critical thinking has become a fundamental competence in twenty-first-century education because students are expected not only to acquire knowledge but also to analyse information, evaluate evidence, solve problems, and make reasoned decisions in increasingly complex situations. This competence aligns with Sustainable Development Goal (SDG) 4, which emphasizes quality education that equips learners with higher-order thinking skills essential for lifelong learning. Within mathematics education, critical thinking enables students to interpret quantitative and spatial information, justify mathematical reasoning, and solve authentic problems rather than merely apply memorized procedures (Geiger & Schmid, 2024). Recent studies further indicate that instructional approaches promoting active reasoning, reflection, and problem solving significantly improve students' critical thinking and higher-order thinking skills in mathematics (Barz et al., 2024; Hanggara et al., 2024; Yesnazar et al., 2024). Therefore, strengthening critical thinking has become a major priority in elementary mathematics education, where foundational reasoning skills are first established and influence students' future mathematical learning.

Plane geometry presents unique cognitive demands because students must simultaneously coordinate spatial visualization, mathematical reasoning, and conceptual understanding to solve geometric problems. Rather than memorizing formulas, learners are expected to analyse relationships among shapes, angles, sides, perimeter, and area, justify mathematical reasoning, and evaluate alternative solution strategies. However, these cognitive processes are difficult to achieve through conventional instruction because geometric concepts are inherently abstract and often lack meaningful visual representation. Consequently, students frequently develop misconceptions and experience high cognitive load, limiting their ability to analyse relationships, justify reasoning, and construct mathematical conclusions. Recent studies demonstrate that interactive visual representations, dynamic geometry environments, and concrete–virtual manipulatives significantly improve geometric thinking, conceptual understanding, and mathematical reasoning while reducing cognitive load among elementary learners (Gurmu et al., 2024; Siller & Ahmad, 2024; Walkington et al., 2024;Wu et al., 2024). Collectively, these findings suggest that effective geometry instruction requires learning environments that intentionally integrate visualization, mathematical reasoning, and reflective thinking. Nevertheless, evidence regarding the implementation and effectiveness of such instructional support in elementary classrooms remains limited, highlighting the need to examine existing classroom conditions before developing and evaluating an appropriate instructional solution.

Evidence from the research setting confirmed that these challenges were also evident in elementary mathematics classrooms. Interviews with the fifth-grade teacher at SD Negeri 1 Kunden revealed that students participated passively during geometry lessons, rarely justified mathematical reasoning, seldom sought additional learning resources, and experienced difficulty drawing evidence-based conclusions when solving problems. These classroom observations were corroborated by the 2024 School Education Report, which documented a decline in the critical reasoning indicator from 51% to 48%, while overall numeracy achievement remained at 66.67%. The decline indicates that fewer students were able to analyse information, justify mathematical reasoning, evaluate alternative solution strategies, and formulate evidence-based conclusions despite demonstrating moderate numeracy achievement, reflecting core dimensions of critical thinking in mathematics learning (Geiger & Schmid, 2024;Hanggara et al., 2024). This pattern suggests that existing instructional practices have not adequately supported the higher-order thinking processes required for meaningful geometry learning, where conceptual understanding and mathematical reasoning should develop simultaneously (Gurmu et al., 2024). Consequently, instructional innovation integrating interactive learning and explicit critical thinking processes is required to strengthen students' conceptual understanding and mathematical reasoning in elementary geometry (Debrenti, 2024);Utaminingsih et al., 2024).

Recent studies consistently demonstrate that interactive learning media enhance elementary mathematics learning by strengthening critical thinking, conceptual understanding, mathematical reasoning, and student engagement. Interactive digital worksheets and multimedia applications have been reported as valid, practical, and effective in improving students' critical thinking and analytical skills (Moriska & Hanif, 2024). Likewise, interactive multimedia integrated with realistic geometry learning has significantly improved mathematical reasoning and conceptual understanding (Alim et al., 2024), while ADDIE-based digital learning resources and interactive technologies have promoted meaningful learning experiences through visualization, immediate feedback, and active student participation (Aprilia et al., 2024; Saccardo et al., 2024). Taken together, these studies consistently indicate that effective interactive mathematics learning is characterized by four complementary instructional characteristics: meaningful visualization, structured mathematical reasoning, immediate feedback, and active student engagement. These findings provide a strong theoretical and pedagogical foundation for the continued development of interactive mathematics learning media.

Despite these advances, several important research gaps remain. First, although previous studies have demonstrated the effectiveness of interactive mathematics media, evaluations have generally focused on individual aspects of product quality or have been conducted in different instructional contexts, leaving limited evidence from studies that comprehensively examine validity, practicality, and effectiveness within a single development framework for fifth-grade plane geometry learning (Bhatt & Chakrabarti, 2024). Second, relatively few studies have explicitly aligned individual instructional features with measurable critical thinking indicators, limiting understanding of how specific learning activities systematically foster higher-order thinking (Elmabaredy & Gencel, 2024; Hase & Kuhl, 2024). Third, empirical evidence derived from quasi-experimental classroom comparisons involving fifth-grade elementary students remains limited despite the rapid advancement of digital mathematics learning technologies (Hidajat, 2024). Therefore, further empirical research is needed to develop interactive learning media that systematically integrate critical thinking processes and comprehensively establish their validity, practicality, and effectiveness in elementary plane geometry learning.

To address these gaps, this study proposes an instructional design approach that explicitly aligns interactive learning features with measurable critical thinking processes in elementary plane geometry, consistent with evidence highlighting the importance of intentional instructional design and technology-supported reasoning (Nevrelova et al., 2024). Edumath was developed by systematically connecting contextual problem situations with problem identification, interactive visualizations with analytical reasoning, guided activities with evaluation and justification, immediate feedback with self-correction, and reflective prompts with evidence-based conclusion drawing. Rather than functioning solely as a digital presentation tool, Edumath integrates these complementary instructional features into a coherent learning sequence that progressively develops students' critical thinking. The product was subsequently evaluated through expert validation, teacher and student practicality assessments, and quasi-experimental effectiveness testing, providing integrated empirical evidence of its educational quality and classroom applicability.

Therefore, this study develops Edumath interactive media for fifth-grade plane geometry and comprehensively evaluates its validity through expert review, its practicality through teacher and student responses, and its effectiveness in improving students' critical thinking using a quasi-experimental nonequivalent control group pretest–posttest design. By integrating systematic media development with comprehensive product evaluation, this study seeks to provide empirical evidence supporting interactive geometry instruction and advancing critical thinking in elementary mathematics education.

METHOD

Research Design

Research and Development (R&D) was employed to develop and evaluate Edumath, an interactive learning medium designed to improve fifth-grade students' critical thinking skills in plane geometry. The R&D approach is appropriate for educational product development because it supports a systematic process of needs analysis, instructional design, prototype development, validation, revision, implementation, and evaluation while simultaneously generating empirical evidence of product quality and instructional effectiveness (Creswell & Guetterman, 2023).

The ADDIE instructional design model, comprising Analysis, Design, Development, Implementation, and Evaluation, served as the development framework because of its iterative and systematic structure for producing learner-centered instructional media. The model enables alignment between learning objectives, learner characteristics, instructional content, media design, and continuous product refinement through expert evaluation and classroom implementation (Bhatt & Chakrabarti, 2024;Elmabaredy & Gencel, 2024).

An embedded quasi-experimental approach was incorporated during the implementation stage to examine the instructional effectiveness of the developed product. Effectiveness was evaluated using a nonequivalent control group pretest–posttest design, in which the experimental class learned using Edumath, whereas the control class received conventional mathematics instruction. This design was selected because random assignment of students was not feasible in the natural school setting while still allowing rigorous comparison of learning outcomes between intact classes (Creswell & Guetterman, 2023). Integration of the ADDIE model with the quasi-experimental design enabled comprehensive evaluation of Edumath beyond product development.

Research Setting, Population, Participants, and Sampling

Research activities were conducted during the 2024/2025 academic year at SD Negeri 1 Kunden and SD Negeri 2 Kunden, Blora Regency, Central Java, Indonesia. Both schools implement the same national curriculum, possess comparable learning facilities, and serve students with similar academic characteristics, providing appropriate settings for evaluating the developed learning media under equivalent classroom conditions. Preliminary classroom observations and teacher interviews identified persistent difficulties in students' critical thinking during plane geometry learning, supporting the selection of both schools as the research setting.

Participants comprised 59 fifth-grade students, including 30 students in the experimental class at SD Negeri 1 Kunden and 29 students in the control class at SD Negeri 2 Kunden. Purposive sampling was employed because both schools satisfied predetermined research criteria, including comparable curriculum implementation, similar student characteristics, and administrative approval for classroom intervention. Maintaining intact classrooms preserved authentic learning conditions while allowing meaningful comparison between instructional approaches, which is appropriate when random assignment is impractical in educational research (Hase & Kuhl, 2024). Table 1 summarizes the research setting, participant characteristics, and group allocation employed during the quasi-experimental phase.

Table 1. Research Setting, Participants, and Group Allocation

Variable	Experimental Group	Control Group
School	SD Negeri 1 Kunden, Blora Regency, Central Java, Indonesia	SD Negeri 2 Kunden, Blora Regency, Central Java, Indonesia
Grade Level	Fifth Grade	Fifth Grade
Number of Students (*n*)	30	29
Sampling Technique	Purposive Sampling	Purposive Sampling

Variable	Experimental Group	Control Group
Learning Treatment	Edumath Interactive Media	Conventional Mathematics Instruction
Research Design	Nonequivalent Control Group Pretest–Posttest	Nonequivalent Control Group Pretest–Posttest

Participant allocation ensured comparable classroom conditions between groups, providing an appropriate basis for evaluating the validity, practicality, and instructional effectiveness of Edumath during classroom implementation.

ADDIE Development Procedures

Development of Edumath followed the ADDIE instructional design model, comprising Analysis, Design, Development, Implementation, and Evaluation. Each phase generated a specific output that served as the input for the subsequent phase, ensuring systematic product development and comprehensive evaluation. Figure 1 illustrates the sequential workflow of the ADDIE development procedures adopted in this study.

Analysis

Analysis involved classroom observations, teacher interviews, and needs analysis to identify students' learning difficulties, instructional limitations, curriculum requirements, and media needs in fifth-grade plane geometry learning. Information collected during this stage was synthesized into a Need Analysis Report, which established the pedagogical and instructional requirements for the subsequent design phase (Lozano et al., 2023).

Design

Design translated the identified learning needs into instructional objectives, storyboards, media blueprints, and critical thinking indicators that guided the organization of learning content, navigation, assessment, interactive activities, and multimedia elements. The resulting Media Blueprint served as the primary development guideline

Development

Development involved constructing the Edumath prototype, conducting expert validation by subject-matter, media, and learning experts, revising the product based on expert recommendations, and testing the research instruments before classroom implementation. This iterative process ensured continuous refinement of both the learning media and assessment instruments until predetermined quality criteria were achieved, resulting in a Validated Product ready for classroom implementation (Nevrelova et al., 2024).

Implementation

Implementation consisted of administering the pretest, delivering instructional treatment using Edumath in the experimental class and conventional instruction in the control class, administering the posttest, and collecting teacher and student response questionnaires immediately after classroom implementation to evaluate the practicality of the developed media. Product effectiveness was subsequently determined by comparing learning outcomes between the experimental and control groups (Hase & Kuhl, 2024).

Evaluation

Evaluation integrated formative evaluation throughout the development process and summative evaluation following classroom implementation to comprehensively determine the validity, practicality, and effectiveness of Edumath. Formative evaluation supported continuous product refinement, whereas summative evaluation generated empirical evidence regarding the educational quality, usability, and instructional effectiveness of the developed learning media (Bhatt & Chakrabarti, 2024).

The ADDIE model guided the systematic development and refinement of the learning media, whereas the quasi-experimental phase provided empirical evidence of its classroom effectiveness. Consequently, the research design supported comprehensive evaluation of validity, practicality, and effectiveness, consistent with the study objectives and the identified research gaps.

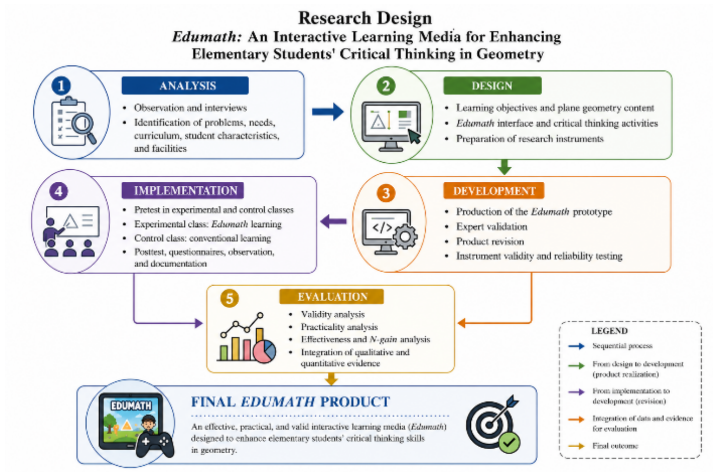

Figure 1. Research Design of Edumath Based on the ADDIE Model

Figure 1 depicts the complete research workflow, showing how the ADDIE development model was integrated with the embedded quasi-experimental design to comprehensively evaluate Edumath in terms of validity, practicality, and effectiveness.

Research Instruments

Research instruments were developed to evaluate the validity, practicality, and effectiveness of Edumath in accordance with the research objectives. Each instrument was constructed based on the corresponding evaluation indicators and administered to specific respondents to generate evidence supporting product quality and instructional effectiveness. Instrument selection ensured alignment between the research objectives, data sources, and analytical procedures, thereby enhancing the credibility and comprehensiveness of the evaluation process (Schmitt-Cerna et al., 2024). Table 2 summarizes the research instruments, respondents, measured indicators, and corresponding data analysis techniques.

Table 2. Research Instruments

Instrument	Respondent	Measured Indicator	Data Analysis
Material Validation Sheet	Subject-Matter Expert	Content accuracy, curriculum alignment, conceptual suitability	Percentage analysis
Media Validation Sheet	Media Expert	Interface design, usability, navigation, visual communication	Percentage analysis
Learning Validation Sheet	Learning Expert	Instructional design, learning activities, assessment alignment	Percentage analysis
Teacher Response Questionnaire	Classroom Teacher	Practicality, usability, implementation feasibility	Percentage analysis
Student Response Questionnaire	Students	Practicality, attractiveness, ease of use, engagement	Percentage analysis
Critical Thinking Test (Essay)	Students	Problem identification, analysis, evaluation, justification, conclusion drawing	Pearson Product-Moment, Cronbach's Alpha, descriptive statistics, paired-samples t-test, independent-samples t-test, N-gain
Observation Sheet	Researcher	Learning implementation and classroom activities	Descriptive analysis
Interview Guide	Classroom Teacher	Learning needs and implementation feedback	Qualitative descriptive analysis
Documentation	Researcher	Learning process and supporting evidence	Document analysis

All instruments were administered according to their respective functions within the ADDIE development stages, ensuring that evidence collected during product validation, classroom implementation, and effectiveness testing directly addressed the study objectives of evaluating the validity, practicality, and effectiveness of Edumath.

Data Collection Procedures

Data collection followed the sequential stages of the ADDIE development model to ensure systematic acquisition of evidence throughout product development and evaluation. The process began with classroom observations, teacher interviews, and needs analysis to identify instructional problems, followed by media design and prototype development. The prototype was subsequently subjected to expert validation, revised based on expert recommendations, and pilot-tested before classroom implementation. During the implementation phase, students completed a pretest, participated in instructional activities using Edumath (experimental group) or conventional instruction (control group), and completed a posttest. Following the learning intervention, teacher and student response questionnaires were administered to evaluate product practicality, while documentation was collected throughout the research to support and verify the implementation process (Creswell & Guetterman, 2023; Schmitt-Cerna et al., 2024). Figure 2 summarizes the sequence of data collection procedures employed in this study.

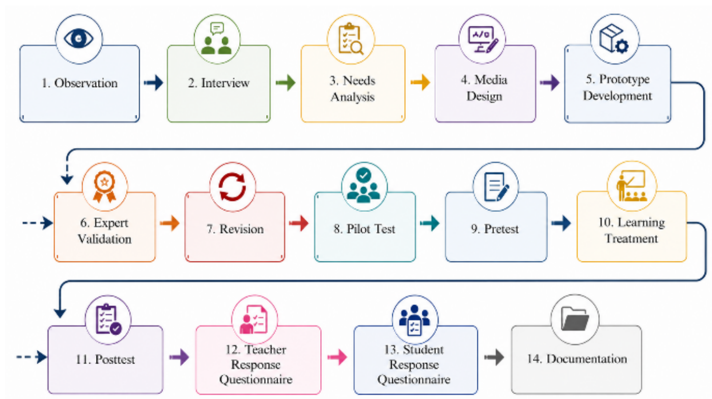

Figure 2. Data Collection Procedures

Figure 3 illustrates the sequential data collection procedures employed in this study, beginning with needs identification, followed by product development and validation, classroom implementation, and concluding with practicality assessment and documentation to support comprehensive evaluation of Edumath.

Data Analysis

Data analysis was conducted sequentially to comprehensively evaluate the validity, practicality, and effectiveness of Edumath in accordance with the research objectives. Analysis began with expert validation to determine product feasibility, followed by practicality analysis based on teacher and student responses, instrument testing, descriptive statistics, assumption testing, inferential statistics, and normalized gain analysis. Sequential implementation of these analyses ensured that the developed learning media satisfied the required quality standards before its instructional effectiveness was evaluated (Creswell & Guetterman, 2023).

Validity Analysis

Validity analysis evaluated the feasibility of Edumath before classroom implementation through expert judgment involving subject-matter, media, and learning experts. Each expert assessed the product using structured validation sheets covering content accuracy, instructional design, media presentation, language, and usability. Validation scores obtained from each expert were converted into percentages and interpreted according to predetermined validity criteria to determine the overall feasibility of the developed product (Ehm et al., 2023).
Percentage validity was calculated using Equation (1)

$$P = \frac{obtained\ score}{maximum\ possible\ score}\ x\ 100\%$$

where:
P = validity percentage;
Obtained Score = total score assigned by the validator;
Maximum Score = maximum possible score for all assessment items.

Validity percentages were subsequently interpreted using the criteria presented in Table X to classify the product as invalid, less valid, sufficiently valid, valid, or highly valid. Products achieving the valid or highly valid category were considered appropriate for classroom implementation, whereas products receiving lower ratings were revised based on expert recommendations before proceeding to the practicality and effectiveness evaluation stages.

Practicality Analysis
Practicality analysis evaluated the practicality of Edumath based on teacher and student response questionnaires administered immediately after classroom implementation. Questionnaire scores were converted into percentages using Equation (1) and interpreted according to the predetermined practicality criteria to classify the developed media as impractical, sufficiently practical, practical, or highly practical. Products classified as practical or highly practical were considered suitable for classroom implementation without substantial revision, whereas lower classifications required further improvement before broader application.

Instrument Testing
Instrument testing verified the validity and reliability of the critical thinking test before classroom implementation. Item validity was examined using the Pearson Product–Moment correlation, whereas internal consistency was determined using the Cronbach's Alpha coefficient. Items satisfying the predetermined validity criteria were retained for subsequent analysis, and the reliability coefficient confirmed the consistency of the instrument before its application in the quasi-experimental phase. Only valid and reliable instruments were employed during data collection to ensure the accuracy, consistency, and credibility of the research findings.

Descriptive Statistics
Descriptive statistics summarized students' critical thinking scores before and after the learning intervention. Mean, minimum, maximum, and standard deviation were calculated for the pretest and posttest scores of both the experimental and control groups to describe score distribution and learning achievement prior to inferential analysis.

Assumption Tests
Assumption testing verified the suitability of the data for parametric analysis. Score normality was examined using the Shapiro–Wilk test, whereas variance homogeneity between groups was assessed using Levene's test. Statistical decisions were made at a significance level of $\alpha = 0.05$, where $p > 0.05$ indicated that the assumptions for parametric testing were satisfied.

Paired-Samples t-test
Paired-samples *t*-test compared pretest and posttest critical thinking scores within the experimental and control groups to determine whether each instructional approach produced statistically significant learning improvements. Statistical decisions were based on a significance level of 0.05 ($p < 0.05$).

Independent-Samples t-test
Independent-samples *t*-test compared the pretest, posttest, and normalized gain (N-gain) scores of the experimental and control groups to determine whether Edumath produced significantly greater improvements in students' critical thinking than conventional instruction. Statistical significance was determined at the 0.05 level ($p < 0.05$), with statistically significant differences indicating superior learning outcomes in the experimental group.

N-gain Analysis
Normalized gain (N-gain) analysis measured the magnitude of improvement in students' critical thinking following the learning intervention. N-gain values were calculated using Equation (2):

$$P = \frac{posttest\ score - pretest\ score}{maximum\ possible\ score\ - pretes\ score}$$

where:
g = normalized gain;
Posttest = post-intervention score;
Pretest = pre-intervention score;
Maximum Score = maximum possible score.

N-gain values were interpreted as high ($g \geq 0.70g$), moderate ($0.30 \leq g < 0.70$, and low ($g < 0.30$) to determine the effectiveness of the learning intervention. Interpretation followed the normalized gain criteria commonly applied in educational intervention studies (Christman et al., 2024).

RESULTS

Need Analysis Findings

Need analysis identified several instructional challenges that justified the development of Edumath for fifth-grade plane geometry learning. Data were obtained through classroom observations, teacher interviews, and needs analysis. Table 3 summarizes the principal findings that guided product development.

Table 3. Summary of Need Analysis Findings

Data Source	Key Findings	Implications for Edumath Development
Classroom observation	Mathematics instruction relied mainly on textbooks, worksheets, and teacher explanations.	Interactive multimedia was needed to increase student engagement.
Teacher interview	Students experienced difficulties identifying information, analysing geometric relationships, justifying reasoning, evaluating solutions, and drawing conclusions.	Learning activities were designed to explicitly support critical thinking processes.
Needs analysis	Existing instructional media provided limited visualization, interaction, and feedback.	Edumath integrated visual representations, contextual problems, immediate feedback, and reflective activities.

Need analysis confirmed that existing instructional practices had not adequately supported critical thinking in plane geometry. These findings established the instructional requirements that guided the design and development of Edumath.

Product Design of Edumath

Product design translated the identified instructional needs into the structural components of Edumath. Learning objectives, instructional content, interactive activities, assessment, and navigation were systematically organized to support students' critical thinking in plane geometry. Each component was intentionally aligned with specific critical thinking indicators to ensure consistency between instructional design and learning outcomes. Table 4 summarizes the final design components of Edumath.

Table 4. Final Design Components of Edumath

Edumath Component	Instructional Function	Critical Thinking Indicator
Learning objectives	Introduce expected learning outcomes	Problem orientation
Apperception activity	Activate prior knowledge	Problem identification
Plane geometry materials	Develop conceptual understanding	Analysis
Interactive visualization	Explore geometric relationships	Analysis
Contextual problems	Apply concepts to authentic situations	Evaluation
Interactive exercises	Practice structured problem solving	Justification
Quiz with immediate feedback	Verify understanding and correct misconceptions	Evaluation
Reflective questions	Formulate evidence-based conclusions	Conclusion drawing

Instructional components were systematically integrated into Edumath to support a progressive learning sequence from problem identification to conclusion drawing. Alignment between media features and critical thinking indicators established the pedagogical foundation for subsequent validity, practicality, and effectiveness evaluation.

Product Validity

Expert validation evaluated the content, media, and instructional quality of Edumath before classroom implementation. Assessments were conducted by a subject-matter expert, a media expert, and a learning expert to determine whether the developed product satisfied the predetermined validity criteria. Table 5 presents the expert validation results.

Table 5. Expert Validation Results of Edumath

Validator	Obtained Score	Maximum Score	Percentage (%)	Category
Subject-matter expert	89	100	89.00	Highly Valid
Media expert	87	100	87.00	Highly Valid
Learning expert	90	100	90.00	Highly Valid
Average	266	300	88.67	Highly Valid

Average expert validation reached 88.67%, indicating that Edumath satisfied the predetermined validity criteria and was appropriate for classroom implementation. Product refinement was subsequently carried out by incorporating recommendations from all validators to improve instructional quality before classroom implementation. Table 6 summarizes the revisions implemented based on expert feedback.

Table 6. Summary of Product Revisions Based on Expert Feedback

Validator	Recommendation	Revision Implemented
Subject-matter expert	Improve the sequencing of plane geometry concepts and contextual examples.	Learning materials were reorganized according to conceptual progression and enriched with contextual examples.
Media expert	Enhance navigation consistency and improve visual layout.	Navigation buttons were standardized, interface consistency was improved, and visual elements were refined.
Learning expert	Clarify learning instructions and align activities with critical thinking indicators.	Learning instructions were simplified, and interactive activities were explicitly aligned with critical thinking indicators.

Implemented revisions improved the organization of learning content, interface consistency, instructional clarity, and alignment between media features and critical thinking indicators. Completion of these revisions resulted in a validated version of Edumath that fulfilled the required quality standards and was subsequently evaluated for practicality and effectiveness during classroom implementation.

Instrument Quality

Instrument quality was evaluated before classroom implementation to ensure that the critical thinking test provided valid and reliable measurements. Item validity was examined using the Pearson Product–Moment correlation, followed by reliability analysis using Cronbach's Alpha. Table 7 summarizes the results of the instrument quality evaluation.

Table 7. Summary of Instrument Quality

Instrument Analysis	Result	Interpretation
Initial number of items	10 essay items	Evaluated during instrument testing
Valid items	Items 1, 2, 3, 5, 6, 7, 9, and 10	Retained
Invalid items	Items 4 and 8	Excluded
Valid-item correlation coefficient	0.568–0.786	Valid
Cronbach's Alpha	0.825	Reliable
Final instrument	8 essay items	Suitable for classroom implementation

Instrument testing retained eight valid essay items and excluded two items that did not satisfy the predetermined validity criteria. Reliability analysis produced a Cronbach's Alpha coefficient of 0.825, indicating good internal consistency. Consequently, the final eight-item instrument was considered valid and reliable for measuring fifth-grade students' critical thinking and was subsequently employed during the classroom implementation and effectiveness evaluation.

Product Practicality

Product practicality was evaluated following classroom implementation through teacher and student response questionnaires to determine the usability and implementation feasibility of Edumath. Table 8 summarizes the practicality evaluation results.

Table 8. Product Practicality Results

Respondent	Practicality Score (%)	Category
Teacher	90.00	Highly Practical
Students	89.00	Highly Practical
Average	89.50	Highly Practical

Teacher and student evaluations consistently classified Edumath as highly practical, with an average practicality score of 89.50%. High practicality ratings indicated that the media was easy to use, instructionally appropriate, and readily implemented during classroom learning. These findings confirmed that Edumath satisfied the required practicality criteria and was appropriate for classroom application without substantial revision.

Product Effectiveness

Descriptive Statistics

Descriptive statistics summarized students' critical thinking scores before and after classroom implementation to provide an initial comparison between the experimental and control groups. Mean, standard deviation, minimum, and maximum scores were calculated for the pretest and posttest. Table 9 presents the descriptive statistics of students' critical thinking scores.

Table 9. Descriptive Statistics of Students' Critical Thinking Scores

Group	Test	n	Mean	SD	Minimum	Maximum
Experimental	Pretest	30	18.17	2.408	14	22
Experimental	Posttest	30	26.67	2.171	22	31
Control	Pretest	29	18.07	2.344	14	22
Control	Posttest	29	22.07	2.034	18	26

Comparable pretest mean scores indicated similar initial critical thinking abilities between the experimental (M = 18.17) and control (M = 18.07) groups. Following classroom implementation, both groups demonstrated improved posttest performance; however, the experimental group achieved a substantially higher mean score (M = 26.67) than the control group (M = 22.07). These descriptive findings provided initial evidence that students who learned using Edumath demonstrated greater improvement in critical thinking prior to inferential statistical analysis.

Assumption Tests

Assumption tests were performed before hypothesis testing to verify the suitability of the data for parametric analysis. Normality was evaluated using the Shapiro–Wilk test, whereas homogeneity of variance was assessed using Levene's test. Table 10 presents the results of the assumption tests.

Table 10. Results of the Assumption Tests

Variable	Group	Shapiro–Wilk (Sig.)	Normality	Levene's Test (Sig.)	Homogeneity
Pretest	Experimental	0.219	Normal	0.880	Homogeneous
	Control	0.310	Normal		
Posttest	Experimental	0.855	Normal	0.763	Homogeneous
	Control	0.599	Normal		

Shapiro–Wilk test results showed that all significance values exceeded 0.05, indicating that the pretest and posttest scores were normally distributed. Levene's test also produced significance values greater than 0.05, confirming homogeneous variances between the experimental and control groups. These results indicated that the assumptions for parametric statistical analysis were satisfied, allowing subsequent paired-samples and independent-samples *t*-tests to be performed.

Paired-Samples t-test

Paired-samples *t*-test compared the pretest and posttest critical thinking scores of the experimental group to determine whether learning with Edumath produced significant improvement. Table 11 presents the paired-samples *t*-test results.

Table 11. Paired-Samples *t*-Test Results for the Experimental Group

Comparison	Pretest Mean	Posttest Mean	Mean Difference	t	df	p	Interpretation
Pretest vs. Posttest	18.17	26.67	8.50	81.342	29	< .001	Significant improvement

Posttest scores were significantly higher than pretest scores ($t(29) = 81.342$, $p < .001$), indicating that learning with Edumath produced a significant improvement in students' critical thinking. These findings confirmed meaningful within-group improvement following the implementation of the developed learning media.

Independent-Samples t-test

Independent-samples *t*-test compared the critical thinking scores of the experimental and control groups to determine the effectiveness of Edumath relative to conventional instruction. Comparisons were conducted for both the pretest and posttest scores. Table 12 presents the independent-samples *t*-test results.

Table 12. Independent-Samples *t*-Test Results

Comparison	Experimental Mean	Control Mean	t	df	p	Interpretation
Pretest	18.17	18.07	-0.158	57	.875	No significant difference
Posttest	26.67	22.07	-8.388	57	< .001	Significant difference

Pretest results indicated no significant difference between the experimental and control groups ($t(57) = -0.158$, $p = .875$), confirming comparable initial critical thinking abilities. In contrast, posttest results revealed a statistically significant difference in favor of the experimental group ($t(57) = -8.388$, $p < .001$), demonstrating that Edumath produced significantly greater improvements in students' critical thinking than conventional instructio

N-gain Analysis

Normalized gain (N-gain) analysis evaluated the magnitude of improvement in students' critical thinking after classroom implementation. Mean N-gain, standard deviation, and gain categories were calculated for both groups. Table 13 presents the N-gain analysis results.

Table 13. N-gain Analysis Results

Group	Mean N-gain	SD	Category
Experimental	0.6487	0.066	Moderate
Control	0.2387	0.064	Low

The experimental group achieved a mean N-gain of 0.6487 (moderate category), whereas the control group obtained 0.2387 (low category). These findings indicate that students who learned using Edumath demonstrated substantially greater improvement in critical thinking than those who received conventional instruction, confirming the superior educational impact of the developed learning media.

Summary of Effectiveness

Overall effectiveness evaluation consistently demonstrated the superiority of Edumath in improving fifth-grade students' critical thinking. Descriptive statistics showed greater posttest achievement in the experimental group, assumption tests confirmed that the data satisfied the requirements for parametric analysis, paired-samples *t*-test indicated significant within-group improvement, independent-samples *t*-test revealed significant differences in favor of the experimental group, and N-gain analysis demonstrated a moderate level of improvement compared with the low gain achieved by the control group. Collectively, these findings confirmed that Edumath satisfied the effectiveness criterion and successfully achieved the research objective of improving students' critical thinking in plane geometry.

DISCUSSION

Validation in educational media development serves not merely to verify product quality but to ensure that instructional design is pedagogically coherent before classroom implementation. From this perspective, the validity of Edumath reflects the successful integration of visualization, learning activities, assessment, and critical thinking into a unified instructional design rather than the inclusion of digital features alone. Such alignment is fundamental because meaningful technology integration depends on the consistency between instructional objectives, learning processes, and assessment strategies (Hidajat, 2024; Zhang et al., 2025).

Research and development also emphasizes that expert validation is an iterative refinement process rather than a final evaluation stage. Expert feedback enables instructional, technical, and usability aspects of a product to be optimized before effectiveness testing, thereby strengthening the credibility of subsequent classroom findings. This interpretation supports the argument of (Bhatt & Chakrabarti, 2024) that systematic refinement through expert review enhances both product quality and the reliability of educational intervention outcomes.

Product practicality should be interpreted as evidence that the instructional design of Edumath was compatible with authentic classroom practice. Practical educational media are characterized not simply by ease of operation but by their ability to integrate learning content, interactive activities, navigation, and assessment into a coherent learning experience that can be implemented without disrupting instructional flow. Such coherence enables teachers to focus on facilitating learning while allowing students to engage actively with mathematical tasks (Hase & Kuhl, 2024).

This interpretation reinforces previous evidence that the success of interactive learning media depends primarily on instructional design rather than technological sophistication. Elmabaredy & Gencel, (2024) argued that digital learning environments become practical when interactive features consistently support learning objectives and classroom activities. From this perspective, the practicality of Edumath suggests that its instructional components functioned as an integrated learning system, indicating its potential for sustainable implementation in elementary mathematics classrooms.

Effective development of critical thinking depends on learning experiences that actively engage students in identifying problems, analysing mathematical relationships, evaluating alternative solutions, and constructing evidence-based conclusions. Constructivist learning theory and multimedia learning principles explain that meaningful understanding emerges through active interaction with instructional resources that integrate visualization, exploration, feedback, and reflection into coherent learning experiences. Consequently, improvement in students' critical thinking can be interpreted as the outcome of systematic instructional design rather than the presence of digital technology alone.

Consistent evidence from recent studies indicates that interactive mathematics learning environments enhance reasoning and higher-order thinking by combining visualization, active exploration, immediate feedback, and student engagement (Ji et al., 2024); (Gurmu et al., 2024;Walkington et al., 2024;Hui & Mahmud, 2023). Distinctive contribution of Edumath lies in systematically connecting interactive visualization with sequential critical thinking processes, beginning with problem identification, followed by analysis, evaluation, reflection, and evidence-based conclusion drawing. Integration of these instructional components extends previous research by demonstrating how digital learning media can intentionally embed critical thinking into elementary plane geometry instruction rather than functioning solely as interactive multimedia.

CONCLUSION

Development of Edumath through the ADDIE research and development model resulted in an interactive learning medium that fulfilled the required criteria of validity, practicality, and effectiveness for fifth-grade plane geometry learning. Systematic integration of visualization, contextual problem solving, interactive feedback, and reflective learning activities with explicit critical thinking indicators enabled Edumath to function not only as digital instructional media but also as a structured learning environment that supports students' critical thinking.

Principal contribution of the present study lies in demonstrating that effective interactive mathematics learning depends on the systematic alignment of instructional design, learning activities, assessment, and critical thinking processes rather than on technology integration alone. Integration of problem identification, analysis, evaluation, reflection, and evidence-based conclusion drawing into a single instructional framework represents the novelty of Edumath and provides empirical evidence for strengthening critical thinking in elementary plane geometry learning.

Educational implementation of Edumath offers teachers an evidence-based instructional alternative for promoting student-centered mathematics learning while fostering higher-order thinking in elementary classrooms. Future research should examine long-term learning retention, broader mathematical topics, diverse educational settings, and larger participant groups to strengthen the generalizability and sustainability of the developed learning media.

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AUTHOR CONTRIBUTION STATEMENT

DMD conceptualized the study, developed Edumath, collected and analyzed the data, and drafted the manuscript. AB supervised the research methodology, reviewed the instruments, and contributed to data interpretation. JS provided academic supervision and critically revised the manuscript. All authors reviewed and approved the final version of the manuscript.

AI DISCLOSURE STATEMENT

The authors used ChatGPT by OpenAI during the preparation of this manuscript to assist with language refinement, organization, and clarity of presentation. The tool was not used to generate, modify, or analyze the research data. After using the tool, the authors thoroughly reviewed, verified, and edited the content and take full responsibility for the accuracy and integrity of the publication.

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