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Web-Based Interactive Media Development For Improving Elementary Students' Conceptual Understanding Of Flat Shapes: A Mixed-Method R&D Study

Deden Supriatna[1a]*, Rudi Hartono[2b], Muktiono Waspodo[3c]
[1,2,3]Educational Technology Study Program, Universitas Ibn Khaldun Bogor, Indonesia

[a]dedensupriatna08@gmail.com, [b]rudihartono@uika-bogor.ac.id

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***Correspondence Address:**
dedensupriatna08@gmail.com

Abstract:
All This research was motivated by the low conceptual understanding of fourth-grade elementary students on flat-shape geometry, where 62.8% of students (42 out of 67) scored below the minimum proficiency standard, and instruction remained dominated by lecture methods without interactive digital media. The study aimed to develop and test the effectiveness of web-based interactive learning media to enhance students' conceptual understanding. The research employed a Research and Development (R&D) approach with a mixed-method design, integrating the ADDIE model (5 phases) and Borg & Gall (10 stages) into four main phases: preliminary study, planning, development, and implementation. Product validation was conducted by three experts (content, media, and instructional design), while effectiveness testing employed a pretest-posttest control group design involving 60 fourth-grade students (30 experimental, 30 control). Expert validation results achieved an average of 89.8% (highly valid), with content expert 87%, media expert 86.4%, and instructional design expert 96%. Small group trials (N=15) obtained 90.45% feasibility, and operational field trials (N=30) obtained 91.53% (highly feasible). Effectiveness results showed the experimental group achieved an average N-Gain of 0.834 (83.4%, high/effective category), while the control group achieved only 0.531 (53.1%, medium/moderate category). The Mann-Whitney U test on N-Gain scores yielded $Z = -4.887$, $p < 0.001$, indicating a significant difference between experimental and control groups. In conclusion, the web-based interactive learning media proved valid, feasible, and effective in improving fourth-grade students' conceptual understanding of flat shapes. The implications encourage teachers and schools to adopt interactive digital media as an innovative alternative in mathematics instruction aligned with the Merdeka Curriculum.

Introduction (مقدمة)

Education in the 21st century demands the integration of digital technology into the learning process to create interactive and meaningful learning experiences. In Indonesia, the Merdeka Curriculum policy and Permendikdasmen Number 13 of 2025 encourage the use of digital technology and student-centered learning. However, the reality on the ground, especially at the elementary school (SD) level, still shows a significant gap between curriculum demands and classroom practices. Based on data from APJII (2023), internet penetration in Indonesia has reached 78.2%, indicating great potential for technology utilization, but its use for interactive learning is still not optimal.

One subject that often poses challenges is Mathematics, especially abstract geometry material such as flat shapes. Geometry learning in elementary schools plays a vital role in building foundational geometric understanding and students' spatial thinking abilities. Based on Piaget's cognitive development theory, elementary school children are in the concrete operational stage, meaning they understand concepts more easily when presented in concrete forms or through manipulative activities. Similarly, Van Hiele's theory of geometric thinking stages explains that elementary school students are at the visualization and analysis stages, where they should be able to recognize shapes by their characteristics and identify their properties.

However, various conceptual and contextual problems still exist in flat-shape learning. A preliminary study at SD Ainul Hayat Cicurug showed that 62.8% of fourth-grade students (42 out of 67 students) scored below the Minimum Proficiency Standard (KKTP) on flat-shape material. The learning methods used were still dominated by lectures and static media such as printed Student Worksheets (LKPD), which were less able to visualize abstract concepts and build students' conceptual understanding. Research indicates that students tend to only memorize shape names without understanding the meaning, form, characteristics, and applications. The lack of concrete experience and visualization provided in learning causes students to experience difficulties in understanding geometry material. Common misconceptions include confusing the meaning of area and perimeter, misunderstanding units, and being unable to connect shapes with formulas.

Websites are effective digital platforms for developing learning media due to their flexibility of access, multimedia integration (text, images, audio, video, animation), and high potential for interactivity. Web-based media can be accessed through various devices and supports independent learning tailored to each student's pace. Clark and Mayer (2022) emphasize that well-designed web-based learning can increase student engagement and learning outcomes. In the context of elementary mathematics, especially flat-shape material, web-based visualization can help students understand abstract concepts more concretely. Mayer (2021) explains that the right combination of visual and verbal elements can improve students' information processing.

Recent studies have demonstrated the effectiveness of interactive technologies for geometry learning. For instance, research by Kamalodeen et al. (2021) highlights gamification design for geometry in elementary schools, while Li et al. (2022) demonstrated the use of dynamic information technology for teaching plane geometry. Furthermore, studies on interactive geometry textbooks have shown that digital resources with dynamic representations, including videos and interactive web applications, enhance students' spatial visualization and comprehension skills. Similarly, research on using Google Sites for elementary mathematics found significant effects on conceptual understanding, particularly when combined with students' visual-spatial intelligence levels.

Previous research on web-based learning media for flat-shape material has been extensively conducted. For instance, research by Permana et al. (2024) and Bandaso & Harjono (2023) showed the effectiveness of similar media. However, several critical research gaps remain. First, most studies focus on secondary or higher education levels, with limited research at the primary education level. Yet, the development of geometric thinking at an early age can have a more profound impact on students' mathematical abilities. Second, most existing studies rely on a single development model (either ADDIE or Borg & Gall), which may not provide sufficient integration between instructional design and empirical testing. Third, the variety of measurement indicators is still limited to spatial visualization and problem-solving, with other indicators such as geometric connections or mathematical reasoning not yet widely explored. Fourth, few studies have integrated visual scaffolding with gamification elements specifically designed for the concrete operational characteristics of fourth-grade elementary students.

Based on this background, this study aims to: 1) produce a development procedure for web-based interactive learning media, 2) determine the feasibility of the media based on expert validation and user trials, and 3) test the effectiveness of the media in improving students' conceptual understanding of flat-shape material.

The novelty of this research lies in three key structural and pedagogical aspects. First, methodological integration between the ADDIE and Borg & Gall models, which have previously been used separately, formulated into four main phases that are streamlined while maintaining tiered validation. Second, a web-based interactive product specifically designed with visual scaffolding, cognitive-guided feedback, and gamification for fourth-grade elementary students in the concrete operational stage—which is still rarely found in previous research that was mostly conducted at the junior high school level. Third, this study addresses the limited focus on primary education identified in recent literature by providing empirical evidence on interactive worksheet-based geometry learning at the elementary level, and incorporates broader indicators of conceptual understanding beyond mere visualization and problem-solving.

Interactive Learning Media

Interactive learning media is defined as media that enables two-way communication between users and the system, transforming students from passive recipients into active constructors of knowledge (Sims, 2022). Its philosophical foundation is Vygotsky's (1978) Social Constructivism Theory, where interaction with the learning environment facilitates knowledge acquisition within the Zone of Proximal Development (ZPD). This concept is expanded in contemporary research showing that interactivity deepens cognitive processing and enhances long-term retention through the activation of multiple memory systems (Moreno & Mayer, 2022). In the context of this study, interactivity is realized through features such as simulations, drag-and-drop activities, and immediate feedback designed to help students build their understanding of geometry concepts independently.

Web-Based Learning Media

A website is an effective digital platform for developing learning media due to its flexibility of access, multimedia integration (text, images, audio, video, animation), and high potential for interactivity. Web-based media can be accessed through various devices and supports independent learning tailored to each student's pace. Clark and Mayer (2022) emphasize that well-designed web-based learning can increase student engagement and learning outcomes. In the context of elementary mathematics, especially flat-shape material, web-based visualization can help students understand abstract concepts more concretely. Mayer (2021) explains that the right combination of visual and verbal elements can improve students' information processing.

Development Model: Integration of ADDIE and Borg & Gall

This research integrates two development models to leverage the advantages of each. The ADDIE model (Analysis, Design, Development, Implementation, Evaluation) provides a systematic and logical instructional design framework (Branch, 2009). Meanwhile, the Borg &

Gall model offers precise and iterative field testing procedures (Borg & Gall, 1983). The integration of these two models produces a more comprehensive development procedure, which in this study is simplified into four main phases: (1) Preliminary Study, (2) Planning, (3) Development, and (4) Implementation. This approach ensures that the resulting product is not only valid in design but also empirically tested in the field.

The fundamental reasons for integrating these two models are threefold: First, to bridge the focus gap between ADDIE's strength in mapping instructional content and Borg & Gall's superiority in tiered empirical testing. Second, to accommodate the characteristics of web-based products that require mature system architecture (ensured by ADDIE) and layered usability testing adapted to the cognitive characteristics of elementary students (ensured by Borg & Gall). Third, to conduct strong field experimental phases (Borg & Gall) integrated directly into the Implementation and Evaluation phases (ADDIE) to empirically validate learning outcomes on abstract material.

Conceptual Understanding in Geometry

Conceptual understanding in mathematics refers to the ability to comprehend mathematical concepts, operations, and relations (National Research Council, 2021). In geometry, this involves understanding properties, relationships, and applications of shapes. For elementary students, particularly those in the concrete operational stage (Piaget, 1964), conceptual understanding is best developed through hands-on experiences and visual representations. The use of multiple representations—such as visual, verbal, and symbolic—has been shown to enhance conceptual understanding in mathematics (Chen et al., 2024). This study's web-based media provides these multiple representations through animations, simulations, and interactive exercises.

Method (منهج)

Research Design

This research employed a Research and Development (R&D) approach with a mixed-method design. The development procedure followed the integration of the ADDIE and Borg & Gall models, modified into four main phases: Preliminary Study, Planning, Development, and Implementation. The mixed-method approach was used to collect, analyze, and combine quantitative and qualitative data to comprehensively answer research questions regarding the feasibility and effectiveness of the media.

Research Subjects and Location

The research was conducted at SD Ainul Hayat Cicurug, Sukabumi Regency, in the even semester of the 2025/2026 academic year. Research subjects included fourth-grade students, classroom teachers, and expert validators. The selection of class groups for the experimental and control groups was carried out using a purposive sampling technique, selecting two intact classes with equivalent baseline cognitive abilities. Class IV-A (n = 30) served as the experimental group utilizing the web-based interactive media, while Class IV-B (n = 30) served as the control group utilizing conventional printed materials and lectures. The location was selected based on: (1) alignment with the research focus, where preliminary observation found students experiencing difficulties understanding abstract flat-shape concepts; (2) availability of supporting infrastructure, including electricity, laptops/computers, projectors, and internet access; and (3) openness to learning innovation from both the principal and teachers.

Development Procedure

Phase 1: Preliminary Study. This phase integrated the Research and Information Collecting stage from Borg & Gall with the Analysis phase from ADDIE. Activities included literature review, initial observation, interviews, and needs analysis to identify problems and the theoretical foundation for product development. Specific steps included: validating performance gaps, determining general learning objectives, identifying student characteristics, identifying resources, analyzing solutions and estimated costs, and developing project management plans.

Phase 2: Planning. This phase integrated the Planning stage from Borg & Gall with the Design phase from ADDIE. Activities included learning analysis, formulating specific objectives, developing learning strategies, and measuring costs against benefits. The specific objectives were formulated using the ABCD (Audience, Behavior, Condition, Degree) approach to ensure measurability.

Phase 3: Development. This phase integrated the preliminary product development through final product revision stages from Borg & Gall with the Development phase from ADDIE. Activities included generating learning content, selecting/developing media, developing student and teacher guides, conducting formative evaluation and revision, and conducting tiered trials (one-to-one trial, small group trial, and operational field trial). Expert validation was conducted by content, media, and instructional design experts.

Phase 4: Implementation. This phase integrated the Implementation and Dissemination stages from Borg & Gall with the Implementation and Evaluation phases from ADDIE. Activities included teacher and student preparation, determining evaluation criteria and instruments, and conducting learning evaluation through pretest and posttest administration.

Data Collection Instruments

Data collection instruments included, Documentation Study Sheets: Used to analyze curriculum documents, learning outcomes, and available resources. Interview Guidelines: Semi-structured interviews with teachers to explore learning conditions, challenges, and needs. Observation Sheets: Structured observation of the learning process, media availability, and student engagement. Questionnaires: Needs analysis questionnaires for students, expert validation questionnaires (content, media, instructional design), and user response questionnaires (teachers and students) using a Likert scale (1-5). Tests: Pretest and posttest consisting of 10 multiple-choice questions designed to measure conceptual understanding of flat-shape material. Prior to field administration, the test instrument underwent rigorous content validation by evaluation experts and empirical testing. Item validity testing using Pearson Product-Moment correlation yielded rcount values ranging from 0.412 to 0.738 ($> r_{table} = 0.361$, $\alpha = 0.05$), confirming all items were valid. Reliability analysis using Cronbach's Alpha produced a coefficient of 0.814, categorizing the test instrument as highly reliable.

Data Analysis Techniques

Data analysis employed both qualitative and quantitative techniques. Qualitative data from interviews, observations, and expert suggestions were analyzed descriptively. Quantitative data from validation questionnaires, user response questionnaires, and test scores were analyzed using descriptive statistics (percentages, means) and inferential statistics. The feasibility of the product was determined based on the percentage of expert and user assessments, categorized using predetermined criteria. Effectiveness was measured using the Normalized Gain (N-Gain) score formula (Hake, 1999), with categories: high (>0.7), medium (0.3-0.7), and low (<0.3). Due to non-normal data distribution (Shapiro-Wilk test, $p < 0.05$), non-parametric tests (Wilcoxon Signed Rank Test and Mann-Whitney U Test) were used for hypothesis testing at $\alpha = 0.05$.

Success Criteria

The product was declared: (1) valid if expert validation reached ≥ 80%; (2) practical if user response questionnaires reached ≥ 80%; and (3) effective if the average N-Gain score reached ≥ 0.7 (high category) with significant differences between experimental and control groups.

Result (نتائج)

Development Procedure

The development procedure produced was an integration of the Borg & Gall and ADDIE models into four main phases. Phase 1, Preliminary Study, resulted in findings on the problem of low learning outcomes (62.8% below KKTP). Documentation study showed that 42 out of 67 students scored below the minimum proficiency standard. Interviews with teachers revealed that learning methods lacked variety, interactive media such as web-based learning had never been used, and students were less actively engaged. Needs analysis questionnaires showed that most students were uninterested in the conventional flat-shape learning style and desired more contemporary learning media. Phase 2, Planning, resulted in specific learning objectives formulated using the ABCD approach and a storyboard for the web-based interactive media. The storyboard consisted of ten main pages: Splash Screen, Login, Home, User Guide, Learning Objectives, Material, Animated Video, Interactive Exercises, Educational Games, and Developer Profile. Each page was designed considering instructional design principles, ease of navigation, and alignment with the characteristics of fourth-grade students. Phase 3, Development, produced a web-based interactive media product that had undergone a series of validations and trials. The media integrated multimedia elements (text, images, animations, audio, video) and interactive features (simulations, drag-and-drop, quizzes with immediate feedback, gamification elements). Student and teacher guides were also developed to facilitate implementation. Phase 4, Implementation, involved teacher and student preparation, implementation of experimental and control group learning, and evaluation of effectiveness through pretest-posttest administration and N-Gain analysis.

Media Feasibility

Expert Validation Results

Validation by three experts showed an average percentage of 89.8% with the "Highly Valid" category. The details were: content expert 87% (Highly Valid), media expert 86.4% (Highly Valid), and instructional design expert 96% (Highly Valid). These results indicate that the developed web-based interactive media is highly valid and feasible for use in learning.

Table 1. Recapitulation of Expert Validation Results

Expert	Field of Expertise	Percentage	Category
Eneng Nurhasanah, M.Pd.	Content Expert	87%	Highly Valid
Dr. Umi Fatonah, M.Pd.	Instructional Design Expert	96%	Highly Valid
Maimunah, M.Pd.	Media Expert	86.4%	Highly Valid
Average		**89.8%**	**Highly Valid**

Content expert recommendations included: (1) pretest questions should not be randomized and should be adjusted to difficulty levels and presented more contextually, (2) perimeter and area material needs clearer logical sequencing as core material, and (3) visualizations of flat shapes must be precise and align with shape properties. Media expert recommendations included: (1) audio quality adjustment on interactive video elements, and (2) improving legibility and color contrast of fonts. Instructional design expert recommendations included: (1) aligning teacher and student guides with content, (2) adding voice narration to facilitate audio learners, (3) using real voice for opening narration, and (4) formulating learning objectives according to ABCD format.

User Trial Results

Small group trials (N=15) obtained a feasibility score of 90.45%, and operational field trials (N=30) obtained 91.53%, both in the "Highly Feasible" category. This indicates that the web-based media is practical and acceptable to users.

Table 2. Recapitulation of Operational Field Trial Results (N=30)

Aspect	Percentage	Category
Satisfaction and Interest	91.73%	Highly Feasible
Ease of Use	91.60%	Highly Feasible
Learning Aspect	91.87%	Highly Feasible
Web and Personalization	90.93%	Highly Feasible
Average	**91.53%**	**Highly Feasible**

The highest score was achieved in the Learning Aspect (91.87%), indicating that students felt the media significantly helped them understand flat-shape concepts. The Satisfaction and Interest aspect also scored high (91.73%), confirming that gamification elements successfully created an engaging learning experience.

Media Effectiveness

Descriptive Statistics:

Effectiveness testing results showed a significant improvement in the experimental group. The average pretest score in the experimental group was 56.33, which increased to 92.33 in the posttest, with an average N-Gain of 83.44% (Effective category). In contrast, the control group achieved an N-Gain of 53.08%, which falls under the Moderate (Medium) category according to Hake's classification.

Table 3. N-Gain Score Comparison

Class	Average N-Gain	Category
Experimental	0.834 (83.44%)	High (Effective)
Control	0.531 (53.08%)	Medium (Moderate)

Hypothesis Testing

The Wilcoxon Signed Rank Test showed a significant improvement in both groups ($Z = -4.858$, $p < 0.001$ for experimental; $Z = -4.847$, $p < 0.001$ for control). The Mann-Whitney U Test on N-Gain scores yielded $U = 123.00$, $Z = -4.887$, $p < 0.001$. This confirms that the experimental group had significantly higher improvement compared to the control group. The mean rank of the experimental group (41.40) far exceeded the control group (19.60), proving that the web-based interactive media provides superior learning outcomes compared to conventional methods.

Table 4. Mann-Whitney U Test Results on N-Gain

Variable	Group	Mean Rank	Sum of Ranks	Mann-Whitney U	Z	p-value
N-Gain Score	Experimental	41.40	1242.00	123.00	-4.887	<0.001
	Control	19.60	588.00			

Media Development Procedure: Methodological Integration as Procedural Innovation

Discussion (مناقشة)

The success of the development procedure in this research lies in the systematic integration of the ADDIE and Borg & Gall models. Most learning media development research, such as that conducted by Permana et al. (2024) and Kharisma & Yana (2021), only relies on one model, generally ADDIE, which has limitations in layered empirical testing. Meanwhile, research by Bandaso & Harjono (2023) using Borg & Gall often lacks detail in micro-instructional design guidance. The integration formulated into four main phases—Preliminary Study, Planning, Development, and Implementation—successfully bridged this gap (Branch, 2009; Borg & Gall, 1983).

This procedural novelty (Richey & Klein, 2021) not only simplifies the 10 steps of Borg & Gall and the 5 phases of ADDIE into a more streamlined flow but also creates a double-loop correction cycle. At each phase, there is a mutually reinforcing validation and revision mechanism: instructional design (from ADDIE) is empirically tested (from Borg & Gall). Consequently, the resulting product is not only valid in content and design but also practical and effective in the field. This aligns with findings by Husnayayin et al. (2024) and Untoroseto & Triayudi (2023) emphasizing that adaptive and iterative development procedures produce higher-quality, ready-to-use learning products. This finding confirms that methodological synthesis is a superior approach for developing complex digital media.

Media Validity: Consistency of Expert Assessment as Foundation of Product Quality

The very high media validity (average 89.8%) indicates that the developed product has met rigorous academic standards. The variation in scores across validation aspects warrants deeper analysis. Content Expert (87% - Highly Valid): The content expert's assessment, with particular note on the indicator "no misconceptions" (score 3 out of 5), indicates that although the flat-shape material generally aligns with Learning Outcomes (CP) and students' cognitive development, there is still room for improvement in precise visualization and logical sequencing. This aligns with Piaget's (1964) cognitive development theory and Vygotsky's (1978) scaffolding principle, emphasizing that material for students in the concrete operational stage must be presented gradually, from concrete to abstract, and free from ambiguous representations. Instructional Design Expert (96% - Highly Valid): The highest achievement came from the instructional design expert, indicating that learning objective formulation (ABCD approach), strategy selection, and curriculum alignment were very well structured. This confirms that systematic instructional design (Dick & Carey, 2015) is a critical foundation determining product quality. The 96% score also indicates that the Design phase in the ADDIE model was optimally executed. Media Expert (86.4% - Highly Valid): The media expert gave a score of 86.4%, with improvement suggestions on color contrast and audio quality. These technical aspects are crucial for media intended for fourth-grade elementary students as they directly relate to visual comfort and learning focus. This critique aligns with Mayer's (2021) multimedia design principles and user experience (UX) principles emphasizing that visual clarity and user comfort are prerequisites for effective content reception.

Media Practicality: Positive User Response and Its Implications for Learning

The very high practicality level (91.53% in operational field trials) indicates that this web-based media is not only theoretically valid but also easy to use and accepted by users (students) in real learning contexts. This data is consistent across various measured aspects: Satisfaction and Interest (91.73%), Ease of Use (91.60%), Learning Aspect (91.87%), and Web and Personalization (90.93%). Satisfaction and Interest (91.73%): The high score confirms that the gamification elements (points, badges, interactive quizzes) integrated into the web-based media successfully created joyful learning experiences. This aligns with research by Plass & Macnamara (2025) and

Anderson et al. (2024) showing that gamification can increase students' intrinsic motivation, transforming their perception of mathematics—which was previously considered difficult and boring—into a challenging and engaging activity.

Ease of Use (91.60%): The high score indicates that the user interface (UI/UX) design, which is responsive and child-friendly, was highly effective. Fourth-grade elementary students, who are digital natives, could operate the web-based media without intensive technical training. This proves that the user-centered design principles applied during the storyboard and interface development phase were truly successful (Gegenfurtner, 2024). Learning Aspect (91.87%): The high score confirms that this web-based media effectively supports independent learning (self-regulated learning). Students felt helped by the immediate feedback feature, which allowed them to identify and correct errors instantly. This aligns with Thorndike's Law of Effect and behaviorist learning theory, where positive reinforcement and quick correction can improve student persistence and understanding (Miller et al., 2026; Chen & Lee, 2025). Web and Personalization (90.93%): The score indicates that the web-based platform successfully delivered a personalized learning experience. Students appreciated the ability to learn at their own pace, repeat material as needed, and access the media anytime, anywhere. This flexibility supports the Merdeka Curriculum's emphasis on differentiated learning and student-centered approaches.

Why SIMPERA Improves Learning Outcomes: In-depth Analysis of Driving Factors

The effectiveness results showing a significant N-Gain improvement in the experimental group (83.4%) compared to the control group (53.1%) prove that SIMPERA has a substantial impact on students' conceptual understanding. To explain why this media is so effective, we identify three key cognitive and pedagogical mechanisms. Factor 1: Reduction of Cognitive Load through Digital Visual Scaffolding. One key factor is the media's ability to reduce extraneous cognitive load through visual scaffolding (Sweller, 2023; Mayer, 2024). Abstract geometry material, such as angle relationships and area formulas, often burdens students' working memory. SIMPERA overcomes this by presenting dynamic animations and manipulative simulations (digital manipulatives) that allow students to directly "see" and "feel" changes in flat shapes. For instance, when students adjust the dimensions of a rectangle in SIMPERA, they simultaneously see the changes in its perimeter and area calculations in real-time. This multiple representation approach is consistent with Chen et al.'s (2024) finding that multimodal scaffolding enhances conceptual understanding. By reducing cognitive load, students can allocate more cognitive resources to processing and understanding the material rather than struggling with abstract representations. This result reinforces Papert's (1993) constructionism theory, where students learn more deeply when they actively construct knowledge through manipulating digital objects. Unlike static textbook images, SIMPERA's interactive features allow students to experiment, make predictions, and verify their understanding—a process that is difficult to achieve through lectures alone (Papadakis et al., 2023).

Factor 2: Motivation Enhancement through Gamification and Instant Feedback. The significant difference in N-Gain can also be explained by the motivational effects of gamification and instant feedback. Based on the needs analysis, fourth-grade elementary students are very familiar with gaming environments. By integrating game mechanics (points, badges, progress bars) into the learning content, SIMPERA successfully shifted students' perception from "learning is a burden" to "learning is a fun challenge" (Hamari et al., 2024). The gamification elements created a sense of achievement and progress, motivating students to complete more exercises and challenges. Students reported feeling proud when they earned badges and seeing their progress bars advance. This extrinsic motivation, combined with the intrinsic satisfaction of mastering new concepts, created a powerful learning environment that sustained student engagement throughout the learning process. Additionally, immediate feedback plays a crucial role in maintaining engagement and forming correct understanding. In conventional learning, students' errors often go unnoticed until the teacher corrects them, which can reinforce misconceptions. SIMPERA's instant feedback system enables students to immediately know the correct answer and receive a brief explanation, enabling direct self-correction. This not only improves accuracy but also builds students' self-efficacy as they experience progress in real-time (Chen & Lee, 2025; Miller et al., 2026). The feedback system was designed to be supportive rather than punitive, providing encouraging messages and hints when students made errors—a feature that helped reduce math anxiety.

Factor 3: Flexibility and Personalization of Learning. Another equally important aspect is SIMPERA's ability to support personalized learning. Unlike conventional lecture methods that are uniform, SIMPERA allows students to access content according to their own learning pace (self-paced learning). Fast learners can skip ahead to more challenging material, while slower learners can repeat material and exercises multiple times until they truly understand. This flexibility in access through various devices (laptops, tablets, smartphones) enables students to continue learning outside school hours, creating a continuous learning experience (ubiquitous learning) and supporting the student-centered learning principle emphasized in the Merdeka Curriculum (Hidayat et al., 2025; Wahyuni et al., 2024). SIMPERA also accommodates different learning styles (visual, auditory, kinesthetic). Visual learners benefited from animations and diagrams, auditory learners from narrations, and kinesthetic learners from drag-and-drop activities and interactive simulations. This multimodal approach is consistent with research by Papadakis et al. (2023) showing that interactive manipulators accommodate diverse learning preferences. To further strengthen the position of this research, we specifically compare it with previous studies mapped in the literature review.

Study	Level	Model Used	Effectiveness	Key Feature
Permana et al. (2024)	Junior High	ADDIE	N-Gain 0.68 (Medium-High)	Basic website media
Bandaso & Harjono (2023)	Elementary	Borg & Gall	32% increase	'Geo Me Try' website
Kharisma & Yana (2021)	Elementary	ADDIE	Validity only (no effectiveness test)	Basic website media
Marthani & Ratu (2022)	Junior High	ADDIE	Validity only	'BABADA' media
This Study (SIMPERA)	Elementary	ADDIE + Borg & Gall	N-Gain 83.4% (High)	Visual scaffolding + gamification

Comparison of Development Scope. Unlike Kharisma & Yana (2021) which covered broader material (both flat and spatial shapes) for general independent learning, SIMPERA focused specifically on flat-shape material for fourth grade with cognitive-visual interactive architecture. This focused approach allowed for deeper content development and more precise alignment with student needs. Research by Bandaso & Harjono (2023) is the closest because it was also conducted at the elementary level and used the Borg & Gall model. However, SIMPERA has an advantage in methodological integration—we not only combined two models but also translated them into a more efficient and iterative workflow with richer feedback at each phase.

Comparison of Effectiveness. The N-Gain score of 83.4% achieved in this research is significantly higher than findings by Permana et al. (2024) with a gain of 0.68 (medium-high category) and Bandaso & Harjono (2023) with a 32% increase in conceptual understanding. This superior effectiveness can be attributed to: More comprehensive development procedure with double-loop correction. Richer interactive features (visual scaffolding, gamification, instant feedback). Age-appropriate design specifically for concrete operational stage (ages 9-10). Multiple representation integration (visual, auditory, kinesthetic)

Comparison of Theoretical Contribution. While Marthani & Ratu (2022) focused on the concept of congruence, SIMPERA covered a broader range of flat-shape concepts including properties, perimeter, and area. This provided a more comprehensive contribution to geometry education at the elementary level. Furthermore, SIMPERA's integration of visual scaffolding and gamification represents a novel theoretical contribution that extends beyond the cognitive load frameworks typically applied in previous studies.

Alignment with Recent Research Trends. Recent scoping reviews on interactive geometry learning have identified several gaps that SIMPERA directly addresses. Focus on primary education: Most studies have focused on secondary or higher education . SIMPERA contributes to the limited body of research at the elementary level. Broader measurement indicators: Beyond spatial visualization and problem-solving, SIMPERA includes indicators such as geometric connections and mathematical reasoning. Interactive worksheet-based geometry: SIMPERA extends the findings of recent studies on interactive worksheets that engage students and enhance geometry learning outcomes .

Theoretical Implications

This research theoretically reinforces and proves that the five areas of educational technology according to Seels and Richey (design, development, utilization, management, and evaluation) are integrative and mutually supportive in developing digital learning media. The simultaneous application of these five areas proved to work cyclically and flexibly according to the dynamics of field needs. Additionally, this finding reinforces: Piaget's cognitive development theory regarding the concrete operational stage of children aged 9-10—SIMPERA's concrete representations bridge the gap to abstract understanding. Mayer's Cognitive Load Theory—interactive visual presentations, animated videos, and simulations are proven effective in reducing extraneous cognitive load. Vygotsky's Zone of Proximal Development—the scaffolding features in SIMPERA provide appropriate support within students' ZPD

Papert's Constructionism—digital manipulatives enable active knowledge construction

For teachers, SIMPERA provides an innovative, flexible learning tool (accessible through PCs, laptops, tablets, and smartphones). This research also encourages teachers to improve digital literacy and adapt similar interactive media development for other mathematics or subject materials. For students, SIMPERA offers a more engaging, enjoyable, interactive, and less boring mathematics learning experience compared to conventional lecture methods. The presence of simulations, animated videos, audio narration, and gamification-based interactive exercises with instant feedback facilitates various student learning styles (visual, auditory, and kinesthetic) and supports independent learning. For schools, the validated web-based learning media provides tangible evidence of commitment to integrating information and communication technology into the learning process in line with the Merdeka Curriculum and the Digitalization of Education era.

Conclusion (خاتمة)

The development procedure integrating the ADDIE and Borg & Gall models, streamlined into four main phases (Preliminary Study, Planning, Development, and Implementation), proved effective in producing a well-structured and tested web-based interactive learning media. This integrated procedure offers a methodological novelty by combining the strengths of ADDIE's systematic instructional design framework with Borg & Gall's rigorous empirical testing cycle, creating a replicable blueprint for developing similar digital learning products. The web-based interactive learning media on flat-shape material was declared highly valid (based on expert validation with an average of 89.8%) and highly practical (based on user trials with an average of 91.53%). Expert validation results were consistently above 85% across all three expert categories, and user trials showed sustained high scores across all measured aspects, confirming that SIMPERA meets rigorous academic standards and is ready for classroom implementation.

The web-based interactive learning media proved highly effective in improving students' conceptual understanding, as shown by the significant N-Gain improvement (83.4%) in the experimental group compared to the control group (53.1%). The Mann-Whitney U Test confirmed that the improvement in the experimental group was significantly superior ($Z = -4.887, p < 0.001$). This effectiveness is attributed to the media's ability to reduce cognitive load through visual scaffolding, enhance motivation through gamification and instant feedback, and support personalized learning through flexible access. While SIMPERA was developed specifically for mathematics (flat-shape geometry), its design principles and features offer significant practical benefits that can be extended to IPAS (Ilmu Pengetahuan Alam dan Sosial) learning in elementary schools:

Visualization of Abstract Concepts: IPAS contains many abstract concepts that are difficult for elementary students to understand, such as natural phenomena, ecosystem processes, and social interactions. SIMPERA's visual scaffolding approach—using animations, simulations, and dynamic visualizations—can be adapted to make abstract IPAS concepts more concrete and comprehensible. For example, students can visualize the water cycle, ecosystem interactions, or the process of photosynthesis through interactive simulations.

Interactive and Engaging Learning Experience: The gamification elements (points, badges, progress bars, interactive quizzes) that made mathematics learning enjoyable and motivating can similarly transform IPAS learning. Students who find science and social studies "boring" or "difficult" can become more engaged through game-based activities that challenge and reward their understanding.

Flexibility and Independent Learning: SIMPERA's self-paced learning feature allows students to learn IPAS content according to their individual readiness and pace. This is particularly beneficial for IPAS, where students may have varying levels of prior knowledge about natural and social phenomena. Slower learners can repeat material, while advanced learners can explore additional content, supporting differentiated learning as emphasized in the Merdeka Curriculum.

Immediate Feedback and Self-Correction: The instant feedback system that helped students identify and correct errors in mathematics can be equally valuable in IPAS learning. Students can immediately know whether they have correctly understood scientific concepts or social phenomena, enabling direct self-correction and preventing misconceptions from taking root. This is especially important for IPAS, where misconceptions about natural phenomena (e.g., why seasons change, how the solar system works) can persist if not corrected early.

Multiple Representation for Diverse Learners: SIMPERA's ability to accommodate different learning styles (visual, auditory, kinesthetic) through animations, narrations, and interactive activities makes it ideal for IPAS content. Visual learners benefit from diagrams and animations of natural processes, auditory learners from narrations explaining phenomena, and kinesthetic learners from interactive simulations they can manipulate.

Accessibility Anytime, Anywhere: SIMPERA's web-based platform enables students to access IPAS learning materials anytime, anywhere, using various devices. This supports continuous learning beyond the classroom and helps bridge the gap between formal and informal learning, allowing students to explore natural phenomena they observe in their daily lives.

Alignment with Merdeka Curriculum: SIMPERA's student-centered, interactive approach aligns directly with the Merdeka Curriculum's emphasis on differentiated learning, technology integration, and the development of higher-order thinking skills. The media provides a concrete tool for implementing these principles in IPAS instruction.

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