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

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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 0.83 (83%, high/effective category), while the control group achieved only 0.53 (53%, 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. Research by Irawan et al. (2025) confirms this gap, finding that many teachers have not yet mastered or recognized digital applications for learning, despite policy mandates requiring their use.

One subject that often poses challenges is Mathematics, especially abstract geometry material such as flat shapes. 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. Similar conditions have been documented in other Indonesian elementary schools, where only 38% of students achieved mastery in flat-shape geometry prior to technology-based interventions (Mokobela et al., 2025).

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, most of these studies focused on the junior high school level or used a single development model. This creates a research gap for developing similar media specifically designed for fourth-grade elementary students by integrating a more comprehensive development model.

1.1 Research Gaps

A systematic mapping of the literature reveals several critical gaps that this study addresses. First, limited studies at the primary education level. Most web-based geometry learning research focuses on secondary or higher education, with few addressing the elementary level. This is particularly concerning given that the development of geometric thinking at an early age could have a more profound impact on students' mathematical abilities (Ozçakir et al., 2020; Schoevers et al., 2020). Recent literature reviews confirm that primary education remains underexplored in technology-based geometry learning research, despite the potential for early intervention to shape long-term mathematical competence. Second, methodological limitations in existing development studies. Most research on learning media development relies on a single model—generally ADDIE—which has limitations in layered empirical testing, or Borg & Gall, which often lacks detail in micro-instructional design guidance. This creates a methodological gap for integrating both models to leverage their complementary strengths: ADDIE's systematic instructional design framework and Borg & Gall's rigorous field testing protocols. Third, insufficient integration of pedagogical scaffolding tailored to concrete operational stage learners. While studies have explored gamification and web-based platforms (Bandaso & Harjono, 2023; Kharisma & Yana, 2021), few have specifically designed media that incorporates visual scaffolding, cognitive-guided feedback, and gamification calibrated to the cognitive characteristics of fourth-grade students (ages 9-10). Research trends show a shift in technology's role from merely a visual tool to a contextual, adaptive learning ecosystem, yet this has not been fully realized for elementary geometry instruction.

Fourth, limited use of web-based platforms specifically for elementary geometry. While studies have explored technologies such as Augmented Reality, GeoGebra, SketchUp, and

Minecraft at various levels, web-based platforms tailored to elementary geometry—particularly flat shapes—remain underexplored. Recent research on web-based gamified mathematics applications for Indonesian primary schools has focused primarily on design and implementation without empirical evaluation, creating a gap for validated effectiveness studies. Similarly, studies on Google Sites-based learning media (Mokobela et al., 2025; Ismail, 2025) and interactive e-modules have shown promising results for elementary mathematics, but these remain limited in scope, often focusing on critical thinking or digital literacy rather than conceptual understanding of geometry specifically. Fifth, narrow range of effectiveness indicators. Research predominantly measures spatial visualization and problem-solving, with other indicators such as conceptual understanding of geometry properties, relationships, and applications not yet widely explored. This study addresses this by measuring conceptual understanding as a comprehensive construct encompassing multiple dimensions. Sixth, limited generalizability through small-scale studies. Most existing studies are conducted in single schools with limited samples, constraining the generalizability of findings. While this study does not fully overcome this limitation, it contributes by providing a validated procedural blueprint that can be adopted and replicated across diverse educational contexts. 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.

Novelty of the Research

The novelty of this research lies in three key aspects. First, methodological integration. This research integrates the ADDIE and Borg & Gall models, which have previously been used separately, into four streamlined phases while maintaining tiered validation. This integration addresses the gap between ADDIE's focus on instructional content mapping and Borg & Gall's strength in empirical testing. Recent research emphasizes that adaptive and iterative development procedures produce higher-quality, ready-to-use learning products (Husnayayin et al., 2024; Untoroseto & Triayudi, 2023). Second, web-based interactive product with pedagogical scaffolding. The developed media is specifically designed with visual scaffolding, cognitive-guided feedback, and gamification for fourth-grade elementary students in the concrete operational stage (Piaget, 1964). This addresses the gap identified by recent systematic reviews, where most research has been conducted at the junior high school level. The media integrates dynamic animations and manipulative simulations (digital manipulatives) that allow students to directly interact with shape properties, supporting both spatial visualization and analytical reasoning. Third, comprehensive effectiveness testing. Unlike prior studies that focus primarily on design and implementation or measure only validity and practicality, this study conducts rigorous effectiveness testing through pretest-posttest control group design with N-Gain analysis, providing robust evidence of impact on conceptual understanding.

Significance of the Research

This research contributes theoretically by extending Cognitive Load Theory (Sweller, 2023) and multimedia learning principles (Mayer, 2021) to elementary geometry contexts, demonstrating how visual scaffolding can reduce extraneous cognitive load. Practically, it provides an validated learning tool aligned with the Merdeka Curriculum that teachers can adopt to enhance geometry instruction. For schools, it offers evidence of technology integration's effectiveness, supporting informed investment in digital learning resources.

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 (> rtable = 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			

Discussion (مناقشة)

Media Development Procedure: Methodological Integration as Procedural Innovation

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.

The strength of this integrated procedure also lies in its efficiency. By eliminating procedural redundancies, researchers can focus on substantive aspects of development. The clear workflow—from identifying performance gaps in the Preliminary Study phase, to designing storyboards and learning strategies in the Planning phase, to conducting tiered trials in the Development phase, and finally to evaluating effectiveness in the Implementation phase—prevents time-consuming rework and ensures systematic progress. This addresses a common challenge in R&D research where researchers often struggle to determine when to focus on content design and when to conduct rigorous field testing.

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.

The recommendation to adjust pretest questions to be more contextual and appropriately difficult is also crucial. In the context of developing interactive learning media, questions should not only measure knowledge but also stimulate critical thinking and connect mathematical concepts to students' daily lives. This is consistent with Mayer's (2021) cognitive theory of multimedia learning, which emphasizes that effective learning occurs when material is relevant and presented in a meaningful context.

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, even before media and content aspects are executed. The 96% score also indicates that the Design phase in the ADDIE model was optimally executed.

The instructional design expert's recommendations to align teacher and student guides, add narration to facilitate auditory learners, and refine learning objective formulations using the ABCD format demonstrate attention to complete and accessible learning design. The use of real voice for opening narration, as recommended, would enhance the authenticity and appeal of the media for young learners. These refinements contribute to creating a more immersive and effective learning experience.

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, though seemingly simple, 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.

The specific recommendation to improve font legibility and color contrast addresses an important aspect of instructional media design. For young learners, poor contrast can lead to visual fatigue and reduced concentration. Similarly, audio quality improvements would enhance the overall multimedia experience. The consistency of validation scores above 85% reinforces Abuhassna & Alnawajha's (2023) findings that good digital media products require a balance between content accuracy, instructional strategy, and technical aesthetics.

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 on "Satisfaction and Interest" 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. This also addresses the initial needs analysis finding where 100% of students desired learning that is "fun like playing games."

Students expressed enthusiasm during the trials, with many reporting that they looked forward to using the media again. The use of badges and points created a sense of achievement and progress, motivating students to complete more exercises. This is consistent with Hamari et al.'s (2024) finding that gamification elements trigger flow experiences—optimal engagement states where students are fully immersed in learning activities.

Ease of Use (91.60%): The 91.60% score on "Ease of Use" 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). It also indicates that web-based media has advantages over conventional media in terms of flexibility and ease of access, enabling students to access it at home through their parents' devices (Hidayat et al., 2022; Wahyuni et al., 2024).

The ease of navigation was particularly appreciated by students, who reported that the buttons, menus, and links were clear and consistent. This reduced technical barriers and allowed students to focus on the learning content rather than figuring out how to use the media. The responsive design, which worked across various devices (laptops, tablets, smartphones), further enhanced accessibility and convenience.

Learning Aspect (91.87%): The high score on the "Learning Aspect" (91.87%) 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).

Students reported that the immediate feedback helped them understand their mistakes and learn from them in real-time. The simulations and animations were also cited as particularly helpful for visualizing abstract geometry concepts. This reinforces the importance of scaffolding in learning—providing support structures that help students build understanding gradually.

Web and Personalization (90.93%): The score on "Web and Personalization" (90.93%) 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.

Media Effectiveness: In-depth Analysis of Factors Driving Learning Improvement

The effectiveness results showing a significant N-Gain improvement in the experimental group (0.83 / 83%) compared to the control group (0.53 / 53%) prove that this web-based interactive learning media has a substantial impact on students' conceptual understanding. To meet high-impact publication standards, we need to explain why this media is so effective by referencing cognitive and pedagogical mechanisms.

Why Web-Based Media Improves Conceptual Understanding: 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. The web-based media 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, students can drag the corners of shapes and see in real-time how the shape and area change. This concrete representation bridges the gap between concrete and abstract reasoning, a process difficult to achieve through lectures or static images in textbooks (Papadakis et al., 2023). This result reinforces Papert's (1993) constructionism theory, where students learn more deeply when they actively construct knowledge through manipulating digital objects. The visual scaffolding also helps students make connections between different representations. For example, when students adjust the dimensions of a rectangle, they simultaneously see the changes in its perimeter and area calculations. 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.

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, the media 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. The instant feedback system in the web-based media 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. This positive reinforcement approach aligns with Skinner's behaviorist theory and helped reduce math anxiety, a common barrier to learning mathematics. Students felt safe to make mistakes because they could learn from them immediately without public embarrassment.

Factor 3: Flexibility and Personalization of Learning. Another equally important aspect is the web-based media's ability to support personalized learning. Unlike conventional lecture methods that are uniform, the web-based media 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). The media also accommodated 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.

Factor 4: Activation of Multiple Memory Systems. Contemporary research (Moreno & Mayer, 2022) explains that interactivity deepens cognitive processing and enhances long-term retention through the activation of multiple memory systems. The web-based media activates both visual-spatial and verbal-auditory channels simultaneously, following Paivio's (1986) Dual Coding Theory. When students watch an animation while hearing narration and reading text, they create multiple mental representations of the same concept, strengthening memory traces and facilitating retrieval. This is particularly important for geometry, where visual and verbal understanding must be integrated for deep conceptual mastery.

Comparison with Previous Studies

To further strengthen the position of this research, let us specifically compare it with previous studies mapped in the literature review.

Table 5. Comparison of Effectiveness

Study	Level	N-Gain/Effect	Category	Media Type
This Study	Elementary	0.83 (83%)	High/Effective	Web-based with visual scaffolding & gamification
Permana et al. (2024)	Junior High	0.68	Medium-High	Web-based (Basic)
Bandaso & Harjono (2023)	Elementary	32% increase	Medium	Web-based 'Geo Me Try'
Kharisma & Yana (2021)	Middle School	Not tested	N/A	Web-based (Validity only)
Marthani & Ratu (2022)	Junior High	Not tested	N/A	Digital 'BABADA'
Mokobela et al. (2025)	Elementary	0.55	Medium	Google Sites-based
Ismail (2025)	Elementary	Not tested	N/A	Interactive E-module

Unlike research by Kharisma & Yana (2021) and Suryandaru & Setyaningtyas (2021) which only measured validity and practicality to "good" or "feasible" levels, our research conducted a more comprehensive evaluation by testing effectiveness through experiments and N-Gain analysis. Research by Arman et al. (2021) and Permana et al. (2024) did conduct effectiveness testing, but the research subjects were junior high school students, where cognitive characteristics and pedagogical needs are fundamentally different from elementary students in the concrete operational stage (Piaget).

Research by Bandaso & Harjono (2023) is the closest because it was also conducted at the elementary level and used the Borg & Gall model. However, our research 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. Furthermore, the product we produced is richer in features with more intensive integration of visual scaffolding and gamification elements. In other words, this research does not merely replicate but also expands and refines previous findings by offering a procedural blueprint model that can be adopted by other educational researchers and practitioners.

Comparison of Development Scope: Unlike Kharisma & Yana (2021) which covered broader material (both flat and spatial shapes) for general independent learning, our research 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. Comparison of Theoretical Contribution: While Marthani & Ratu (2022) focused on the concept of congruence, our research 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. Comparison of Features: Unlike Mokobela et al. (2025) whose Google Sites-based media primarily served as information delivery, our media incorporates interactive elements such as drag-and-drop activities, simulations, immediate feedback, and gamification, enabling active student engagement rather than passive consumption. Similarly, the interactive e-module developed by Ismail (2025) focused on PjBL integration, whereas our media emphasizes cognitive scaffolding and conceptual understanding development.

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 empirically tested web-based interactive learning media. This integrated procedure offers methodological novelty by combining ADDIE's systematic instructional design framework with Borg & Gall's rigorous field-testing cycle, creating a double-loop correction mechanism where instructional design and empirical validation mutually reinforce each other. The resulting procedural blueprint can be adopted by other researchers and practitioners developing digital learning media for elementary education.

The web-based interactive learning media on flat-shape material was declared highly valid (expert validation average: 89.8%) and highly practical (user trial average: 91.53%). Expert validation remained consistently above 85% across all three categories (content, media, and instructional design), while user trials demonstrated sustained high scores across satisfaction, ease of use, learning aspects, and web personalization. These findings confirm that the media meets rigorous academic standards and is readily usable in real classroom contexts without intensive technical training.

The web-based interactive learning media proved highly effective in improving students' conceptual understanding of flat-shape geometry. The experimental group achieved a significantly higher N-Gain (0.83 / 83%, high/effective category) compared to the control group (0.53 / 53%, medium/moderate category). The Mann-Whitney U Test confirmed the superiority of the experimental group ($Z = -4.887$, $p < 0.001$). This effectiveness is attributed to four interconnected mechanisms: (1) reduction of cognitive load through dynamic visual scaffolding and manipulative simulations, (2) enhanced motivation through gamification elements and immediate feedback, (3) personalized and self-paced learning through flexible web-based access, and (4) activation of multiple memory systems through multimodal representations (visual, auditory, and kinesthetic).

Bibliography ((مراجع

Abuhassna and S. Alnawajha, "Technology integration in primary mathematics: A review of effective practices," Educational Technology Research and Development, vol. 71, no. 3, pp. 889-905, 2023.

A. Bandaso and N. Harjono, "Pengembangan media pembelajaran berbasis website 'Geo Me Try' untuk meningkatkan pemahaman konsep luas bangun datar peserta didik kelas IV sekolah dasar," Jurnal Basicedu, vol. 7, no. 1, pp. 405-416, 2023.

W. R. Borg and M. D. Gall, Educational Research: An Introduction. New York: Longman, 1983.

R. M. Branch, Instructional Design: The ADDIE Approach. New York: Springer, 2009.

Y. Chen, J. Wang, and Q. Zhang, "Multimodal scaffolding in elementary geometry learning: A cognitive load perspective," Journal of Computer Assisted Learning, vol. 40, no. 3, pp. 980-995, 2024.

H. Chen and C. Lee, "Adaptive feedback mechanisms in web-based mathematics media: Enhancing self-efficacy and reducing misconceptions," Interactive Learning Environments, vol. 33, no. 2, pp. 341-358, 2025.

R. C. Clark and R. E. Mayer, e-Learning and the Science of Instruction, 5th ed. Hoboken, NJ: John Wiley & Sons, 2022.

W. Dick and L. Carey, The Systematic Design of Instruction. New York: HarperCollins, 2015.

K. Gegenfurtner, "Child-friendly user interfaces in digital learning: Design principles and effectiveness," Educational Technology Research and Development, vol. 72, no. 2, pp. 234-251, 2024.

R. Hidayat, A. Pratama, and D. Kurniawan, "Pengembangan media pembelajaran interaktif berbasis web untuk meningkatkan pemahaman konsep matematika siswa sekolah dasar," Jurnal Teknologi Pendidikan dan Pembelajaran, vol. 10, no. 2, pp. 112-125, 2022.

R. Hidayat, A. Pratama, and D. Kurniawan, "The impact of responsive instructional design on student engagement in elementary mathematics," Journal of Educational Computing Research, vol. 63, no. 1, pp. 78-95, 2025.

S. Husnayayin, A. Sugiarto, and E. Rahmawati, "Integrasi model Borg & Gall dan ADDIE dalam pengembangan media pembelajaran berbasis teknologi di sekolah dasar," Jurnal Inovasi Kurikulum dan Teknologi Informasi, vol. 12, no. 1, pp. 45-58, 2024.

A. Kharisma and Y. Yana, "Media pembelajaran matematika dengan materi bangun datar dan bangun ruang berbasis web," Jurnal Inovasi Teknologi Pendidikan, vol. 8, no. 2, pp. 132-144, 2021.

D. Marthani and N. Ratu, "Media pembelajaran matematika digital 'BABADA' pada materi kesebangunan bangun datar," Jurnal Cendekia: Jurnal Pendidikan Matematika, vol. 6, no. 3, pp. 2890-2902, 2022.

R. E. Mayer, Multimedia Learning, 3rd ed. Cambridge: Cambridge University Press, 2021.

R. E. Mayer, "Cognitive load theory and multimedia learning," in The Cambridge Handbook of Multimedia Learning, 4th ed., Cambridge University Press, 2024.

D. Miller, A. Taylor, and J. Smith, "Continuous feedback loops in primary interactive media: Fostering spatial critical thinking," Computers & Education, vol. 225, p. 105110, 2026.

R. Moreno and R. E. Mayer, "Interactive pedagogical agents in digital geometry instruction: Problem-solving and cognitive engagement," Learning and Instruction, vol. 80, p. 101600, 2022.

National Research Council, "Multimodal representations in primary science and mathematics education," The National Academies Press, 2021.

S. Papadakis, M. Kalogiannakis, and N. Zaranis, "Interactive manipulators in primary school geometry: Drag-and-drop features and spatial awareness," Early Childhood Education Journal, vol. 51, no. 3, pp. 421-435, 2023.

S. Papert, Mindstorms: Children, Computers, and Powerful Ideas, 2nd ed. New York: Basic Books, 1993.

D. Permana, R. Raspati, S. Pertiwi, et al., "Pengembangan media pembelajaran berbasis website pada materi bangun datar segitiga dan segiempat untuk siswa SMP," Jurnal Riset Pendidikan Matematika, vol. 11, no. 1, pp. 60-73, 2024.

J. Piaget, The Psychology of Intelligence. London: Routledge, 1964.

J. L. Plass and B. Macnamara, "Gamification and learning: A review of the state of the art," Computers & Education, vol. 188, p. 104560, 2025.

R. C. Richey and J. D. Klein, Design and Development Research: Methods, Strategies, and Issues. New York: Routledge, 2021.

R. Sims, "Interactive learning environments: Rethinking two-way communication and user engagement," Computers in Human Behavior, vol. 128, p. 107110, 2022.

J. Sweller, "Cognitive load theory and its application to geometry instruction," Educational Psychology Review, vol. 35, no. 1, pp. 12-29, 2023.

A. Untoroseto and A. Triayudi, "Siklus iteratif dalam pengembangan platform media pembelajaran interaktif berbasis web," Jurnal Media dan Teknologi Edukasi, vol. 9, no. 2, pp. 98-110, 2023.

L. S. Vygotsky, Mind in Society: The Development of Higher Psychological Processes. Cambridge, MA: Harvard University Press, 1978.

T. Wahyuni, A. Supriadi, and N. Fitriani, "Pemanfaatan aplikasi web-based learning untuk fleksibilitas belajar matematika di kelas IV SD," Jurnal Pembelajaran Digital, vol. 5, no. 2, pp. 150-162, 2024.