Journal of Educational Sciences
Journal homepage: https://jes.ejournal.unri.ac.id/index.php/JES

P-ISSN 2581-1657
E-ISSN 2581-2203

Development of Android-Based MACCA Interactive Multimedia to Improve Second-Grade Students' Understanding of Arithmetic Operations

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ARTICLE INFO

Article history:

Received: 29 May 2026
Accepted: 07 Sept 2026
Available Online: 15 Sept 2026

Keywords:

Interactive Multimedia,
Android,
Arithmetic Operations,
ADDIE,
Conceptual Understanding

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Article Doi:

https://doi.org/10.31258/jes.10.9.p.842-857

A B S T R A C T

Limited access to age-appropriate interactive mathematics media can make arithmetic operations difficult for elementary school students to understand. This study aimed to develop and evaluate MACCA (Mathematics Android-based Creative and Contextual Application), an Android-based interactive multimedia application for second-grade arithmetic learning. The study employed Research and Development using the ADDIE model: analysis, design, development, implementation, and evaluation. Participants were 30 second-grade students at SD Islam Athirah 2 Makassar. Data were collected through expert-validation sheets, pretest and posttest measures, student-response questionnaires, observation, and interviews. Material and media experts rated the product as highly feasible. Student responses averaged 3.46, equivalent to 86.5%, indicating very high practicality. Classroom mastery reached 83.33%, and the paired-samples test identified a significant pretest-posttest difference. The effect-size estimate also indicated a large educational effect. These findings show that MACCA is valid, practical, and effective for supporting students' conceptual understanding of arithmetic operations. Its combination of verbal explanations, concrete illustrations, animation, audio, guided practice, and immediate feedback provides an engaging bridge between abstract symbols and concrete learning experiences.

1. Introduction

Digital transformation has shifted education from conventional instruction toward interactive and student-centred learning. In elementary mathematics, this shift is especially important because young learners must connect symbolic notation with concrete experience. Multimedia can coordinate words, pictures, audio, animation, and learner-controlled practice, thereby supporting the selection, organization, and integration of information described in the Cognitive Theory of Multimedia

Learning (Wulandari et al., 2023). The appropriate use of learning media can improve clarity, participation, and learning outcomes, particularly when technology is aligned with students' needs (Kim, 2015; Maasum et al., 2014). Recent studies in the Journal of Educational Sciences also show that digital and interactive resources can make elementary mathematics more visible, engaging, and accessible (Aida et al., 2025; Rahman et al., 2021; Rokhman et al., 2014).

The need for stronger mathematics support is also evident in international assessment. Indonesian students' mathematics performance in PISA 2022 remained below the OECD average, indicating persistent difficulty with foundational concepts and mathematical reasoning (Rokhman et al., 2014). At the school level, preliminary observation at SD Islam Athirah 2 Makassar showed that only 72% of students met the minimum mastery criterion, whereas the institutional target was 90%. Classroom instruction still relied mainly on textbooks and teacher explanation, while available digital media did not provide integrated visualization, guided practice, and immediate feedback. These conditions limited students' opportunities to explore arithmetic concepts actively and to correct misconceptions during learning.

Arithmetic operations require more than memorizing procedures. Second-grade students need concrete representations, meaningful contexts, and repeated opportunities to explain how quantities change. Research on arithmetic learning confirms that manipulatives and visual representation help elementary students connect calculation procedures with the underlying concepts (Gbormittah et al., 2025; Rokhman et al., 2014). Gamified interactive multimedia can also make integer operations more understandable and engaging (Habeahan & Prayitno, 2022; Harahap et al., 2023). Contextual mathematics media such as Pamitung and Lubaku have demonstrated that tangible or visual representations can increase elementary students' interest and help them understand calculation relationships (Muhammad Novriansyah Lubis, Hermanu Joebagio, Musa Pelu et al., 2019; Sihombing & Silooy, 2023). Similarly, interactive e-comics and digital teaching materials developed with systematic models have shown strong feasibility and positive learning responses (Duwi Priyono & Siregar, 2021; Nyaaba & Zhai, 2025). However, many products focus on one presentation format or one specific feature and do not combine complete multimedia elements within a portable Android application.

Mobile devices create an opportunity to provide flexible learning both inside and outside the classroom. Smartphone-supported learning can improve access, interactivity, and motivation when accompanied by appropriate guidance and control (Duwi Priyono & Siregar, 2021). Android-assisted learning tools have also demonstrated potential to improve motivation and learning outcomes when digital interaction is aligned with instructional activities (Duwi Priyono & Siregar, 2021; Nyaaba & Zhai, 2025). Android applications have been used to support independent learning and to present contextual content through portable digital media (Birhan et al., 2021; Zeng et al., 2025). Nevertheless, technology alone does not guarantee conceptual learning. The media must reduce unnecessary cognitive processing, connect verbal and visual representations, provide clear navigation, and place

practice immediately after explanation. Augmented-reality and interactive multimedia can strengthen visualization and learning outcomes by making abstract or unobservable content more accessible to elementary students (Daulay, 2022; Hamid et al., 2024). Therefore, an Android application for young learners should be designed from pedagogical needs rather than from technological novelty alone.

The identified research gap concerns the limited availability of an integrated Android-based mathematics application designed specifically for second-grade arithmetic operations and evaluated in terms of validity, practicality, and effectiveness. Mathematics learning in the current curriculum requires learning experiences that strengthen conceptual understanding and prepare students for increasingly technology-rich environments (Arifiah & Siregar, 2022; Firmando, 2021). To address this gap, this study developed MACCA, meaning Mathematics Android-based Creative and Contextual Application. MACCA integrates concise explanations, concrete illustrations, narration, animation, video, guided exercises, navigation buttons, and immediate feedback in one learning environment. The product was developed using ADDIE so that needs analysis, design decisions, expert review, classroom implementation, and evaluation formed a connected and iterative process.

The theoretical contribution of this study lies in demonstrating how the Cognitive Theory of Multimedia Learning can be operationalized for early-grade arithmetic through three linked design principles: coordinated verbal and visual representations, progressive movement from concrete illustrations to mathematical symbols, and learner interaction followed by immediate feedback. The study also provides an applied pattern for using ADDIE as an iterative evidence-based development cycle rather than as a purely linear production sequence. Each evaluation results informed revisions to content difficulty, instructions, typography, navigation, and interactivity before broader classroom use. This study therefore aimed to develop Android-based MACCA interactive multimedia and determine its validity, practicality, and effectiveness in improving second-grade elementary students' understanding of arithmetic operations.

2. Methodology

Research Design

This study used a Research and Development design with the ADDIE model, comprising analysis, design, development, implementation, and evaluation. The model was selected because it connects instructional needs with product design, expert validation, user testing, and evidence-based revision. A systematic digital-platform development process likewise requires iterative review so that the product remains aligned with learning and evaluation needs (Iskandarsyah Siregar, 2022). During analysis, the researchers examined classroom conditions, learning outcomes, curriculum requirements, student characteristics, and teacher needs. During design, they prepared learning objectives, content flow, a storyboard, interface layouts, navigation, exercises, and assessment components. During

development, these plans were converted into an Android application and reviewed by material and media experts. Implementation consisted of a limited trial followed by a field trial. Formative and summative evaluation occurred throughout the process.

Research Participants and Setting

The research was conducted at SD Islam Athirah 2 Makassar. Participants were selected purposively because the school had identified a need for interactive support in arithmetic learning. The limited trial involved 15 second-grade students, while the field trial involved 30 second-grade students representing varied initial achievement levels. Two elementary teachers and two university lecturers participated as validators. The study was conducted over approximately two months, covering product preparation, expert validation, revision, limited testing, field implementation, and evaluation.

Research Instruments

Five instruments were used. First, material- and media-validation sheets assessed content accuracy, curricular alignment, presentation quality, interface design, navigation, and interactivity. The attention given to content accuracy and instructional presentation is important because teachers' mathematical knowledge and the quality of instruction are closely related to students' opportunities to understand mathematics. Second, a student-response questionnaire assessed clarity, attractiveness, ease of use, and perceived learning support. Third, parallel pretest and posttest measures assessed conceptual understanding of arithmetic operations. Fourth, an observation sheet documented implementation fidelity, student participation, and technical difficulties. Fifth, semi-structured interviews captured students' and teachers' experiences. Instrument content was reviewed before use to ensure alignment with the research objectives.

Data Collection and Analysis

Data collection proceeded sequentially across the ADDIE stages. Needs data were gathered through observation and review of learning outcomes. Expert ratings and written suggestions were collected during development and used to revise the prototype. During implementation, the researchers documented how the teacher introduced MACCA, demonstrated navigation, guided individual exploration, facilitated practice, and discussed feedback. Pretests were administered before the treatment and posttests afterward. Questionnaire, observation, and interview data were then collected to evaluate practicality and user experience.

Expert-validation and questionnaire scores were summarized descriptively using means and percentages. Learning mastery was calculated from the proportion of students meeting the predetermined criterion. Pretest and posttest scores were analysed with a paired-samples t-test, and practical magnitude was examined using Cohen's d. Qualitative responses from observation and interviews were condensed, categorized, compared across sources, and used to interpret quantitative results.

Because the effectiveness test used a one-group pretest-posttest design without a control group, the findings support improvement associated with the intervention but do not establish causality as strongly as a controlled quasi-experiment.

3. Results and Discussion

MACCA was applied through a structured classroom treatment. The teacher first activated students' prior knowledge and explained the learning objectives, then demonstrated the application's menu and navigation. Students explored short explanations and concrete illustrations, listened to narration, observed animations, and completed guided exercises. Immediate feedback enabled them to reconsider incorrect answers before moving to the next task. The teacher monitored progress, assisted students who needed technical or conceptual support, and concluded the lesson with discussion and reflection. The following subsections report how this treatment was developed and evaluated through ADDIE.

Analysis

Observation and learning-outcome review identified the main instructional needs, as summarized in Table 1.

Table 1. Results of the Analysis Stage

Analysis Aspect	Main Finding	Implication
Learning Needs	Students had difficulty understanding arithmetic-operation concepts	Media should make abstract concepts concrete
Learning Outcomes	Only 72% met the mastery criterion; the target was 90%	Learning effectiveness should be improved
Student Characteristics	Students preferred visual and interactive media	Media should combine audio, visuals, and animation
Learning Media	Learning relied mainly on textbooks and teacher explanation	Technology-based media innovation was needed
Technology Use	Students were familiar with smartphones	Android-based learning was feasible
Main Problem	Abstract concepts and limited learner engagement	Interactive media should increase engagement
Teacher Needs	Teachers needed practical and accessible media	The application should be user-friendly and flexible

Design

The multimedia design included the content structure, application flow, interface, navigation, and integration of text, images, audio, animation, and video. These elements were adapted to the developmental characteristics of second-grade students. The application design is shown in Figure 1.

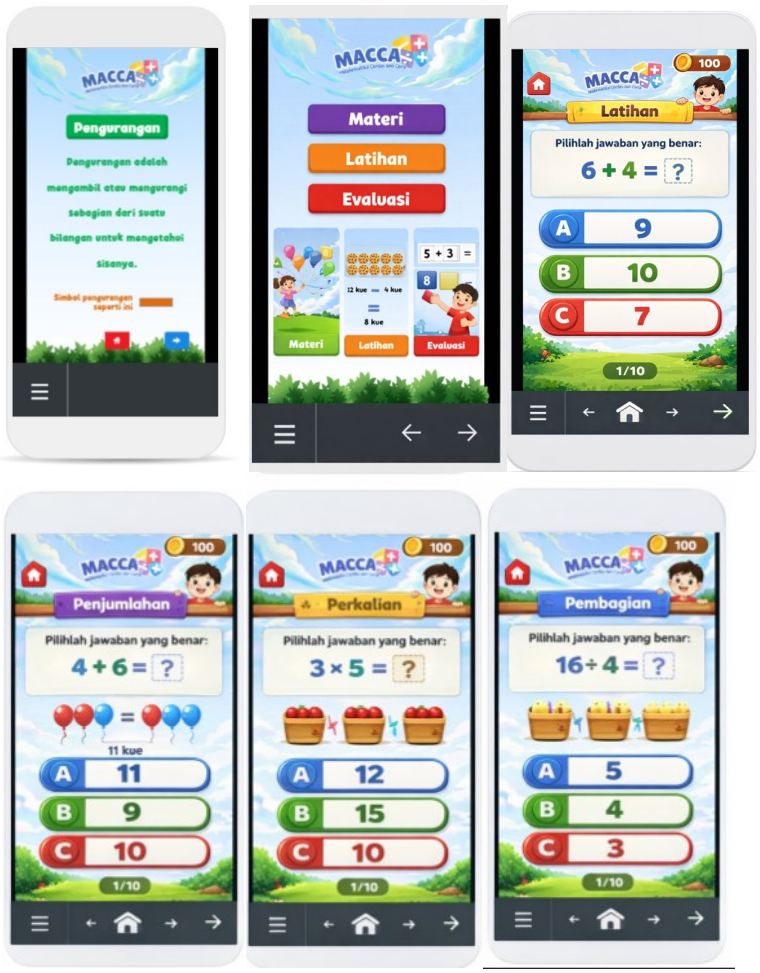

Figure 1. MACCA Application Design. Interface-label translation: Materi = Learning Materials; Petunjuk = Instructions; Latihan = Exercises; Profil = Profile; Mulai = Start; and Keluar = Exit.

Development

Material validation examined curricular alignment, conceptual accuracy, clarity, coherence, contextual relevance, examples, language, and difficulty. Media validation examined legibility, visual consistency, navigation, interactivity, feedback, and usability. Four validators, consisting of two teachers and two lecturers, reviewed the prototype. Their suggestions were used to improve question difficulty, instructions, font size, navigation cues, and interactive feedback before classroom testing. Table 2 presents material-validation results.

Table 2. Validation of Mathematical Content

No.	Assessment Aspect	Mean Score
1	Content Quality	3.75
2	Currency of Content	3.94
3	Content Scope	3.56
4	Content Adequacy	3.63
	Overall Mean	3.72 (Very Valid)

The material-validation results placed MACCA in the very valid category. The strongest aspects were the clarity of learning objectives, material selection, and contextual presentation. These findings indicate that the content was sufficiently accurate and aligned with the intended arithmetic-learning outcomes. The validators nevertheless recommended strengthening the level of challenge and completing the user guide. These revisions were implemented before the trials. Media-display and interactivity results are presented in Table 3. The validation of visual design and interactivity is presented in Table 3.

Table 3. Display and Interactivity Validation

No.	Assessment Aspect	Mean Score
1	Suitability and Quality of Media Use	4.00
2	Suitability of Images and Content	3.94
3	Interactivity and Navigation	3.75
4	Media Attractiveness	3.71
	Overall Mean	3.85 (Very Valid)

The media validators rated MACCA as very valid. High ratings were obtained for visual appeal, colour combination, clarity, navigation, and the potential to support learning motivation. Similar development studies show that interactive digital media becomes more meaningful when visual components, navigation, and learner activities are deliberately connected with the targeted concept (Khusnunnisa & Andriani, 2025; Syahrir et al., 2025). This result is also consistent with interactive mathematics products that received positive feasibility judgments when visual elements and user actions were aligned with learning goals (Maaruf & Siraj, 2013; Pane & Patriana, 2016; A. Salsabilah & Syofyan, 2024). The remaining suggestions concerned clearer operating instructions and more explicit navigation guidance. After these revisions, the application was considered suitable for classroom implementation.

Implementation

Implementation was conducted in two stages. A limited trial with 15 students examined usability, comprehension, and technical functioning. The teacher introduced the application, demonstrated its use, and assisted students during exploration and practice. The limited-trial results are presented in Table 4.

Table 4. Limited-Trial Results

No.	Criterion	Frequency	Percentage (%)
1	Not Mastered	4	26.67
2	Mastered	11	73.33
Total		15	100

Most students reached mastery during the limited trial. Students who had not yet achieved mastery required additional support related to prior knowledge and independent navigation. Observations and user feedback informed revisions before the field trial, particularly clearer instructions and more gradual practice. The field trial involved 30 second-grade students under regular classroom conditions.

Students used MACCA to study arithmetic operations, complete guided tasks, receive feedback, and discuss solution strategies. The field-trial results are presented in Table 5.

Table 5. Field-Trial Results

No.	Criterion	Frequency	Percentage (%)
1	Not Mastered	5	16.67
2	Mastered	25	83.33
Total		30	100

Mastery increased after product revision and broader implementation. Students appeared more active and enthusiastic, while animations and concrete illustrations helped connect operations with familiar situations. This pattern is consistent with the development of augmented-reality fraction media, where visual and interactive representation was used to support elementary students' numeracy skills (Firma Harianja & Sudrajat, 2021). The result also supports prior JES studies showing that contextual and interactive mathematics media can strengthen engagement and learning performance (Firma Harianja & Sudrajat, 2021; Mei-Ju et al., 2014; Silanoi, 2012).

Evaluation

Evaluation was continuous and included both formative improvement and summative assessment of learning outcomes.

Formative Evaluation

Formative evaluation occurred during analysis, design, and development, as summarized in Table 6.

Table 6. Formative Evaluation across Development Stages

No.	**Stage**	**Evaluated Aspect**	**Evaluation Activity**	**Evaluation Result**
1	Analysis	Learning needs	Review student and teacher needs	Students needed interactive, visual, and contextual media
		Learning difficulties	Identify difficulties in arithmetic operations	Abstract concepts were difficult without visual support
		Curriculum alignment	Align content with the curriculum	Content was aligned with curriculum and student needs
2	Design	Learning flow	Review flowchart and storyboard	The learning sequence was systematic
		Interface design	Review colour, images, typography, and layout	The interface was attractive; font size required revision

No.	Stage	Evaluated Aspect	Evaluation Activity	Evaluation Result
		Content structure	Review structure and navigation	Navigation required clearer, more intuitive cues
3	Development	Material feasibility	Material-expert validation	The material was rated very valid
		Media feasibility	Media-expert validation	The media was rated very valid
		Product revision	Revise from validator feedback	Difficulty, instructions, and interactivity were improved

At the analysis stage, evaluation confirmed the need for interactive, visual, and contextual support. At the design stage, the storyboard and learning flow were systematic, but typography and navigation required refinement. At the development stage, expert review confirmed overall feasibility while identifying revisions to difficulty, instructions, and interaction. This cycle illustrates the theoretical use of ADDIE as an iterative process in which evaluation evidence changes the product before implementation. The revisions improved the alignment among content, representation, and learner action. This alignment is important because multimedia is educationally effective when verbal and visual information are coordinated and unnecessary processing is minimized (Sakti et al., 2024; Ülger et al., 2014).

Summative Evaluation

Summative evaluation examined change in conceptual understanding after students used MACCA. Pretest and posttest scores were compared with a paired-samples test. The pretest was administered before treatment and the posttest after the MACCA-supported lesson sequence. Results are presented in Table 7.

Table 7. Paired-Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Pre_Test - Post_test	-7.70833	7.46460	1.36284	-10.49566	-4.92101	-5.656	29	.000

Posttest performance was higher than pretest performance, and the paired-samples test indicated a statistically significant difference. The confidence interval was consistently in the direction of improvement, suggesting that the increase was not limited to only a few students. Because there was no control group, this result should be interpreted as evidence of improvement associated with MACCA rather than definitive proof that no other classroom factor contributed.

Effectiveness Analysis

Cohen's d was calculated to examine the practical magnitude of the pretest-posttest difference, as presented in Table 8.

Table 8. Paired-Samples Effect Sizes

Paired Samples Effect Sizes						
					95% Confidence Interval	
			Standardizer[a]	Point Estimate	Lower	Upper
Pair 1	Pre_Test Post_test	-Cohen's d	7.46460	-1.033	-1.472	-.582
		Hedges' correction	7.56289	-1.019	-1.453	-.574

The absolute effect-size estimate was in the large category, indicating that the improvement was educationally meaningful as well as statistically detectable. The negative sign reflects the subtraction order of pretest minus posttest and therefore indicates higher posttest scores. The confidence interval remained away from zero. Student responses are presented in Table 9.

Table 9. Student Responses by Item

No.	Item	Mean	Percentage (%)	Category
1	P1	3.43	85.83	Very Practical
2	P2	3.53	88.33	Very Practical
3	P3	3.47	86.67	Very Practical
4	P4	3.43	85.83	Very Practical
5	P5	3.50	87.50	Very Practical
6	P6	3.47	86.67	Very Practical
7	P7	3.47	86.67	Very Practical
8	P8	3.50	87.50	Very Practical

Students responded very positively to MACCA. The overall average was 3.46, equivalent to 86.5%, in the very practical category. Students reported that concrete illustrations and animation made arithmetic operations easier to understand and that the presentation increased their motivation. These responses support the observed increase in participation during the lesson. Students also rated the application positively for ease of use, attractive colours, understandable language, and simple navigation. They actively selected answers, followed feedback, and completed interactive tasks. Thus, MACCA functioned not only as a presentation medium but also as a learning environment that elicited student action and reflection.

Taken together, expert validation, limited testing, field implementation, learning measures, and student responses indicate that MACCA met the criteria of validity, practicality, and effectiveness for second-grade arithmetic learning. The application changed a mainly teacher-centred lesson into a sequence of explanation, visualization, guided interaction, feedback, and discussion. The improvement can be explained through the Cognitive Theory of Multimedia Learning. Coordinated narration and images allowed students to process verbal and visual representations, while concrete illustrations helped connect symbols with quantities. Immediate

feedback reduced the persistence of incorrect procedures. These design features operationalize multimedia principles in early-grade arithmetic rather than merely adding decorative digital elements (Prayitno et al., 2022; Santat & Tan, 2023).

The progression from the limited trial to the field trial also shows the value of iterative development. Validator and user feedback led to clearer instructions, improved navigation, and more appropriate task difficulty. Similar evidence from JES studies indicates that systematic development and contextual representation contribute to the feasibility and effectiveness of elementary mathematics media (Saing, 2024; A. S. Salsabilah et al., 2021; Samosir & Pandian, 2024; Yew & Goh, 2016). MACCA supported cognitive, affective, and behavioural engagement. Cognitively, students connected concrete situations to arithmetic symbols and improved solution accuracy. Affectively, they displayed stronger interest and confidence. Behaviourally, they navigated the application, attempted exercises, responded to feedback, and discussed solutions. These mutually reinforcing processes help explain why the product was perceived as useful and engaging.

The study has practical implications for teachers. MACCA can supplement direct explanation, provide consistent visual examples, and support independent or guided practice. A productive lesson does not begin by giving students unrestricted device time. The teacher first identifies the target concept, connects it with prior knowledge, and explains how students should use the representations. While students work, the teacher observes whether they understand the mathematical relationship or merely select answers by trial and error. Digital feedback should then be followed by questions such as why an answer is correct, how another strategy might work, and how the illustration corresponds to the number sentence. This facilitation turns application use into mathematical discourse. Schools should also ensure compatible Android devices, basic technical orientation, scheduled access, and equitable participation when devices must be shared. Teachers can use response patterns to identify misconceptions and provide additional concrete examples for students who need support.

The findings extend prior research by integrating multiple media formats, contextual representation, interaction, and immediate feedback in one Android application for second-grade arithmetic. Unlike static resources, MACCA requires learners to act on representations and use feedback. The contribution is therefore not the device alone but the structured relationship among representations, learner control, practice, and teacher facilitation. This distinction is pedagogically important. Colour, sound, and animation can attract attention, but they do not automatically produce understanding. In MACCA, each feature was retained because it served a learning function: narration supported short explanations, illustrations represented quantities, animation displayed change, exercises required a response, and feedback connected the response with the intended concept (Abdul RahimZakwanZakwan Abdul Rahim, 2020; Mualif, 2022). The resulting design provides a replicable decision rule for developers: every multimedia element should be traceable to a specific cognitive or instructional purpose. Elements that do not clarify, guide, practise, or provide feedback should be simplified or removed to avoid distraction.

Nevertheless, the one-group design, one-school setting, modest sample, and focus on one content area limit generalization. The statistically significant gain cannot independently rule out maturation, testing effects, teacher influence, or familiarity with the assessment. The study also measured outcomes immediately after implementation, so it cannot determine whether conceptual gains were retained over time or transferred to unfamiliar problem formats. Student-response scores indicate perceived usability and usefulness, but favourable responses do not substitute for direct evidence of long-term learning (Duwi Priyono & Siregar, 2021; Ma'rufah, 2022). Device ownership, screen size, operating-system version, and teacher confidence may also affect implementation in other settings. These limitations should be addressed through controlled studies and replication in schools with different technological and learner characteristics (Kaptiasih et al., 2023; Omeri, 2020; A. S. Salsabilah et al., 2021). A future quasi-experiment could compare MACCA-supported learning with an equivalent lesson using printed visual media, use pretest scores as a covariate, report implementation fidelity, and administer a delayed posttest. Qualitative interviews could then examine how students interpret representations and feedback rather than only whether their answers are correct.

The findings support an evidence-based pattern for Android multimedia development: diagnose a specific conceptual difficulty, coordinate verbal and visual representations, move from concrete contexts to symbols, incorporate guided action and immediate feedback, and revise the product using expert and learner evidence. This pattern provides a specific theoretical and developmental contribution beyond the claim that multimedia is generally beneficial.

4. Conclusion

Android-based MACCA interactive multimedia was successfully developed and met the criteria of validity, practicality, and effectiveness for supporting second-grade students' understanding of arithmetic operations. Its coordinated use of concise verbal explanation, concrete illustration, audio, animation, guided exercises, learner-controlled navigation, and immediate feedback helped bridge abstract symbols and concrete experience. The specific theoretical contribution is an operational pattern for the Cognitive Theory of Multimedia Learning in early-grade arithmetic: coordinate verbal and visual representations, progress from concrete contexts to symbols, and connect learner action with immediate feedback. The study also shows how ADDIE can function as an iterative evidence-based cycle because expert and learner evaluations directly informed revisions to content difficulty, instructions, typography, navigation, and interactivity. Generalization remains limited by the one-school, one-group pretest-posttest design and the focus on one topic. Future research should therefore use a quasi-experimental design with a comparison group, larger multisite samples, delayed retention measures, and outcomes such as critical, spatial, or mathematical-reasoning skills.

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How to cite this article:

Cahaya, M., Akib, I., & Mukhlis. (2026). Development of Android-Based MACCA Interactive Multimedia to Improve Second-Grade Students' Understanding of Arithmetic Operations. *Journal of Educational Sciences*, *10(9)*, 842-857.