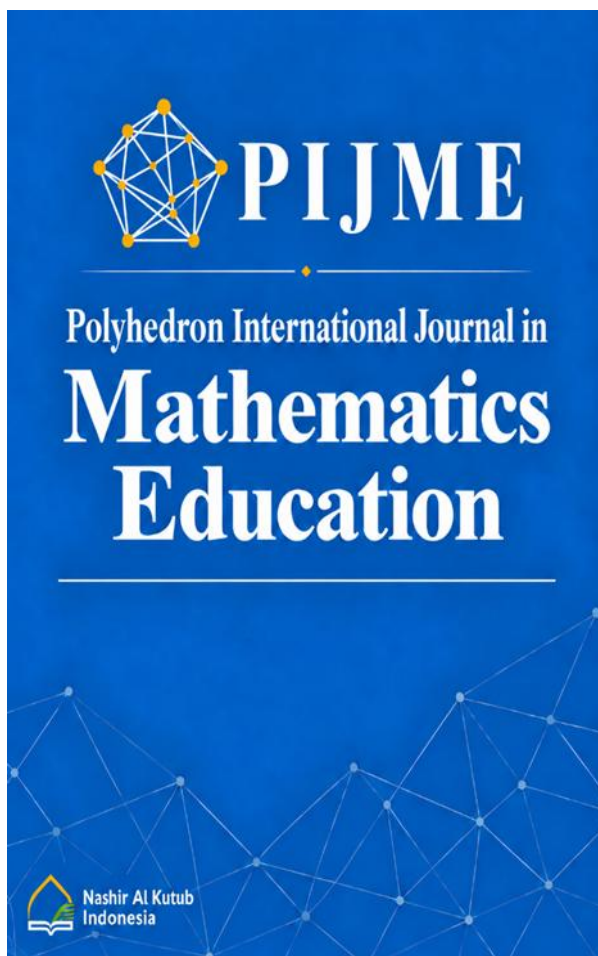




From gong to geometry: Developing and testing Gameland, a Javanese gamelan-based digital worksheet for Grade 5 plane figures

Nanda Fitri Nur Rohmah¹, I Made Sulandra², Sudirman Sudirman³, Dharmendra Kumar Yadav⁴

¹Master's Program in Basic Education, Postgraduate School, Universitas Terbuka, Tangerang Selatan, Indonesia, j.sam1234548@gmail.com

²Department of Mathematics, Universitas Negeri Malang, Malang, Indonesia, made.sulandra.fmipa@um.ac.id

³Master's Program in Mathematics Education, Postgraduate School, Universitas Terbuka, Tangerang Selatan, Indonesia, sudirman.official@ecampus.ut.ac.id

⁴University Department of Mathematics Lalit Narayan Mithila University Darbhanga, Bihar, India, mdrdkyadav@gmail.com

To cite this article:

Rohmah, N. F. N., Sulandra, I. M., Sudirman, S., & Yadav, D.K. (2026). From gong to geometry: Developing and testing Gameland, a Javanese gamelan-based digital worksheet for Grade 5 plane figures. *Polyhedron International Journal in Mathematics Education*, 4(2), 211–236.

To link to this article:

<https://nakiscience.com/index.php/pijme>

Published by:

Nashir Al-Kutub Indonesia

Residential Street Kila Rengganis, Block I, Number 11, Labuapi, Indonesia, 83361

From gong to geometry: Developing and testing Gameland, a Javanese gamelan-based digital worksheet for Grade 5 plane figures

Nanda Fitri Nur Rohmah^{1*}, I Made Sulandra², Sudirman Sudirman³, Dharmendra Kumar Yadav⁴

¹Master's Program in Basic Education, Postgraduate School, Universitas Terbuka, Tangerang Selatan, Indonesia, j.sam1234548@gmail.com

²Department of Mathematics, Universitas Negeri Malang, Malang, Indonesia, made.sulandra.fmipa@um.ac.id

³Master's Program in Mathematics Education, Postgraduate School, Universitas Terbuka, Tangerang Selatan, Indonesia, sudirman.official@ecampus.ut.ac.id

⁴University Department of Mathematics Lalit Narayan Mithila University Darbhanga, Bihar, India, mdrdkyadav@gmail.com

*Correspondence: j.sam1234548@gmail.com

Abstract

Plane-geometry instruction in Indonesian elementary schools often relies on printed worksheets with limited cultural relevance or support for independent learning. This design and development study created Gameland, an Android-based digital worksheet integrating Javanese gamelan instruments and carving motifs into geometry tasks, and evaluated its validity, practicality, and effectiveness for Grade 5 students' conceptual understanding and self-directed learning (SDL). Following ADDIE, six requirements informed the application's navigation and interface. Features included culturally contextualized materials, videos, enrichment quizzes, and five tiered quiz levels with worked explanations. Content and media experts rated Gameland valid (79.60% and 68.75%), while six students rated it very practical (88.50%). Their feedback informed readability revisions. A quasi-experimental non-equivalent control-group trial compared Gameland with printed worksheets in two intact classes ($n = 22$ each). Pretest scores did not differ significantly ($p = .439$). The experimental class showed higher normalized gains (0.62 versus 0.40; $p < .001$, $d = 2.21$), particularly among students with lower initial scores, and higher post-intervention SDL (79.91 versus 67.45; $p < .001$, $d = 1.96$). These findings support Gameland's validity, practicality, and potential educational value. However, the non-randomized, single-school design limits causal inference and generalizability, requiring further confirmation through stronger research designs conducted across diverse school settings.

Article History

Received:
August 27, 2026
Revised:
September 30, 2026
Accepted:
October 11, 2026
Published Online:
October 13, 2026

Keywords:

ADDIE model;
Digital worksheet;
Ethnomathematics;
Javanese gamelan;
Plane geometry;
Self-directed learning

1. Introduction

Geometry gives elementary students their first systematic experience of reasoning about shape, space, and measurement, and it underpins later work on area, volume, and proof (Clements & Battista, 1992). Yet plane figures remain a persistent source of difficulty. According to van Hiele theory, many upper-elementary students still reason at the visual level: they recognize a figure by its overall appearance rather than by its properties, so a rotated square may not be identified as a square, and a square may not be accepted as a special rectangle (van Hiele, 1986; Vojtkůvková, 2012). Reasoning of this kind produces misconceptions about the attributes, classification, perimeter, and area of plane figures (Clements & Battista, 1992), and students often reject the hierarchical relationships among quadrilaterals because their personal images of the figures override the formal definitions (Fujita & Jones, 2007). Indonesian students describe similar difficulties; a recent phenomenological study traced them to limited use of learning aids, the complexity of the material, and a lack of contextual application rather than to cognitive limitations alone (Ainiyah et al., 2025). Learning environments are therefore needed that help students move from recognizing shapes to describing and using their properties in meaningful contexts.

Ethnomathematics offers one route toward such environments. The term refers to the mathematical ideas and practices embedded in the activities and artifacts of cultural groups (D'Ambrosio, 1985; Rosa & Orey, 2011), and bringing these artifacts into the classroom can make abstract concepts more meaningful by anchoring them in objects that students already know. Javanese culture, for example, has been used to design a learning sequence in which students construct set concepts from shadow-puppet characters (Prahmana & Istiandaru, 2021), and culture-based worksheets have improved Indonesian students' mastery of geometric transformations (Khairunnisa et al., 2025). Nevertheless, research on ethnomathematics in geometry remains concentrated in a few countries (Kyeremeh et al., 2023), and teachers' limited understanding of the approach, weak geometry content knowledge, and resistance to change still hinder its integration into everyday instruction (Sunzuma & Maharaj, 2019). Ethnomathematics is also argued to strengthen students' cultural identity; in the present study, however, this benefit is treated as a design rationale rather than as a measured outcome.

The Javanese gamelan is a particularly rich source of geometric forms. The faces of the gong, kempul, and bonang are circular; the metal keys (*wilah*) of the saron and demung are rectangular; and the carved wooden frames (*rancakan*) display rectangular, trapezoidal, and triangular panels. Because these instruments belong to the cultural environment of many Javanese students, they offer a familiar setting in which the properties, perimeter, and area of plane figures can be observed, measured, and compared.

Turning such a context into an effective learning resource also requires a suitable medium. Technology-supported mathematics instruction has positive effects on students' achievement, motivation, and attitudes (Higgins et al., 2019), and digital worksheets in particular allow students to access material flexibly, follow multimedia explanations, and complete interactive tasks with immediate feedback. A recent e-worksheet that embedded the farming practices of Pandanwangi rice growers, for instance, was rated highly valid and practical for online learning (Sugiarni et al., 2026). Digital media are also well placed to support self-directed learning (SDL), the process in which learners take the initiative, with or without the help of others, to diagnose their learning needs, formulate goals, identify resources, choose strategies, and evaluate their outcomes (Knowles, 1975). In elementary mathematics, SDL is visible when students begin tasks on their own initiative, take responsibility for completing them, show curiosity, check their own answers, and look for alternative solutions (Sumarmo, 2016; Zimmerman, 2002). Self-regulated learning is consistently associated with higher academic achievement from childhood through adolescence (Dent & Koenka, 2016), and in Indonesian junior secondary classrooms it has predicted students' critical thinking in problem-based learning (Adriani et al., 2026).

Previous studies support the integration of culture, technology, and learning independence, but each addresses only part of the problem. Evidence linking self-regulated learning strategies to achievement in technology-rich environments comes mainly from higher education (Broadbent & Poon, 2015). GeoGebra-assisted discovery learning increased fifth-grade students' interest in learning plane area measurement, but it used no cultural context and did not examine learning independence (Basri et al., 2025). Ethnomathematics-based worksheets and modules have been developed and validated for number patterns (Aulia et al., 2025), proportion (Sugiarni et al., 2026), and trigonometry (Yulizarti et al., 2026), and contextual instruction integrated with gamification has improved mathematical connection ability (Nurmiati et al., 2026); these products, however, targeted secondary school students and topics other than plane figures. The geometric content of the gamelan, for its part, has so far been documented mainly in local exploratory studies rather than turned into a tested instructional product. Consequently, little is known about whether a digital worksheet that uses a local cultural artifact as the task context can support both Grade 5 students' understanding of plane geometry and their self-directed learning.

A preliminary study at SD Negeri 2 Bolorejo, an elementary school in Tulungagung, East Java, confirmed this need. Classroom observation, a teacher interview, and a review of the printed worksheets showed that technology use depended on the teacher, that the worksheets were monotonous, that students relied on memorized formulas, and that many could not solve plane-figure problems independently. These findings motivated the development of Gameland, a digital worksheet that connects plane figures to the familiar instruments of the Javanese

gamelan and provides tiered tasks with immediate feedback. The study aimed to (a) develop Gameland following the ADDIE model, (b) evaluate its validity and practicality, and (c) compare understanding of geometry concepts and post-intervention self-directed learning between students who learned with Gameland and students who used printed worksheets. Gameland was considered effective if the experimental class obtained a significantly higher mean normalized gain than the control class and a significantly higher post-intervention SDL score ($\alpha = .05$). Because the classes were not randomly formed, these criteria indicate a comparative advantage in this setting rather than a causal effect.

2. Methods

2.1 Research Design

This study followed a design and development research approach (Richey & Klein, 2007) using the ADDIE model, which comprises the analysis, design, development, implementation, and evaluation stages (Branch, 2009). ADDIE was chosen because it provides systematic stages for identifying needs, designing and building a product, revising it on the basis of validation, and evaluating its practicality and effectiveness, and it has recently been used to develop culturally grounded mathematics modules that were then tested in quasi-experimental trials (Yulizarti et al., 2026). The study had two components, which are reported separately. The development component covered the analysis, design, and development stages and the small-group trial, during which the product was revised iteratively. The evaluation component was a field trial in which the finalized product was compared with conventional instruction using a quasi-experimental non-equivalent control-group pretest–posttest design (Shadish et al., 2002). Figure 1 summarizes the stages, activities, and outputs.

Figure 1

Research Procedure Based on the ADDIE Model

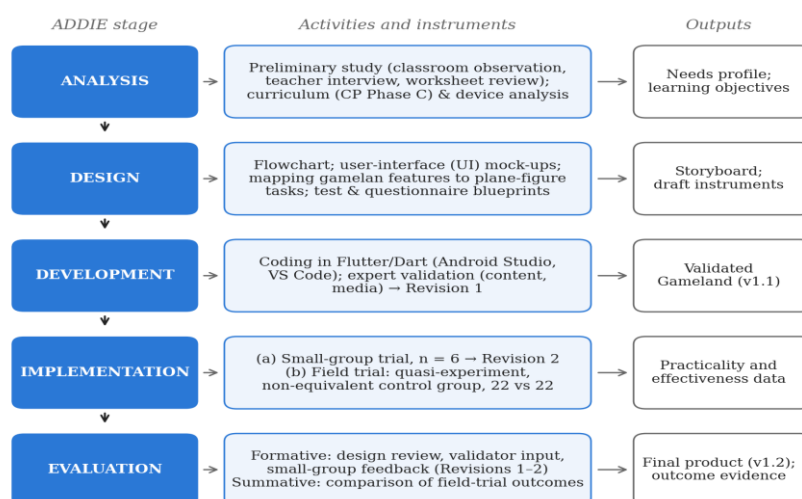


Figure 1 shows that the product was revised at only two points: after expert validation (Revision 1) and after the small-group trial (Revision 2). The version used in the field trial (v1.2) was therefore fixed before any comparative data were collected, which separates the formative evaluation that guided the revisions from the summative evaluation of classroom effectiveness.

2.2 Participants and Setting

The study was conducted at SD Negeri 2 Bolorejo, Tulungagung, East Java, Indonesia, in the odd semester of the 2024/2025 academic year. The school has two parallel Grade 5 classes, which were used as intact groups because the timetable did not permit individual random assignment. The classes were allocated to conditions by a coin toss: Class 5A became the experimental group ($n = 22$) and Class 5B the control group ($n = 22$). Both classes were taught by the same mathematics teacher, covered the same plane-figure topics and objectives, received the same number of sessions and the same instructional time, and completed identical tests and questionnaires. The small-group trial involved six Grade 5 students who did not take part in the field trial; they were selected purposively from the teacher's ranking of their latest mathematics scores (two high-, two moderate-, and two low-achieving students). The product was validated by a content expert, an elementary school principal who coordinates curriculum development at the subdistrict level and has experience in elementary mathematics instruction, and by a media expert, a university lecturer with a doctorate who develops digital learning media.

2.3 Instruments and Data Collection

Data were collected through tests, questionnaires, observations, and document analysis. Table 1 summarizes the instruments.

Table 1

Research Instruments

Instrument	Respondents	Content	Scoring
Geometry concept test (pretest and posttest)	Small-group and field-trial students	Ten essay items on the properties, classification, perimeter, and area of plane figures (Sumarmo, 2016)	Rubric of 0–4 per item; converted to 0–100
SDL questionnaire	Field-trial students, after the intervention	Twenty statements on initiative, responsibility, curiosity, self-evaluation, and creativity (Sumarmo, 2016)	Four-point Likert scale; negative items reversed; converted to 0–100
Expert validation sheets	Content expert and media expert	Content (16 items): relevance, accuracy, completeness, basic concepts, and student-centered presentation. Media (20 items): general appearance, screen design, and presentation	Four-point scale; percentage of the maximum score
Practicality questionnaire	Small-group students	Ease of use, readability, attractiveness, and usefulness	Four-point scale; percentage of the maximum score
Observation sheet	Class teacher and one observer, every field-trial session	Implementation of the planned lesson steps and student engagement	Checklist and field notes

The geometry test and the SDL questionnaire were the outcome measures of the evaluation component, whereas the validation sheets and the practicality questionnaire served the development component. The same test form was used at pretest and posttest, and the SDL questionnaire was administered only once, after the posttest, so SDL could be compared only as a post-intervention outcome. In a sample test item, students see a photograph of a saron key measuring 30 cm × 6 cm and are asked to name its shape, state two of its properties, and determine its perimeter and area. Both instruments were reviewed by experts before use; an instrument pilot, item–total correlations, and internal-consistency coefficients were not available, and this is acknowledged as a limitation. The test blueprint and questionnaire items are provided in the Supplementary Material (Table S1). Document analysis was used to collect the mathematical and cultural content of the application, and observations by the class teacher and one research assistant were used to identify students' needs during the analysis stage and to confirm that every field-trial lesson followed its plan.

2.4 Data Analysis

Qualitative data from observations and validator comments were analyzed descriptively to identify product needs and revisions. Validation and practicality data

were converted into percentages using $P = (\Sigma x / \Sigma x_{\max}) \times 100\%$ and interpreted with the criteria in Table 2.

Table 2

Interpretation Criteria for Validity, Practicality, Normalized Gain, and Effect Size

Indicator	Range	Category
Validity or practicality (%)	81–100; 61–80; 41–60; 21–40; 0–20	Very valid or practical; valid or practical; fairly valid or practical; less valid or practical; not valid or practical (Riduwan, 2012)
Normalized gain (g)	$g \geq 0.70$; $0.30 \leq g < 0.70$; $g < 0.30$	High; medium; low (Hake, 1998)
Cohen's d	0.20; 0.50; 0.80	Small; medium; large (Cohen, 1988)

Understanding of geometry concepts was the primary outcome. The normalized gain was computed for each student as $g = (\text{posttest} - \text{pretest}) / (100 - \text{pretest})$ (Hake, 1998), and the individual gains were averaged within each group, as recommended by Coletta and Steinert (2020). Baseline comparability was assessed by comparing pretest means with an independent-samples t-test and a standardized mean difference. Normality was examined with the Shapiro–Wilk test, Q–Q plots, and boxplots, and homogeneity of variance with Levene's test. Welch's t-test, which does not assume equal variances (Delacre et al., 2017), was used when Levene's test indicated unequal variances; otherwise, Student's t-test was used, and Welch's test was reported as a check.

Because student-level pretest and posttest scores were available, an analysis of covariance (ANCOVA) of posttest scores with the pretest as covariate was run as a sensitivity analysis. Homogeneity of regression slopes was tested through a group $\times$ pretest interaction; because this assumption was violated, the Johnson–Neyman technique (Johnson & Neyman, 1936) was used to identify the pretest range in which the groups differed. Because SDL was measured only after the intervention, it was compared as post-intervention scores rather than as gains. Effect sizes are reported as Cohen's d with 95% confidence intervals (Lakens, 2013). All tests were two-tailed at $\alpha = .05$ and were run in SPSS.

2.5 Ethical Considerations

Because the participants were minors, the study obtained school permission, written parental or guardian consent, and child assent. Participation was voluntary, and students could withdraw without consequences for their grades. Data were coded and anonymized, and no identifiable images of children are reported. After the posttest, the control class was also given access to Gameland.

3. Results

The results are reported stage by stage following the ADDIE model. Each stage produced an output that became the input for the next, and the product moved through three versions before the field trial. Table 3 summarizes this progression; the subsections that follow present the evidence for each stage.

Table 3

Summary of the ADDIE Stages, Key Results, and Product Versions

Stage	Main activities	Key results	Output
Analysis	Classroom observation, teacher interview, worksheet and curriculum review	Four learning problems and two technical conditions identified	Six design requirements and a content map (Tables 4–5)
Design	Navigation flowchart, interface design, supervisor review	Four-phase navigation; five-screen interface	Approved blueprint, v0.9 (Figures 2–3; Table 6)
Development	Coding in Flutter/Dart; content and media validation; Revision 1	Valid: content 79.60%, media 68.75%	Validated application, v1.1 (Figures 4–5; Table 7)
Implementation	Small-group trial ($n = 6$); Revision 2; field-trial lessons	Very practical (88.50%); mean N-Gain 0.56	Final application, v1.2 (Table 8)
Evaluation	Formative review of all revisions; summative comparison of two classes	N-Gain 0.62 vs. 0.40; SDL 79.91 vs. 67.45	Evidence of comparative effectiveness (Tables 9–11; Figures 6–7)

3.1 Analysis Stage

The analysis stage was carried out before the product was designed and combined classroom observation, an interview with the Grade 5 teacher, a review of the printed worksheets in use, and a review of the curriculum documents. It comprised a needs analysis, a technology analysis, and a curriculum analysis. Table 4 lists the main findings and the design requirement derived from each.

Table 4

Needs Analysis Findings and Their Implications for the Design of Gameland

Aspect	Main finding	Design requirement
Learning media	Printed worksheets were compulsory but black-and-white and monotonous	A full-color application whose visuals, narration, and background music draw on the gamelan
Use of technology	Technology use was led by the teacher; teachers used digital media in fewer than half of their lessons	Self-access design: simple login, user guide, and a progress display
Concept understanding	Understanding of plane figures was low and rested on memorized formulas	Material pages that present properties before perimeter and area, with videos and enrichment quizzes
Independent problem solving	Students could not yet solve plane-figure problems on their own	Five tiered quiz levels with an immediate score and a worked explanation for each item
Devices and teacher capacity	All students could operate an Android phone; teachers lacked time to develop digital media	A ready-to-use Android application distributed through a download link
Cultural context	Lessons rarely drew on local culture	Gamelan instruments and motifs as task stimuli, plus a page on gamelan history and instruments

Table 4 shows that the analysis did more than confirm the need for a new medium; it fixed the main constraints of the design. Every student could use a smartphone, so an Android application was feasible, but it had to be simple enough for teachers without specialist technical skills. The needs analysis also pointed to two learning problems that the product had to address together: reliance on memorized formulas and dependence on the teacher when solving problems.

The curriculum analysis aligned Gameland with the learning outcomes (*Capaian Pembelajaran*, CP) for Phase C of the Merdeka Curriculum (BSKAP, 2024) and with the school's Grade 5 learning objectives (*Tujuan Pembelajaran*, TP) and their sequence (*Alur Tujuan Pembelajaran*, ATP). It identified the figures to be covered (squares, rectangles, triangles, and circles) and the features of the gamelan in which these figures appear. Table 5 maps each objective to its gamelan context and to the Gameland feature in which students work on it.

Table 5

Mapping of Grade 5 Learning Objectives, Gamelan Contexts, and Gameland Features

Learning objective (CP Phase C)	Gamelan context	Gameland feature and activity
Identify plane figures and their properties	Outlined carving motifs and instrument frames; saron keys; gong and bonang faces	Material pages; quiz items that ask students to name an outlined figure and read an explanation of its properties (Figure 5c)
Determine the perimeter and area of squares, rectangles, and triangles	Instrument parts and motifs with given dimensions	Reading page and video for each figure, followed by an enrichment quiz (Figure 5a)
Recognize the circle and its properties	Faces of the gong and bonang	Circle material page; quiz items on circle properties, such as rotational symmetry (Figure 5d)
Solve problems involving plane figures	Gamelan instruments as problem contexts	Five quiz levels of increasing difficulty, each ending with a score and explanations (Figures 5b–5e)
Supporting cultural knowledge	History and types of gamelan instruments	Javanese Gamelan page with text and video

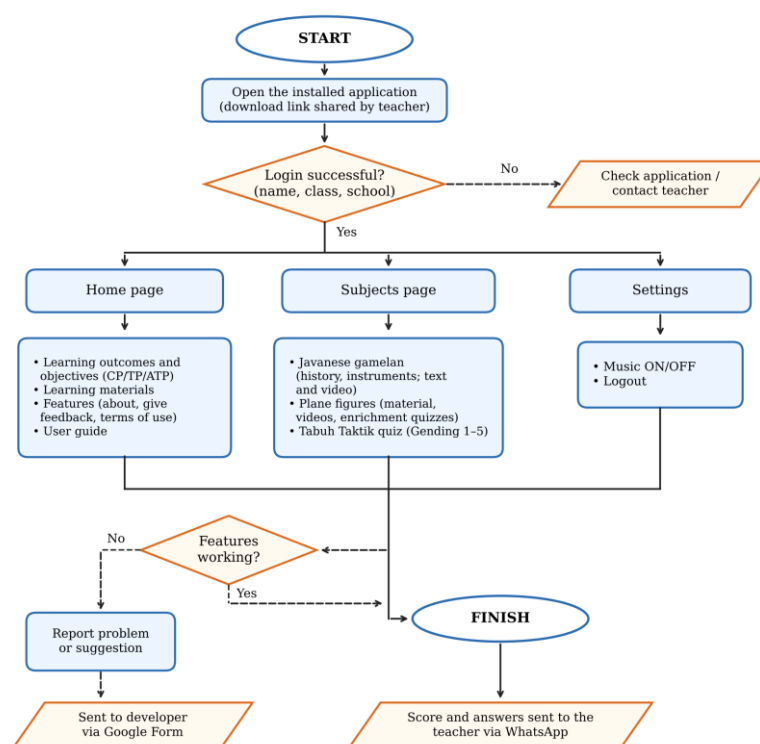
Table 5 shows that the gamelan served as the stimulus of the mathematical activity rather than as decoration: each objective is linked to an instrument or motif that students observe before they name, measure, or compute. The coverage stays within the Phase C outcomes, so the worksheet adds no material beyond the curriculum. The output of the analysis stage was therefore a set of six design requirements and a content map, which became the input for the design stage.

3.2 Design Stage

The design stage translated these requirements into a navigation flowchart and a user-interface (UI) blueprint. The flowchart (Figure 2) defines four phases of use. Students first install Gameland from a link shared by the teacher and then log in with their name, class, and school, which identifies the scores they later submit. The application then opens three main pages: the home page (learning objectives, materials, application features, and the user guide), the subjects page (the gamelan page, the plane-figure material, and the Tabuh Taktik quiz), and the settings page. Finally, after each quiz level, students send their score and answers to the teacher through WhatsApp, a channel already used by teachers, students, and parents. A feedback feature linked to a Google Form lets students report problems to the developer.

Figure 2

Navigation Flowchart of the Gameland Digital Worksheet



Ellipses = start/finish; rectangles = processes and screens; diamond = decision; parallelograms = input/output; dashed lines = conditional paths

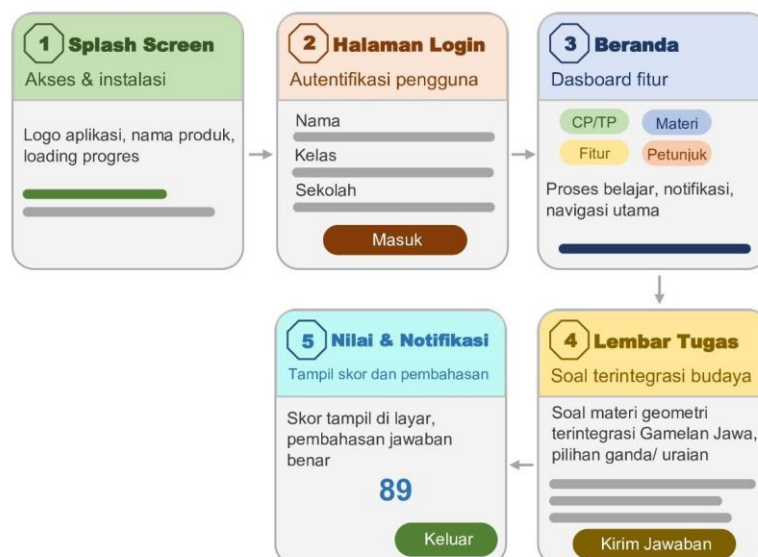
Note. Redrawn and translated from the original Indonesian flowchart.

Figure 2 shows that the subjects page is the core of the learning path. Students can open the gamelan page, the material, or the quiz in any order, so they decide what to study first and when to test themselves. The quiz is the only path that ends in a report to the teacher, which keeps students' independent work visible without requiring the teacher to supervise every step.

The UI followed a user-centered approach for elementary school students: short text segments supported by images, large buttons, consistent navigation, and gamelan visual elements as the identity of the product. Figure 3 shows the blueprint of the five screens, and Table 6 relates each planned screen to the two targeted outcomes.

Figure 3

Interface Blueprint of Gameland



Note. Screen labels are in Indonesian: (1) splash screen; (2) *halaman login*, login page; (3) *beranda*, home; (4) *lembar tugas*, task sheet; (5) *nilai & notifikasi*, score and notification.

Table 6

Planned Screens of Gameland and Their Intended Functions

Screen	Planned content	Function for concept understanding	Function for SDL
Splash screen	Product name, logo, and gamelan illustration	—	Offers a recognizable entry point that students open on their own
Login	Name, class, and school; welcome message	—	Links work and scores to each student, establishing ownership of results
Home	Learning objectives, materials, features, guide, and progress percentage	Makes the objectives explicit before learning begins	Shows targets and lets students monitor their own progress
Task sheet (Tabuh Taktik)	Gamelan-based problems in five levels of increasing difficulty	Moves students from naming figures to computing and applying	Students decide when to attempt each level and set their own pace
Score and feedback	Immediate score, correct and incorrect answers, and worked explanations	Shows why an answer is correct and where an error lies	Supports self-evaluation and the decision to review material

Table 6 shows that every screen was planned to serve at least one outcome and that the features supporting SDL, namely the progress display, self-paced levels, and immediate feedback, were built into the same screens as the geometry tasks rather than added as separate activities. Before development, the supervisor reviewed the flowchart and the interface, and this review led to improvements in the UI design. The output of the design stage was the approved blueprint (v0.9).

3.3 Development Stage

In the development stage, the blueprint was realized as an Android application. Android Studio was used for configuration, emulator testing, and building, Visual Studio Code served as the code editor, and the application was written in Dart with the Flutter framework. Figures 4 and 5 present the main screens of the resulting product.

Figure 4

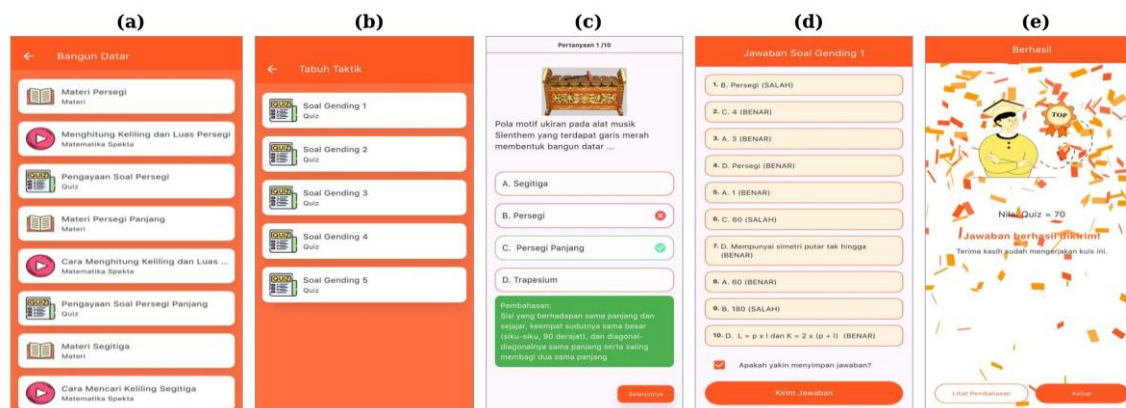
Entry and Navigation Screens: (a) Splash Screen, (b) Login, (c) Home, (d) Subjects Page, and (e) Settings



The splash screen (Figure 4a) displays the product name and a gamelan-playing character while the application loads. The login page (Figure 4b) asks for the student's name, class, and school. The home page (Figure 4c) greets the student by name and gives access to the learning objectives (CP/TP/ATP), the materials, the features menu (information about the application, a feedback form, and terms of use), and the user guide. The subjects page (Figure 4d) offers the gamelan page, the plane-figure material, and the Tabuh Taktik quiz, and the settings menu (Figure 4e) switches the background *gending* music on or off and logs the student out.

Figure 5

Learning and Assessment Screens: (a) Plane-Figure Material, (b) Quiz Levels, (c) Quiz Item With Worked Explanation, (d) Answer Summary, and (e) Score Screen



For each figure, the material list (Figure 5a) follows the same sequence: a reading page, a short video on computing perimeter and area, and an enrichment quiz. The Tabuh Taktik quiz (Figure 5b) is organized into five levels named after *gending*, the compositions played by a gamelan ensemble, so that moving through the levels resembles moving through a performance. Figure 5c shows how a gamelan feature becomes a geometry task: students see a photograph of a slenthem, identify the figure outlined in red on its carved frame, and, after answering, read an explanation of the properties of a rectangle (opposite sides equal and parallel, four right angles, and equal diagonals that bisect each other). At the end of a level, students see which answers were correct (Figure 5d) and their score (Figure 5e), from which they can open all explanations or send the score to the teacher.

The completed application (v1.0) was then validated by the two experts. Table 7 presents their scores, their suggestions, and the revisions made in response.

Table 7

Expert Validation Results and Follow-Up Revisions (Revision 1)

Validator	Score	Suggestion	Revision
Content expert	Mean 3.18; 79.60% (valid)	(a) Learning-objective indicators were not explained (b) Competency-achievement indicators were not stated	(a) Objective indicators added to the CP/TP/ATP page (b) Competency-achievement indicators added
Media expert	Mean 2.75; 68.75% (valid)	(a) The font on several screens was too small (b) Text-background contrast in the material pages was unbalanced	(a) Font enlarged from 11 pt to 13 pt (b) Text and background colors adjusted

Note. Content aspects (16 items): relevance, accuracy, completeness of presentation, basic concepts, and suitability for student-centered learning. Media aspects (20 items): general appearance, screen design, and media presentation. Both experts judged the product suitable for trial after revision.

Table 7 shows that both experts judged Gameland valid according to the criteria in Table 2. The lower media score reflected readability problems rather than problems with navigation or content, and Revision 1 addressed only the explicitness of the learning objectives and the readability of the screens; the mathematical content and the sequence of tasks were unchanged. Because each domain was judged by one expert who provided only a total score, the percentages indicate expert-judged adequacy rather than a statistically established validity index. Both validators approved the revised version (v1.1), which was carried into the implementation stage.

3.4 Implementation Stage

Implementation proceeded in two steps: a small-group trial of v1.1 to check usability and initial feasibility, followed, after a second revision, by classroom use of the final version (v1.2) in the field trial.

Small-group trial

The six students completed a pretest, downloaded Gameland through the shared link, studied the plane-figure material with it, completed a posttest, and filled out the practicality questionnaire. Table 8 presents the results for each student.

Table 8

Results of the Small-Group Trial (n = 6)

Student	Pretest	Posttest	N-Gain	Gain category	Practicality (%)	Practicality category
R1	55	78	0.51	Medium	86	Very practical
R2	60	82	0.55	Medium	90	Very practical
R3	50	75	0.50	Medium	84	Very practical
R4	65	88	0.66	Medium	92	Very practical
R5	58	80	0.52	Medium	88	Very practical
R6	62	85	0.61	Medium	91	Very practical
Mean	58.33	81.33	0.56	Medium	88.50	Very practical

Every student's score rose, all individual gains fell in the medium category (0.50–0.66), and every student rated Gameland very practical (84%–92%). Because the trial involved only six students and no comparison group, the gain is treated as evidence of feasibility rather than effectiveness, and the practicality percentage reflects students' judgments of ease of use, readability, and attractiveness rather than SDL. The students also identified two remaining problems: the font in the material section was still small, and some color combinations looked inharmonious. In Revision 2, the font in the material section was enlarged further and the background and text colors were adjusted. The resulting version (v1.2) was fixed for the field trial.

Classroom use in the field trial

In the experimental class, Gameland v1.2 was used in four sessions of 2×35 minutes over two weeks, preceded by the pretest and followed by the posttest and the SDL questionnaire. In the first session, students were introduced to the objectives and topics, guided in installing Gameland through the shared link, and shown its features and the procedure for submitting the quizzes. They then worked individually on their own phones: they logged in, read the user guide, studied the material and videos, and completed the enrichment quizzes and the Tabuh Taktik levels, setting their own pace and returning to parts they had not understood. The teacher circulated to answer procedural questions and resolve technical problems, did not demonstrate solutions before students attempted the tasks, and closed each session with a short discussion. In the control class, the same teacher taught the same objectives through explanation followed by work on the school's printed worksheets, which contained a comparable number of practice items without a cultural context. Observation records confirmed that all planned sessions were delivered in both classes.

3.5 Evaluation Stage

Evaluation was formative during design, development, and the small-group trial, and summative after the product had been finalized. As Table 3 shows, each formative review produced a decision and a new version: the supervisor's review yielded v0.9, expert validation yielded v1.1, and the small-group trial yielded v1.2. All revisions concerned readability and the explicitness of the learning objectives rather than mathematical content, and none was made during the field trial, so the summative results refer to a single, stable version. Table 9 presents the descriptive statistics of the field trial.

Table 9

Descriptive Statistics of Geometry Concept Understanding and Self-Directed Learning

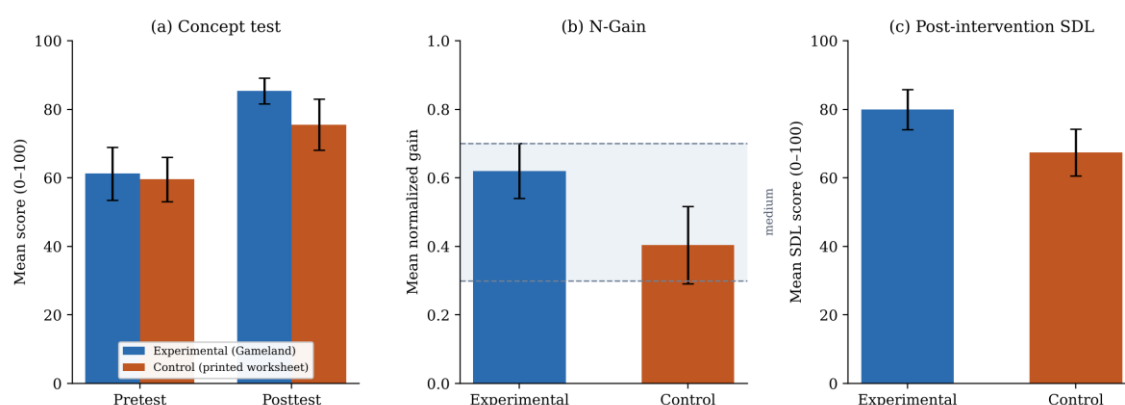
Group	Measure	n	Mean	SD	SE
Experimental	Pretest	22	61.23	7.73	1.65
	Posttest	22	85.36	3.72	0.79
	N-Gain	22	0.620	0.081	0.017
	SDL (post only)	22	79.91	5.88	1.25
Control	Pretest	22	59.55	6.49	1.38
	Posttest	22	75.55	7.42	1.58
	N-Gain	22	0.403	0.113	0.024
	SDL (post only)	22	67.45	6.82	1.45

Note. Concept-test statistics were computed from student-level scores; N-Gain is the mean of individual gains.

The two classes started from similar pretest levels (61.23 and 59.55). At posttest, the experimental class scored higher, and its scores were less dispersed ($SD = 3.72$ vs. 7.42). The mean N-Gain was 0.62 in the experimental class and 0.40 in the control class. Both means fall in the medium category, but the distributions differed: in the experimental class, two students reached the high category and none was in the low category, whereas in the control class, no student reached the high category and four were in the low category. SDL, measured only after the intervention, was higher in the experimental class. Figure 6 visualizes these data.

Figure 6

Mean Scores by Group: (a) Pretest and Posttest, (b) Normalized Gain, and (c) Post-Intervention SDL



Note. Error bars represent one standard deviation; the shaded band in panel (b) marks the medium N-Gain category (0.30–0.70).

Before the groups were compared, the assumptions of the tests were checked (Table 10).

Table 10

Assumption Checks: Shapiro–Wilk Normality and Levene’s Homogeneity Tests

Variable	Group	Shapiro–Wilk W	df	p	Levene’s test
N-Gain	Experimental	0.939	22	.190	$F(1, 42) = 4.84, p = .033$
	Control	0.962	22	.540	Unequal variances
SDL (post only)	Experimental	0.979	22	.905	$F(1, 42) = 0.004, p = .949$
	Control	0.961	22	.506	Equal variances

None of the Shapiro–Wilk tests was significant, and the Q–Q plots and boxplots showed no extreme outliers, which supports the use of t-tests with 22 students per group. For N-Gain, Levene’s test was significant, so Welch’s t-test was used; for SDL, it was not, so Student’s t-test was reported with Welch’s test as a check. Table 11 presents the comparisons.

Table 11

Comparison of the Experimental and Control Classes

Outcome	Test	Mean difference [95% CI]	p	Effect size [95% CI]
Pretest (baseline)	Student's $t(42) = 0.78$	1.68 [-2.66, 6.02]	.439	$d = 0.24$ [-0.36, 0.83]
N-Gain (primary)	Welch's $t(37.98) = 7.33$	0.217 [0.157, 0.277]	< .001	$d = 2.21$ [1.45, 2.96]
Posttest adjusted for pretest (sensitivity)	ANCOVA $F(1, 41) = 46.60$	8.86 [6.24, 11.48]	< .001	$\eta_p^2 = .53$
SDL, post only (secondary)	Student's $t(42) = 6.49$	12.46 [8.58, 16.33]	< .001	$d = 1.96$ [1.23, 2.67]

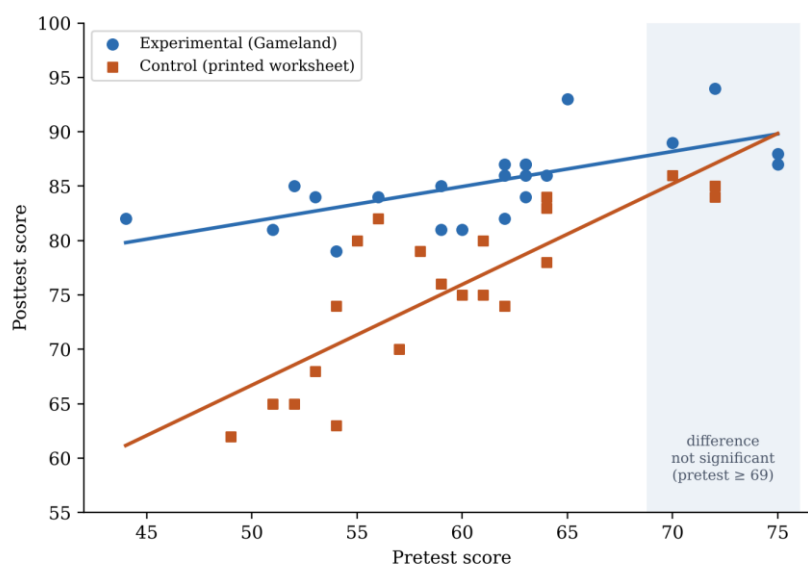
Note. Cohen's d uses the pooled standard deviation, and its confidence interval was computed from the noncentral t distribution. The ANCOVA difference is between pretest-adjusted posttest means (84.88 vs. 76.03); because the regression slopes differed between groups, it is an average over the observed pretest range (Figure 7). Welch's test for SDL gave the same result, $t(41.11) = 6.49$, $p < .001$.

Table 11 shows that the classes did not differ at baseline ($d = 0.24$, although the confidence interval is wide). The mean N-Gain of the experimental class exceeded that of the control class by 0.22, $t(37.98) = 7.33$, $p < .001$, $d = 2.21$, and the conclusion was unchanged when posttest scores were adjusted for the pretest (adjusted difference = 8.86 points, $p < .001$). The ANCOVA also showed that the relation between pretest and posttest differed between the classes (group $\times$ pretest interaction, $t(40) = -3.67$, $p < .001$): the regression slope was 0.93 in the control class but only 0.32 in the experimental class.

Figure 7 shows what this interaction means. According to the Johnson–Neyman analysis, the experimental class scored significantly higher than the control class for pretest scores below about 69, a range that included 37 of the 44 students, whereas for the seven students with pretest scores of 70 or above, the difference was not significant. Post-intervention SDL was higher in the experimental class by 12.46 points, $t(42) = 6.49$, $p < .001$, $d = 1.96$; because SDL was not measured before the intervention, this is a difference between the classes after the intervention rather than an improvement within either class.

Figure 7

Posttest Against Pretest Scores by Group, With Group-Specific Regression Lines



Note. The shaded area marks the pretest range in which the Johnson–Neyman analysis found no significant group difference ($\alpha = .05$).

4. Discussion

4.1 How the ADDIE Process Shaped Gameland

The development results show how each ADDIE stage shaped the final product. The analysis fixed the main design constraints: every student could use an Android phone, yet students depended on the teacher when using technology and solving problems, and the existing worksheets offered neither color nor cultural context. These constraints explain the three defining features of Gameland: a self-access application with a user guide and a progress display, a tiered quiz with immediate worked explanations, and gamelan instruments used as the stimulus of geometry tasks. The two revision rounds, by contrast, changed only the explicitness of the learning objectives and the readability of the screens, suggesting that the content map produced during analysis was already sound. Because the media expert and the students independently identified font size and color contrast as weaknesses, readability should be checked with children before expert validation, not only after it.

4.2 Validity and Practicality

Both experts rated Gameland valid, and the small-group students rated it very practical, indicating that the product was acceptable in content and presentation and could be used by Grade 5 students with limited assistance. These judgments, however, rest on one expert per domain and six students, so they should be read as evidence of adequacy and feasibility rather than as psychometric proof of quality. Other recently developed ethnomathematics-based worksheets obtained expert validity ratings of

about 90% or higher (Aulia et al., 2025; Sugiarni et al., 2026). The media score of Gameland (68.75%) lay only moderately above the lower bound of the valid category, and media quality was the dimension that required the most revision, which identifies readability as the main area for further refinement. The small-group gain of 0.56, computed as the mean of individual gains (Coletta & Steinert, 2020), was used only to decide whether a larger trial was warranted.

4.3 Understanding of Geometry Concepts

In the field trial, the experimental class achieved a larger mean N-Gain than the control class (0.62 vs. 0.40). Because the pretest means were similar and the difference persisted when posttest scores were adjusted for the pretest, initial ability alone is unlikely to explain it, although intact classes may differ in ways that a pretest does not capture. The pattern is consistent with research on realistic and context-based mathematics, in which concepts are built from situations familiar to students (Fajri et al., 2025), and with the high normalized gains reported for culture-based geometry worksheets (Khairunnisa et al., 2025). In Gameland, gamelan instruments served as the stimulus for identifying figures and their properties (Table 5 and Figure 5c), which may have directed students' attention to the properties of figures rather than to their appearance, the transition that van Hiele (1986) identifies as critical at this age.

The tiered quiz levels provide a form of scaffolding consistent with sociocultural theory (van de Pol et al., 2010; Vygotsky, 1978; Wood et al., 1976), and the scores and worked explanations at the end of each level constitute the kind of immediate, task-specific feedback that ranks among the most powerful influences on learning (Hattie & Timperley, 2007). Naming the levels after gamelan compositions also adds a light game element, and contextual instruction integrated with gamification has been found to strengthen students' mathematical connections and motivation (Nurmiati et al., 2026). The combination of a meaningful cultural context, tiered items, and immediate feedback is therefore a plausible explanation for the higher gains. Because no process data, such as usage logs or analyses of student work, were collected, the contribution of each component cannot be separated, and this explanation remains a hypothesis for component-level studies.

The moderation analysis adds an important nuance: the advantage of the experimental class was concentrated among students with lower pretest scores and was not detectable among the seven students who began at 70 or above. Two explanations are plausible. Worked explanations after every item may benefit most the students who make the most errors, and the posttest scores of the experimental class approached the maximum of the test (up to 94), leaving little room to reveal differences among higher-achieving students. In practice, this pattern suggests that Gameland may be most useful for students who are still struggling with plane figures, whereas higher-achieving students may need more demanding tasks than the current levels provide.

4.4 Self-Directed Learning

The experimental class also reported higher SDL after the intervention (79.91 vs. 67.45; $d = 1.96$). Several features of Gameland correspond to the SDL dimensions measured: students chose which material, video, or quiz to open and when, worked at their own pace, saw their progress on the home page, and checked their answers through scores and worked explanations, which supports the self-monitoring and self-evaluation processes described by Zimmerman (2002). Comparable links between self-regulated learning and learning outcomes have been reported in online higher education (Broadbent & Poon, 2015) and in Indonesian junior secondary mathematics (Adriani et al., 2026). Nevertheless, SDL was measured once, after the intervention, with a self-report questionnaire, so the difference may partly reflect novelty or students' enthusiasm for a phone-based application rather than a durable change in learning habits.

4.5 Limitations and Future Research

The effect sizes in this study ($d \approx 2$) are very large and should be interpreted cautiously, because large effects are common in small samples and short interventions and may be inflated by novelty, by an assessment closely aligned with the intervention tasks, and by differences between intact classes. Several further limitations affect the transferability of the findings. First, the field trial involved two intact classes from one school; although the pretest means were similar, unmeasured differences cannot be ruled out, and replication in other schools, regions, and cultural contexts is needed. Second, the same teacher taught both classes, so teacher expectations may have influenced the results. Third, part of the effect may reflect the use of a phone or its novelty rather than the ethnomathematics content itself. Fourth, SDL was measured only after the intervention with a self-report questionnaire, which prevents the estimation of change and is susceptible to social desirability. Fifth, validity was judged by one content expert and one media expert, who provided only total scores, and practicality was tested with only six students. Sixth, the posttest scores of the experimental class approached the maximum of the test, which may have masked differences among higher-achieving students.

In addition, Gameland covers a single topic and draws on a single culture, so its value for other mathematics content and other cultural contexts remains unknown. Its video lessons require internet access, which may limit use in schools with poor connectivity, and scores are currently sent to the teacher manually through WhatsApp. Future studies should use random assignment, involve several teachers and schools, measure SDL before and after the intervention, collect process data on how students use the application, add more demanding tasks for higher-achieving students, and examine whether the cultural-identity rationale presented in the Introduction is realized, for example by assessing whether students' appreciation of the gamelan changes after learning with Gameland.

5. Conclusion

This study developed Gameland, an Android-based digital worksheet that uses Javanese gamelan instruments and motifs as the context for Grade 5 plane-geometry tasks, following the ADDIE model. The analysis showed that the printed worksheets in use were monotonous, did not connect geometry to students' context, and did not support independent problem solving, while all students could operate Android phones. These findings were translated into six design requirements and a map linking the Phase C learning objectives to specific gamelan features. The design stage produced a navigation flowchart and a five-screen interface blueprint, and the development stage produced an application with gamelan-based material pages, videos, enrichment quizzes, and five tiered quiz levels with worked explanations. The experts rated the product valid (content 79.60%; media 68.75%), the small-group students rated it very practical (88.50%), and two rounds of readability revisions produced the version used in the field trial.

In the field trial, the experimental class achieved a higher mean normalized gain in understanding of geometry concepts than the control class (0.62 vs. 0.40; $p < .001$; $d = 2.21$), an advantage concentrated among students with lower pretest scores, and reported higher self-directed learning after the intervention (79.91 vs. 67.45; $p < .001$; $d = 1.96$). Gameland is therefore a valid, practical, and promising culturally grounded medium for plane-geometry learning, particularly for students who are still struggling with plane figures. Because the evidence comes from a non-randomized comparison of two classes in one school, its effectiveness should be confirmed in larger studies with random assignment, several teachers, and a pre-intervention measure of self-directed learning.

Statements and Declarations

Funding:

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing Interests:

The authors declare that they have no competing interests.

Ethics Statement:

The study was conducted with the permission of the principal of SD Negeri 2 Bolorejo. Written consent was obtained from parents or guardians, students gave assent after an age-appropriate explanation, participation was voluntary, and all data were anonymized.

Data Availability:

The anonymized data and instruments are available from the corresponding author upon reasonable request.

Author Contributions:

Nanda Fitri Nur Rohmah: Conceptualization, Methodology, Software (product development), Investigation, Data curation, Formal analysis, Writing – original draft, Visualization.

I Made Sulandra: Supervision, Validation, Writing – review & editing.

Sudirman Sudirman: Supervision, Methodology, Formal analysis, Writing – review & editing.

Dharmendra Kumar Yadav: review & editing

Declaration of Generative AI Use:

Generative AI was used to assist with language editing and manuscript formatting. It was not used to generate data, analyses, or results. The authors reviewed and approved the final text and take full responsibility for its content.

Acknowledgements:

The authors thank the validators, the principal and teachers of SD Negeri 2 Bolorejo, and the participating students and their families for their support and cooperation.

6. References

- Adriani, F., Waluya, S. B., & Masduki, L. R. (2026). Self-regulated learning and critical thinking in socio-emotionally differentiated problem-based learning: A mixed-methods study in Indonesian junior secondary mathematics. *International Journal of Mathematics and Sciences Education*, 4(1), 1–12.
<https://doi.org/10.59965/ijmsed.v4i1.285>
- Ainiyah, R., Rusmayadi, M., & Bahri, S. (2025). Why geometry feels difficult: A phenomenological inquiry into junior high school students' learning experiences in Indonesia. *Panicgogy International Journal*, 3(2), 80–93.
<https://doi.org/10.59965/pij.v3i2.177>
- Aulia, P., Sugiarni, R., & Rodríguez-Nieto, C. A. (2025). Development and validation of ethnomathematics-based worksheets integrating Sundanese Pupuh for enhancing number pattern learning in Indonesian secondary schools. *Polyhedron International Journal in Mathematics Education*, 3(2), 139–152.
<https://doi.org/10.59965/pijme.v3i2.275>
- Basri, H., García-García, J., Rodríguez-Nieto, C. A., Rifanda, A. R., & Indahwati, R. (2025). GeoGebra-assisted discovery learning: An effective strategy to enhance elementary students' interest in learning plane area measurement. *International Journal of Didactic Mathematics in Distance Education*, 2(1), 1–15.
<https://doi.org/10.33830/ijdmde.v2i1.11272>
- Branch, R. M. (2009). *Instructional design: The ADDIE approach*. Springer.
<https://doi.org/10.1007/978-0-387-09506-6>
- Broadbent, J., & Poon, W. L. (2015). Self-regulated learning strategies & academic achievement in online higher education learning environments: A systematic

- review. *The Internet and Higher Education*, 27, 1–13.
<https://doi.org/10.1016/j.iheduc.2015.04.007>
- BSKAP. (2024). *Keputusan Kepala Badan Standar, Kurikulum, dan Asesmen Pendidikan Nomor 032/H/KR/2024 tentang Capaian Pembelajaran pada Pendidikan Anak Usia Dini, Jenjang Pendidikan Dasar, dan Jenjang Pendidikan Menengah pada Kurikulum Merdeka*. Kementerian Pendidikan, Kebudayaan, Riset, dan Teknologi.
- Clements, D. H., & Battista, M. T. (1992). Geometry and spatial reasoning. In D. A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning* (pp. 420–464). Macmillan.
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Lawrence Erlbaum Associates.
- Coletta, V. P., & Steinert, J. J. (2020). Why normalized gain should continue to be used in analyzing preinstruction and postinstruction scores on concept inventories. *Physical Review Physics Education Research*, 16(1), Article 010108.
<https://doi.org/10.1103/PhysRevPhysEducRes.16.010108>
- D'Ambrosio, U. (1985). Ethnomathematics and its place in the history and pedagogy of mathematics. *For the Learning of Mathematics*, 5(1), 44–48.
- Delacre, M., Lakens, D., & Leys, C. (2017). Why psychologists should by default use Welch's t-test instead of Student's t-test. *International Review of Social Psychology*, 30(1), 92–101. <https://doi.org/10.5334/irsp.82>
- Dent, A. L., & Koenka, A. C. (2016). The relation between self-regulated learning and academic achievement across childhood and adolescence: A meta-analysis. *Educational Psychology Review*, 28(3), 425–474.
<https://doi.org/10.1007/s10648-015-9320-8>
- Fajri, H. M., Marini, A., & Suyono. (2025). Trends and patterns in realistic mathematics education research in elementary schools: A bibliometric approach. *Social Sciences & Humanities Open*, 12, Article 101730.
<https://doi.org/10.1016/j.ssaho.2025.101730>
- Fujita, T., & Jones, K. (2007). Learners' understanding of the definitions and hierarchical classification of quadrilaterals: Towards a theoretical framing. *Research in Mathematics Education*, 9(1–2), 3–20.
<https://doi.org/10.1080/14794800008520167>
- Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, 66(1), 64–74.
<https://doi.org/10.1119/1.18809>
- Hattie, J., & Timperley, H. (2007). The power of feedback. *Review of Educational Research*, 77(1), 81–112. <https://doi.org/10.3102/003465430298487>

- Higgins, K., Huscroft-D'Angelo, J., & Crawford, L. (2019). Effects of technology in mathematics on achievement, motivation, and attitude: A meta-analysis. *Journal of Educational Computing Research*, 57(2), 283–319. <https://doi.org/10.1177/0735633117748416>
- Johnson, P. O., & Neyman, J. (1936). Tests of certain linear hypotheses and their application to some educational problems. *Statistical Research Memoirs*, 1, 57–93.
- Khairunnisa, I. A., Mairing, J. P., Sudirman, S., & Rodríguez-Nieto, C. A. (2025). Integrating cultural contexts into mathematics: Effects of culture-based worksheets on students' mastery of geometric transformations. *Polyhedron International Journal in Mathematics Education*, 3(1), 1–10. <https://doi.org/10.59965/pijme.v3i1.167>
- Knowles, M. S. (1975). *Self-directed learning: A guide for learners and teachers*. Association Press.
- Kyeremeh, P., Awuah, F. K., & Dorwu, E. (2023). Integration of ethnomathematics in teaching geometry: A systematic review and bibliometric report. *Journal of Urban Mathematics Education*, 16(2), 68–89. <https://doi.org/10.21423/jume-v16i2a519>
- Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, 4, Article 863. <https://doi.org/10.3389/fpsyg.2013.00863>
- Nurmiati, N., Wahyuningrum, E., Sudirman, S., & Nà, T. L. (2026). Contextual learning integrated with gamification: Effects on mathematical connection ability and learning motivation in ratio and proportion. *International Journal of Mathematics and Sciences Education*, 4(1), 13–37. <https://doi.org/10.59965/ijmsed.v4i1.309>
- Prahmana, R. C. I., & Istiandaru, A. (2021). Learning sets theory using shadow puppet: A study of Javanese ethnomathematics. *Mathematics*, 9(22), Article 2938. <https://doi.org/10.3390/math9222938>
- Richey, R. C., & Klein, J. D. (2007). *Design and development research: Methods, strategies, and issues*. Lawrence Erlbaum Associates.
- Riduwan. (2012). *Skala pengukuran variabel-variabel penelitian*. Alfabeta.
- Rosa, M., & Orey, D. C. (2011). Ethnomathematics: The cultural aspects of mathematics. *Revista Latinoamericana de Etnomatemática*, 4(2), 32–54.
- Shadish, W. R., Cook, T. D., & Campbell, D. T. (2002). *Experimental and quasi-experimental designs for generalized causal inference*. Houghton Mifflin.
- Sugiarni, R., Zulnaldi, H., Ningsih, D. N., Hakim, R. R., & Setiawan, E. (2026). Integrating Pandanwangi ethnomathematics into e-worksheets to support numeracy in online mathematics learning. *International Journal of Didactic Mathematics in*

Distance Education, 3(2), 184–209.

<https://doi.org/10.33830/ijdmde.v3i2.14462>

Sumarmo, U. (2016). *Pedoman pemberian skor pada beragam tes kemampuan matematika*. Pustaka Mandiri.

Sunzuma, G., & Maharaj, A. (2019). Teacher-related challenges affecting the integration of ethnomathematics approaches into the teaching of geometry. *Eurasia Journal of Mathematics, Science and Technology Education*, 15(9), Article em1744. <https://doi.org/10.29333/ejmste/108457>

van de Pol, J., Volman, M., & Beishuizen, J. (2010). Scaffolding in teacher–student interaction: A decade of research. *Educational Psychology Review*, 22(3), 271–296. <https://doi.org/10.1007/s10648-010-9127-6>

van Hiele, P. M. (1986). *Structure and insight: A theory of mathematics education*. Academic Press.

Vojkůvková, I. (2012). The van Hiele model of geometric thinking. In *WDS'12 Proceedings of Contributed Papers, Part I* (pp. 72–75). Matfyzpress.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.

Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry*, 17(2), 89–100. <https://doi.org/10.1111/j.1469-7610.1976.tb00381.x>

Yulizarti, I., Wahyuningrum, E., & Sudirman, S. (2026). Project-based learning integrated with local wisdom: Developing a trigonometry teaching module to enhance HOTS of senior secondary students in Merangin Regency. *Panicgogy International Journal*, 4(1), 1–15. <https://doi.org/10.59965/pij.v4i1.301>

Zimmerman, B. J. (2002). Becoming a self-regulated learner: An overview. *Theory Into Practice*, 41(2), 64–70. https://doi.org/10.1207/s15430421tip4102_2