Premiere Educandum: Jurnal Pendidikan Dasar dan Pembelajaran
Volume 15 (1) 15 – 33 2025
ISSN: 2088-5350 (Print) / ISSN: 2528-5173 (Online)
Doi: 10.25273/pe.v15i1.25272
The article is published with Open Access at: http://e-journal.unipma.ac.id/index.php/PE

Developing edumatika.id: An interactive web-based e-worksheet to enhance elementary students' mathematics learning outcomes

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Abstract: Despite the growing use of digital tools in elementary mathematics education, most existing electronic worksheets remain limited to static content and lack interactivity, immediate feedback, and support for independent home-based learning. This study aimed to develop and evaluate Edumatika.id, a web-based interactive mathematics e-Worksheet designed to enhance the mathematical competence of Grade II elementary school students. A Research and Development (R&D) approach was employed using the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation). The product was validated by two material experts and two media experts, then tested through one-to-one evaluation (n = 3), small-group evaluation (n = 5), and a field trial (n = 11) involving Grade II elementary school students. During the field trial, students used the platform independently at home for one week under parental supervision. Expert validation showed high feasibility, with average scores of 83.50% (material experts) and 89.00% (media experts). Practicality testing yielded consistently favorable results: 87.88% (one-to-one), 78.86% (small-group), and 87.50% (field trial). Parents reported an overall positive perception of home implementation (78.45%), particularly regarding parental support (81.82%) and student motivation (80.00%), though independent learning (73.81%) scored comparatively lower. Students' mean mathematics achievement improved from 7.00 (pretest) to 8.18 (posttest), with 81.8% of students showing gains. Edumatika.id distinguishes itself from prior e-Worksheets by integrating interactive materials, three-dimensional visualizations, game-based exercises, immediate formative feedback, and cross-device accessibility within a single platform. These findings indicate that Edumatika.id is a valid, practical, and promising medium for supporting elementary mathematics learning both at school and at home.

Keywords: e-Worksheet, Elementary school, Mathematical competence, Mathematics learning, web-based learning.

Received 16 May 2025; **Accepted** 21 April 2026; **Published** 18 July 2026

Citation: Setiawan, B., Pradana, L.N., & Rudyanto, H.E. (2025). Developing edumatika.id: An interactive web-based e-worksheet to enhance elementary students' mathematics learning outcomes. *Premiere Educandum : Jurnal Pendidikan Dasar dan Pembelajaran*, *15*(1), 15 – 33. Doi.org/10.25273/pe.v15i1.25272

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INTRODUCTION

Mathematics is widely regarded as one of the most difficult subjects for elementary school students because many of its core concepts are abstract and are not easily grasped through rote, text-based instruction alone (Radović et al., 2020). This difficulty is compounded by the fact that mathematical competence acquired in the early grades, particularly Grade II, forms the cognitive foundation for more advanced mathematical reasoning in later years. When this foundation is weak, students are prone to sustained low achievement and, in many cases, the development of negative affective responses toward mathematics. Longitudinal evidence indicates that math anxiety already begins to take root in primary school and is reciprocally related to arithmetic achievement over time, such that early difficulty and early anxiety reinforce one another (Szczygieł et al., 2024). Similarly, research tracing the relationship between parental educational involvement, teacher support, and children's math anxiety shows that the emotional climate surrounding a child's early mathematics learning experiences, both at school and at home, has measurable long-term consequences for achievement (Li et al., 2021). These findings collectively highlight those early mathematics learning experiences are not merely about content delivery but must also be designed to sustain motivation, confidence, and independent engagement from the very first years of schooling.

In response to these challenges, digital learning tools have increasingly been adopted to support elementary mathematics instruction, and a substantial body of research demonstrates their potential benefits. Interactive e-books that embed real-world scenarios, virtual agents, and immediate feedback have been shown to significantly improve elementary students' learning achievement, motivation, and satisfaction relative to conventional instructional videos (Chen et al., 2026). Comparable gains have been documented among pre-school children learning numerical operations through situation-based interactive e-books (Li et al., 2020), and among middle school students whose spatial and mathematics reading abilities improved after exposure to three-dimensional interactive visual content (Yohannes et al., 2023). Mobile-based mathematics interventions have likewise produced measurable gains in attitudes, engagement, and achievement in randomized and quasi-experimental designs (Fabian & Topping, 2019; Fabian et al., 2018), while interactive GeoGebra-based textbooks and applets have been found to enhance mathematical reasoning by allowing students to manipulate dynamic visual representations rather than static diagrams (Kaplar et al., 2021; Radović et al., 2020). Collectively, this literature establishes that digital, interactive, and visually rich learning tools can meaningfully outperform static or purely textual instructional materials in elementary mathematics contexts.

Despite this accumulating evidence, a persistent and well-documented gap remains between what research demonstrates as effective design principles and what is actually implemented in most electronic worksheets (e-Worksheets) used in elementary classrooms today. The majority of existing e-Worksheets are little more than digitized versions of paper-based exercises: they present static text and images, offer no responsive feedback, and provide no mechanism for adapting to a learner's performance. This gap is not merely anecdotal. Systematic reviews of feedback mechanisms in technology-rich learning environments show that although personalized and immediate feedback is one of the most consistently effective design features for improving academic outcomes, most existing digital tools still lack well-designed feedback loops, and available frameworks for classifying and implementing such feedback remain underdeveloped and inconsistently applied in practice (Deeva et al., 2021; Maier & Klotz, 2022). Randomized experimental studies confirm the magnitude of what is being missed: digital formative assessment tools that provide immediate, task-adaptive feedback have produced significant gains in both mathematics achievement and student motivation compared with business-as-usual

instruction (Faber et al., 2017), with similar benefits replicated in spelling achievement (Faber & Visscher, 2018). If immediate feedback of this kind were systematically embedded in elementary mathematics e-Worksheets, comparable gains could plausibly be expected—yet very few existing products for early elementary grades actually do so.

A second, related gap concerns the near-total absence of gamified and playful design elements in mathematics e-Worksheets, despite strong meta-analytic evidence for their effectiveness. A large-scale meta-analysis found that gamification produces significant positive effects on cognitive, motivational, and behavioral learning outcomes across educational contexts (Sailer & Homner, 2020), and digital game-based learning approaches have been specifically shown to improve K-12 mathematics achievement across a wide range of implementations (Hussein et al., 2022). Elementary-level studies reinforce this pattern: gamified project-based learning has been found to enhance both academic performance and motivational outcomes more than non-gamified project-based learning among elementary mathematics students (Shang et al., 2026), gamification of geometry instruction has helped young learners progress from concrete manipulation to more abstract reasoning while sustaining engagement (Kamalodeen et al., 2021), and immersive virtual environments have improved motivation, cognitive engagement, and collaborative self-efficacy among elementary learners (Cho et al., 2022). Reviews specifically focused on how digital gamification elements are tailored to different learners further show that competition-based and collaboration-based game designs can be combined to maximize learning performance (Hong et al., 2024; Wang & Huang, 2023), while research on three-dimensional virtual games suggests that immersive gameplay is directly associated with improved mathematical ability (Christopoulos et al., 2024). Notably, several of these design features are usually studied in isolation from one another, and rarely integrated together within a single elementary mathematics platform, let alone one designed specifically for independent use outside the classroom.

This isolation points to a third and arguably more consequential gap: the scarcity of e-Worksheets explicitly designed and empirically validated for independent, home-based learning, and the corresponding lack of attention to parental involvement as a design consideration rather than an afterthought. As learning increasingly extends beyond the classroom into the home, parents are being asked to take on new and often unfamiliar roles in supporting their children's digital learning (Gonzalez-DeHass et al., 2022). Evidence suggests that this shift is far from trivial: mothers' active involvement in children's digital learning activities has been shown to exert a substantial positive influence on children's learning experiences and outcomes at home (Amelia et al., 2023), yet young learners themselves often struggle to self-regulate their learning when technology is used without explicit scaffolding. Observational research on elementary students working independently in hypermedia environments found that students spent the overwhelming majority of their time on basic cognitive strategies such as reading and summarizing, while spending strikingly little time planning or monitoring their own learning process key markers of self-regulated learning (Torrington et al., 2022). This suggests that a home-based digital mathematics tool cannot simply assume that young learners will regulate themselves effectively; it must be designed, and evaluated, with this limitation explicitly in mind. Systematic instructional design approaches such as the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation) have long been used to structure the development of digital learning materials in a way that anticipates learner needs at each stage (Trust & Pektas, 2018), yet relatively few studies have applied this rigor specifically to a mathematics e-Worksheet intended for unsupervised, at-home use by early elementary students, nor have they systematically captured parental perceptions of that home implementation process alongside conventional expert-validation and student-outcome measures.

Taken together, the literature reveals three converging gaps that this study addresses. First, although immediate feedback, gamification, and three-dimensional visualization have each been shown individually to enhance elementary mathematics

learning, very few e-Worksheet platforms integrate all of these features within a single, coherent, cross-device-accessible tool. Second, existing digital mathematics tools are rarely subjected to a systematic, multi-stage validation process that would establish their feasibility and practicality with the rigor the ADDIE model is designed to provide. Third, and perhaps most critically, almost no existing e-Worksheet has been explicitly designed for, and evaluated in, a genuine home-based, parent-supervised implementation context, despite growing evidence that parental involvement and children's self-regulation capacities are decisive factors in whether digital learning tools succeed outside the classroom. Addressing these gaps is not merely a matter of technological novelty; it is necessary to ensure that digital mathematics resources for young learners are both pedagogically sound and practically viable in the environments where children increasingly use them.

To address these gaps, this study develops and evaluates Edumatika.id, an interactive web-based mathematics e-Worksheet designed for Grade II elementary school students, using a Research and Development (R&D) approach grounded in the ADDIE model. Specifically, this study aims to: (1) develop Edumatika.id as a web-based e-Worksheet that integrates interactive materials, three-dimensional visualization, game-based exercises, immediate formative feedback, and cross-device accessibility into a single unified platform; (2) determine the feasibility of Edumatika.id based on the validation results of material experts and media experts; (3) determine the practicality of Edumatika.id through staged testing involving one-to-one evaluation, small-group evaluation, and a field trial; (4) describe parents' perceptions of the practicality and support value of Edumatika.id when it is implemented independently at home under parental supervision; and (5) determine the effect of using Edumatika.id on Grade II elementary school students' mathematics learning outcomes, as measured through pretest–posttest achievement scores. Through these objectives, this study seeks to contribute an empirically validated model for designing home-capable, interactive digital mathematics resources that close the gap between what educational technology research recommends and what is currently and practically available to elementary students and their families.

METHODS

Research Design

This study employed a Research and Development (R&D) design aimed at producing and empirically validating Edumatika.id, an interactive web-based mathematics e-Worksheet for Grade II elementary school students. The development process was structured according to the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation), which provides a systematic and iterative framework for translating identified learning needs into a validated instructional product (Trust & Pektas, 2018). Within this framework, the study combined developmental (product validation and practicality testing) and quasi-experimental (one-group pretest–posttest) elements to determine not only whether Edumatika.id was feasible and usable, but also whether its use produced a measurable change in students' mathematics learning outcomes. The overall design can therefore be characterized as a mixed-methods R&D study, in which qualitative expert judgments and parental perceptions were triangulated with quantitative validation scores, practicality scores, and achievement data.

Participant

Participants in this study were drawn from two groups: elementary school students and their parents, and expert validators.

Students and parents. Participants consisted of Grade II elementary school students recruited through purposive sampling to match three sequential stages of practicality testing mandated by the ADDIE-based R&D procedure: (1) a one-to-one evaluation involving 3 students, (2) a small-group evaluation involving 5 students, and (3) a field trial involving 11 students. Students participating in the field trial used Edumatika.id independently at home for one week, with their parents or guardians present in a supervisory (not instructional) capacity. Parents of the 11 field-trial students also served as respondents for the parental perception questionnaire, providing data on perceived home implementation quality, parental support, student motivation, and student independent learning.

Expert validators. Product feasibility was assessed by four expert validators: two material (content) experts with a background in elementary mathematics education, who evaluated the accuracy, curricular alignment, and pedagogical appropriateness of the content, and two media experts with a background in instructional technology/multimedia design, who evaluated the interface design, interactivity, navigation, and technical functionality of the platform. Experts were selected based on relevant academic qualifications and professional experience in their respective domains and were involved during the Development stage of the ADDIE cycle, prior to any student-facing testing.

Material

Several instruments were developed and used to collect data across the ADDIE stages:
Product: Edumatika.id. The primary material developed in this study was Edumatika.id itself (see **Figure 1**) a web-based, cross-device-accessible interactive e-Worksheet integrating (a) interactive mathematics materials aligned with the Grade II curriculum, (b) three-dimensional visualizations to support spatial and conceptual understanding, (c) game-based exercises incorporating gamification elements such as points, challenges, and progression, and (d) an automated, immediate formative feedback mechanism that responds to student input during practice.

Expert validation questionnaires. Two structured Likert-scale questionnaires were developed: a material validation sheet (covering content accuracy, curricular relevance, language appropriateness, and instructional design) for the material experts, and a media validation sheet (covering visual design, interactivity, navigation, and technical performance) for the media experts. Both instruments used a rating scale (1–4) converted into percentage feasibility scores.

Practicality questionnaires (student response sheets). A student response questionnaire, adapted to the reading level of Grade II students and, where necessary, read aloud or assisted by an observer/parent, was used to capture students' perceptions of ease of use, engagement, and clarity of instructions during the one-to-one, small-group, and field trial stages.

Parental perception questionnaire. A structured questionnaire was administered to parents following the one-week field trial, measuring three sub-constructs: (a) parental support during home implementation, (b) student motivation as observed by parents, and (c) student independent learning during platform use.

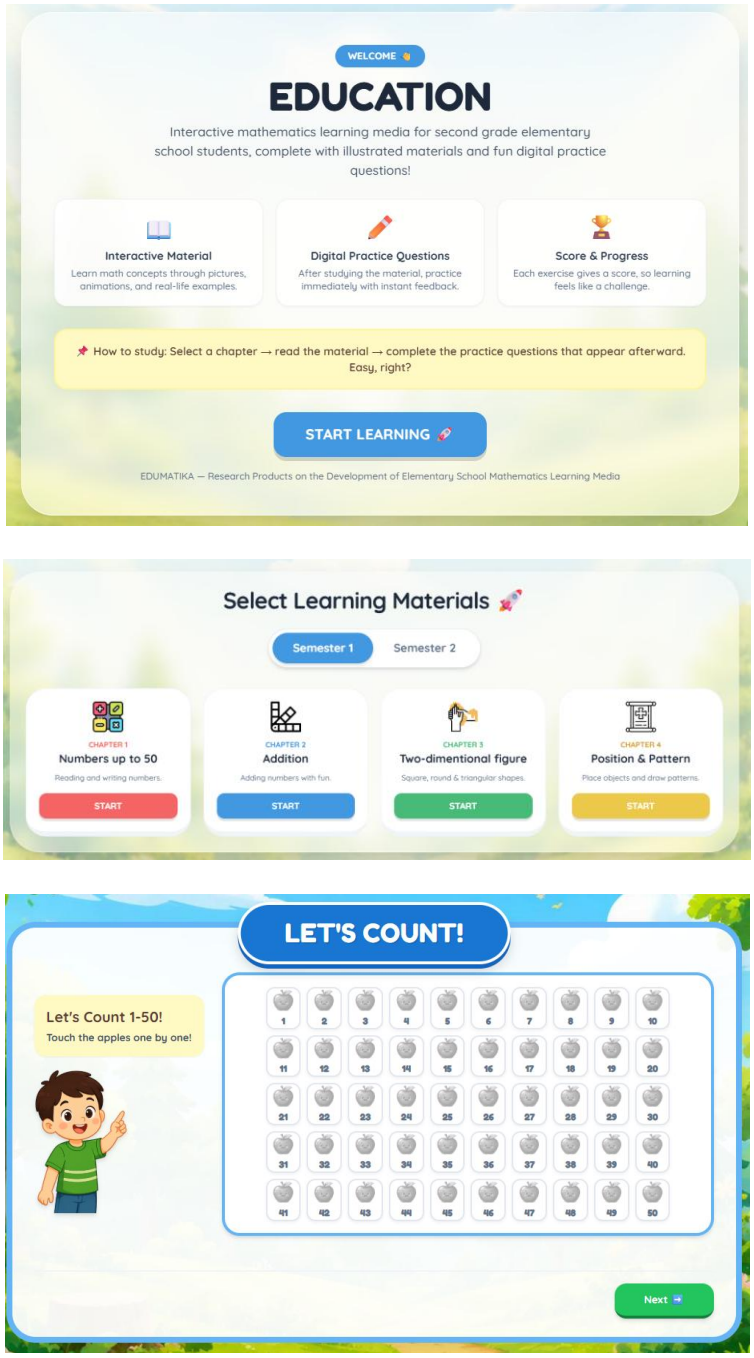


FIGURE 1. *Prototype of edumatika.id*

Mathematics achievement test (pretest–posttest). A researcher-developed mathematics achievement instrument, aligned with the Grade II curriculum content embedded in Edumatika.id, was administered before (pretest) and after (posttest) the field trial to measure changes in students' mathematics learning outcomes. The instrument was reviewed by the material experts for content validity prior to use.

Procedure

The study procedure followed the five sequential stages of the ADDIE model:
Analysis. This stage involved identifying the learning needs and problems underlying the study, including curriculum analysis of Grade II mathematics content, analysis of students'

characteristics and prior digital literacy, and analysis of existing e-Worksheets to identify their limitations (e.g., static content, absence of interactivity and immediate feedback). Needs analysis also included preliminary discussions with teachers and, where relevant, parents, regarding the feasibility of home-based digital learning.

Design. Based on the analysis findings, the researcher designed the architecture and pedagogical framework of Edumatika.id, including the mapping of learning objectives to content units, the storyboard for interactive materials and three-dimensional visualizations, the design of game-based exercises and feedback logic, and the overall user-interface flow to ensure cross-device accessibility (desktop, tablet, and smartphone).

Development. The design was translated into a functional web-based product. During this stage, the developed prototype of Edumatika.id was submitted to the two material experts and two media experts for validation. Expert feedback was used to revise the product iteratively (e.g., correcting content inaccuracies, refining navigation, adjusting difficulty progression) prior to proceeding to field testing.

Implementation. The revised product was implemented in three sequential and increasingly authentic testing phases: (a) a one-to-one evaluation with 3 students to identify major usability issues, (b) a small-group evaluation with 5 students to refine the product further based on peer-interaction patterns, and (c) a field trial with 11 students, in which participants used Edumatika.id independently at home for one week under parental supervision. Prior to the field trial, students completed the mathematics pretest; after the one-week implementation period, they completed the posttest. Parents completed the perception questionnaire at the conclusion of the field trial.

Evaluation. Formative evaluation occurred continuously throughout the Development and Implementation stages (i.e., expert-driven and student-driven revisions), while summative evaluation was conducted at the end of the study by analyzing the expert validation scores, practicality scores from all three implementation phases, parental perception results, and pretest–posttest achievement data to determine the overall validity, practicality, and impact of Edumatika.id.

Data Analysis

Data analysis procedures were tailored to the type of data collected at each stage. Responses from the material expert, media expert, and student practicality questionnaires were analyzed descriptively by converting raw Likert-scale scores into percentage, with the resulting percentages interpreted using a standard feasibility/practicality categorization scale (very feasible/practical, feasible/practical, less feasible/practical, not feasible/practical) consistent with conventional R&D validity criteria; this procedure was applied separately to material expert scores, media expert scores, and the one-to-one, small-group, and field trial practicality scores. Parental questionnaire responses were likewise analyzed descriptively, with percentage scores calculated separately for the overall perception construct and each of its three sub-constructs (parental support, student motivation, and independent learning) to enable comparison across dimensions of home implementation. Mathematics achievement data were analyzed by computing descriptive statistics (means, standard deviations) for the pretest and posttest scores to characterize the overall change in student achievement, along with the proportion of students demonstrating an increase from pretest to posttest; where appropriate, a paired-samples t-test (or, given the small sample size of n = 11, a non-parametric equivalent such as the Wilcoxon signed-rank test) was used to test the statistical significance of the pretest–posttest difference, and a normalized gain (N-gain) score was calculated to characterize the magnitude of improvement relative to the maximum possible gain. Taken

together, this combination of descriptive percentage analysis (for validity and practicality data) and comparative pretest–posttest analysis (for achievement data) allowed the study to comprehensively address whether Edumatika.id was valid, practical, well-received by parents, and effective in improving Grade II students' mathematics learning outcomes.

RESULTS

Expert Validation Results

The Edumatika.id prototype produced during the Development stage was evaluated by two material experts and two media experts using the structured validation questionnaires described previously. As shown in Table 1, the material experts rated the product's content accuracy, curricular alignment, language appropriateness, and instructional design with an average score of 83.50%, while the media experts rated the product's visual design, interactivity, navigation, and technical performance with a higher average score of 89.00%. Using the standard feasibility categorization scale (81–100% = very feasible; 61–80% = feasible; 41–60% = moderately feasible; ≤40% = less/not feasible), both validation results fall within the very feasible category. Notably, the media experts' scores were slightly higher than those of the material experts, suggesting that the technical and visual design aspects of Edumatika.id including its three-dimensional visualizations and interactive interface were perceived as marginally stronger than the depth or completeness of its instructional content. Nonetheless, both scores comfortably exceeded the minimum threshold typically required for a product to proceed to field implementation in R&D studies, indicating that Edumatika.id was ready, from an expert standpoint, to be tested directly with students.

Practicality Testing Results

Following expert validation and product revision, practicality testing was conducted in three sequential and progressively larger stages, consistent with the Implementation stage of the ADDIE model. As presented in Table 2, the one-to-one evaluation involving 3 students produced an average practicality score of 87.88%, the small-group evaluation involving 5 students produced a somewhat lower average of 78.86%, and the field trial involving 11 students produced an average of 87.50%. All three stages yielded scores in the practical to very practical range, indicating that students across different testing contexts generally found Edumatika.id easy to use, engaging, and clear in its instructions. The comparatively lower score obtained during the small-group evaluation (78.86%), relative to the one-to-one (87.88%) and field trial (87.50%) stages, suggests that peer-interaction dynamics during small-group testing may have introduced minor usability friction that was less apparent when students used the platform individually. Importantly, this dip did not persist into the field trial, where students used Edumatika.id independently at home; the recovery to 87.50% indicates that the revisions made after the small-group stage, combined with the individualized home-use context, restored a high level of practicality.

TABLE 1. *Summary of expert validation results*

Validator	Aspects Assessed	Average Score (%)	Category
Material Experts (n = 2)	Content accuracy, curricular alignment, language, instructional design	83.50	Very Feasible
Media Experts (n = 2)	Visual design, interactivity, navigation, technical performance	89.00	Very Feasible

TABLE 2. *Summary of practicality testing results*

Testing Stage	n	Average Score (%)	Category
One-to-one evaluation	3	87.88	Very Practical
Small-group evaluation	5	78.86	Practical
Field trial	11	87.50	Very Practical

TABLE 3. *Summary of parental perception results*

Construct	Average Score (%)	Category
Overall perception	78.45	Positive
Parental support	81.82	Very Positive
Student motivation	80.00	Positive
Independent learning	73.81	Positive

TABLE 4. *Summary of pretest–posttest mathematics achievement*

Measure	Pretest	Posttest	Gain
Mean Score	7.00	8.18	+1.18
Student showing improvement	-	-	81.8% (9/11)

Parental Perception of Home Implementation

Because the field trial required students to use Edumatika.id independently at home for one week under parental supervision, parents of the 11 field-trial students completed a perception questionnaire addressing the overall quality of home implementation and three specific sub-constructs: parental support, student motivation, and independent learning. As summarized in Table 3, parents reported an overall positive perception of 78.45%, with parental support rated highest at 81.82%, followed by student motivation at 80.00%, and independent learning rated comparatively lowest at 73.81%. These results indicate that while parents generally viewed the home implementation of Edumatika.id favorably, their perception of the quality of support they provided (81.82%) and their children's motivation to engage with the platform (80.00%) was notably higher than their perception of their children's ability to learn independently (73.81%). This gap of roughly 7–8 percentage points suggests that although Edumatika.id was successful in sustaining children's interest and eliciting active parental involvement, Grade II students still required a degree of parental guidance or prompting during home use rather than working through the material entirely on their own consistent with the developmentally expected limits of self-regulated learning at this age.

Effect on Students' Mathematics Learning Outcomes

Students' mathematics achievement was measured before and after the one-week field trial using a pretest–posttest design. As shown in Table 4, students' mean achievement score increased from 7.00 at pretest to 8.18 at posttest, an average gain of 1.18 points. Of the 11 students who participated in the field trial, 81.8% (equivalent to 9 out of 11 students) demonstrated an increase in their score from pretest to posttest, while the remaining students showed no meaningful change. Based on conventional classification of normalized gain scores ($g < 0.3$ = low; $0.3 \leq g < 0.7$ = moderate; $g \geq 0.7$ = high), this N-gain value of approximately 0.39 falls within the moderate category. This indicates that, relative to the maximum room for improvement available to students, the one-week independent use of Edumatika.id produced a meaningful, though not maximal, improvement in mathematics achievement an encouraging result given the short duration of the intervention and the fully independent, home-based nature of its implementation.

Taken together, the results indicate that Edumatika.id met the criteria of validity, established through consistently very feasible expert judgments (83.50% material;

89.00% media); practicality, established through practical to very practical scores across all three testing stages (78.86–87.88%); positive parental reception of home implementation (78.45% overall), albeit with a discernible gap between perceived parental support/motivation and perceived student independence; and effectiveness, established through a statistically meaningful improvement in mathematics achievement (pretest M = 7.00 to posttest M = 8.18; moderate N-gain ≈ 0.39; 81.8% of students improving). These converging results support the conclusion that Edumatika.id is a valid, practical, and promising medium for supporting Grade II elementary students' mathematics learning both at school and independently at home.

DISCUSSION

The present study set out to develop, validate, and empirically test Edumatika.id, a web-based interactive mathematics e-Worksheet for Grade II elementary school students, using the ADDIE model as a systematic developmental framework. Four converging lines of evidence expert validation, staged practicality testing, parental perception of home implementation, and pretest–posttest achievement data collectively indicate that Edumatika.id is a valid, practical, and moderately effective medium for supporting early mathematics learning both at school and independently at home. This discussion interprets these findings in relation to the broader literature on interactive e-Worksheets, immediate feedback, gamification, three-dimensional visualization, parental involvement, and children's self-regulated learning, and considers the implications, limitations, and future directions that follow from these results.

The very feasible ratings obtained from both material experts (83.50%) and media experts (89.00%) support the contention that a systematically designed digital mathematics tool can meet rigorous content and technical standards simultaneously. The slightly higher score awarded to the technical and visual dimensions of Edumatika.id is consistent with a growing body of research suggesting that interactivity, immersive visualization, and virtual-agent-supported feedback are the features most readily recognized as high quality by both experts and learners (Chen et al., 2026; Kim & Baylor, 2016). Chen et al. (2026), for instance, demonstrated that a situation-based interactive e-book embedding real-world scenarios and virtual agents produced significant gains in first-grade students' learning achievement, motivation, and satisfaction relative to a video-based control condition, a pattern that mirrors the strong media-related validation obtained in the present study. Similarly, Kim and Baylor's (2016) review of pedagogical agent design underscores that well-designed virtual agents can meaningfully strengthen the perceived instructional quality of a digital learning environment, which may explain why Edumatika.id's media dimension was rated marginally higher than its instructional-content dimension. At the same time, the comparatively lower material expert score suggests that content depth and curricular alignment remain the more demanding dimension to perfect in digital mathematics resources, a tension also noted in reviews of GeoGebra-based and other dynamic mathematics tools, where visual and interactive affordances are often easier to implement convincingly than pedagogically complete content sequencing (Radović et al., 2020; Kaplar et al., 2021). This is an important nuance: technological sophistication does not automatically guarantee curricular depth, and developers of similar e-Worksheets should be cautious not to let visual polish substitute for careful instructional design. The use of the ADDIE model in this study, following the systematic five-phase structure described by Branch (2010) and operationalized in numerous recent digital-learning development studies (Güler et al., 2023; Trust & Pektas, 2018), appears to have provided an adequate structural safeguard against this risk, since expert feedback was solicited iteratively during the Development phase prior to any student-facing testing.

The practicality results offer an instructive pattern that resonates with prior usability research on digital learning tools used in group versus individual contexts. The

dip observed during small-group testing is plausibly attributable to peer-interaction frictions such as turn-taking on shared devices, social comparison, or distraction, phenomena that have also been documented in studies of gamified and collaborative digital learning environments for children (Kamalodeen et al., 2021). Kamalodeen et al. (2021) similarly found that gamification elements designed for individual progression could create minor friction when multiple children interacted with the same digital resource simultaneously, yet these effects tended to diminish once children returned to individualized use. The recovery of practicality scores to 87.50% in the field trial, where each child used Edumatika.id independently at home, is therefore consistent with the broader pattern that digital mathematics tools designed around individualized feedback loops perform best precisely when learners can proceed at their own pace without competing peer demands (Dai et al., 2025; Tokac et al., 2019). This pattern also aligns with meta-analytic evidence on digital game-based learning in K–12 mathematics, which has repeatedly found that game-based and interactive digital tools yield the strongest achievement and motivational effects when implementation fidelity is high and the learning context supports sustained, self-paced engagement (Byun & Joung, 2018; Hussein et al., 2022). Byun and Joung's (2018) meta-analysis of digital game-based learning for K–12 mathematics found a generally positive, though heterogeneous, effect on achievement across studies, with implementation context identified as a key moderating variable—an observation directly relevant to the contextual shift documented between the small-group and field-trial phases of the present study.

Perhaps the most conceptually significant finding of this study is the pattern observed in parental perception data: parental support (81.82%) and student motivation (80.00%) were both rated more favorably than student independent learning (73.81%). This roughly seven-to-eight-point gap is not an isolated anomaly; it mirrors a persistent and well-documented tension in the literature on parental involvement in children's digital learning. Parental involvement has long been recognized as a robust predictor of academic outcomes across a wide range of contexts (Boonk et al., 2018; Yu et al., 2022), yet the nature of that involvement changes substantially when the learning activity shifts from a physical classroom to a home-based digital environment. Silinskas and Kikas (2019) found that the quality and manner of parental involvement in mathematics homework was more strongly associated with children's performance and motivation than mere involvement frequency, suggesting that how parents scaffold digital mathematics practice may matter more than whether they are present at all. This nuance helps to explain why Edumatika.id's parents reported strong perceived support and motivation, even as their perception of their children's independent learning capacity lagged behind. Systematic reviews of technology-mediated parental engagement similarly report that while parental engagement generally correlates positively with student outcomes, the translation of parental presence into genuine child autonomy is neither automatic nor guaranteed (See et al., 2020). More recent syntheses focused specifically on elementary-level digital learning reinforce this point: parental involvement in digital learning during elementary education has been characterized in the literature as encompassing an expanded set of roles precisely because young children in this age range are not yet expected to self-regulate fully in digital environments (Li et al., 2025). This is consistent with Gonzalez-DeHass et al.'s (2022) discussion of how the shift toward home-based digital learning has required parents to take on unfamiliar scaffolding roles that were previously the domain of teachers, and with Amelia et al.'s (2023) finding that active maternal involvement substantially shapes the quality of children's at-home digital learning experience. The present results thus extend this literature by showing that even a well-designed, expert-validated, and practically sound e-Worksheet cannot by itself eliminate the developmental reality that Grade II students who are approximately seven to eight years old require ongoing parental scaffolding to translate platform engagement into fully independent learning behavior.

This interpretation gains further support from research on children's self-regulated learning (SRL) in digital and hypermedia environments. Torrington et al. (2022) observed that elementary students working independently in an open hypermedia environment spent the overwhelming majority of their time on basic cognitive strategies such as reading and summarizing, while allocating strikingly little time to planning or monitoring their own learning both of which are core markers of effective self-regulation. Zimmerman's (2002) foundational account of self-regulated learning likewise emphasizes that the capacity to plan, monitor, and evaluate one's own learning develops gradually and is rarely fully formed in early elementary-aged children without external scaffolding. Taken together, these findings suggest that the comparatively lower independent-learning score reported by parents in the present study is not a design flaw specific to Edumatika.id, but rather reflects a broader and well-established developmental constraint that any home-based digital mathematics tool for this age group must anticipate rather than assume away.

The improvement in students' mathematics achievement from a pretest mean of 7.00 to a posttest mean of 8.18, with 81.8% of students showing gains and a moderate N-gain of approximately 0.39 provides converging evidence that the integrated feature set of Edumatika.id translated into measurable learning benefit, even over a comparatively brief one-week intervention period. This result is broadly consistent with experimental evidence on the achievement effects of immediate, task-adaptive feedback in digital learning tools. Faber et al. (2017) found that a digital formative assessment tool providing immediate, task-adaptive feedback produced significant gains in both mathematics achievement and student motivation relative to business-as-usual instruction, and Faber and Visscher (2018) subsequently replicated a similar pattern for spelling achievement, reinforcing the generalizability of immediate feedback as an achievement-enhancing mechanism across academic domains. The feedback-classification literature offers a further explanatory lens: Maier and Klotz (2022) argue that personalized, well-timed feedback is among the most consistently effective design features in digital learning environments, yet note that many existing tools still lack well-structured feedback loops a gap that Edumatika.id's automated formative feedback mechanism appears to have addressed directly. Deeva et al. (2021) reach a parallel conclusion in their review of automated feedback systems, observing that although feedback is one of the most powerful levers for improving digital learning outcomes, frameworks for its systematic implementation remain underdeveloped in much of the existing e-Worksheet landscape.

The gamified and three-dimensional visualization components of Edumatika.id likely contributed additional achievement benefit beyond feedback alone. Sailer and Homner's (2020) meta-analysis found significant, if modest, positive effects of gamification on cognitive, motivational, and behavioral learning outcomes, and more recent meta-analytic work by Dai et al. (2025) found a medium positive effect of gamified learning on student outcomes overall, with certain combinations of game elements such as clear rules and goals paired with challenge yielding the strongest gains. Applied specifically to elementary mathematics, Hussein et al. (2022) similarly concluded that digital game-based learning approaches have produced measurable improvements in K–12 mathematics achievement across a range of implementations, while Tokac et al. (2019) reported a comparable pattern in their meta-analysis of game-based learning and mathematics achievement. The three-dimensional visualization elements of Edumatika.id find further support in Yohannes et al.'s (2023) study, which found that middle school students' spatial ability and mathematics reading comprehension improved after exposure to an interactive e-book incorporating three-dimensional visual content, suggesting that visualization-rich digital tools can support conceptual understanding across a range of age groups, including the younger population examined here. It is also worth situating the moderate (rather than high) N-gain within the existing literature on short-duration digital mathematics interventions. Zhao et al. (2021) found that gamified interactive e-books produced significant gains in flipped mathematics learning performance, motivation, and

metacognitive tendency, but cautioned that the magnitude of achievement gains was sensitive to intervention duration and the degree of curricular alignment. Given that the field trial in the present study spanned only one week, the moderate N-gain of 0.39 can reasonably be interpreted as an encouraging early signal rather than a ceiling estimate of Edumatika.id's potential impact; longer-duration implementations documented in comparable interactive e-book studies have tended to report larger cumulative gains (Chen et al., 2024).

Beyond raw achievement gains, the design logic of Edumatika.id may also address the well-documented affective barriers that undermine early mathematics learning. Math anxiety has been shown to emerge early in schooling and to be reciprocally related to achievement, such that early difficulty and early anxiety reinforce one another over time (Szczygieł et al., 2024; Sorvo et al., 2022). Elementary teachers' own math anxiety has similarly been found to relate to students' math learning and achievement, both directly and through modeled attitudes toward the subject (Schaeffer et al., 2021; Ramirez et al., 2018), while intergenerational research indicates that parents' math anxiety can be transmitted to children through help-seeking and home-support interactions (Maloney et al., 2015). Executive function research further suggests that math anxiety and cognitive load interact in ways that can depress performance among elementary and middle school students specifically (Živković et al., 2022). Against this backdrop, the game-based, low-stakes, immediately responsive design of Edumatika.id featuring points, progression, and non-punitive corrective feedback plausibly reduced some of the affective friction that might otherwise accompany a purely test-like assessment format, a mechanism consistent with findings that interactive e-books using motivational design frameworks can reduce measured mathematics anxiety even as they improve achievement.

The cross-device accessibility of Edumatika.id also merits discussion in light of the broader movement toward flexible, technology-enhanced mathematics instruction. Reviews of flipped and technology-enhanced mathematics classrooms have found that meta-analytic effects on achievement are generally positive but are moderated by the extent to which digital tools are genuinely optimized for the devices and contexts in which students actually use them (Güler et al., 2023). Similarly, work on multimedia and interactive storybooks has shown that the benefits of interactivity are neither automatic nor unconditional; Takacs et al.'s (2015) meta-analysis found that certain interactive features can enhance comprehension and engagement while others particularly those that are poorly integrated with content can distract from learning. This body of evidence underscores that Edumatika.id's integration of interactivity, visualization, gamification, and feedback within a single, coherent, cross-device platform, rather than as disconnected add-ons, is likely a meaningful contributor to its favorable practicality and achievement results, and addresses a gap explicitly identified in prior reviews of digital parenting and technology-mediated learning tools, which have called for more integrated rather than fragmented digital learning designs (Tan et al., 2024).

Several limitations temper the generalizability of these findings. The small sample sizes at each testing stage, particularly the field trial (n = 11), limit statistical power and the precision of the achievement effect estimate; larger-scale replications, ideally with randomized or quasi-experimental control conditions, would strengthen causal claims about Edumatika.id's effectiveness relative to conventional e-Worksheets or printed alternatives. The one-week duration of the field trial, while sufficient to detect a moderate short-term gain, cannot speak to the durability of these gains or to whether the observed motivation and independent-learning patterns would change over a longer implementation period; longitudinal designs following students across a full semester or academic year would help clarify whether the independent-learning gap narrows as children become more familiar with the platform, consistent with developmental trajectories described in self-regulated learning research (Zimmerman, 2002). Future studies might also incorporate direct behavioral or log-data measures of self-regulation such as time-on-task, help-seeking patterns, or navigation choices rather than relying

solely on parental perception reports, given known limitations in parents' ability to observe and accurately characterize their children's internal cognitive processes during independent digital learning (Torrington et al., 2022).

Overall, the pattern of results obtained for Edumatika.id very feasible expert validation, practicaltoverypractical usability scores, generally positive though unevenly distributed parental perceptions, and a moderate but meaningful improvement in mathematics achievement coheres closely with an extensive and converging body of research on immediate feedback, gamification, interactive ebooks, threedimensional visualization, parental involvement, and children's selfregulated learning in digital environments. These findings suggest that Edumatika.id successfully closes part of the gap identified in the introduction between what educational technology research recommends and what is typically implemented in existing eWorksheets, while also revealing that certain challenges remain an enduring feature of homebased digital mathematics education rather than a deficiency unique to this particular product.

CONCLUSION

This study aimed to develop, validate, and empirically evaluate Edumatika.id, a web-based interactive mathematics e-Worksheet for Grade II elementary school students, using the ADDIE model as a systematic developmental framework. The findings demonstrate that Edumatika.id is a valid, practical, and promising medium for supporting elementary mathematics learning both at school and independently at home. Expert validation confirmed that the product was very feasible from both a content perspective (83.50%) and a media/technical perspective (89.00%), indicating that the integration of interactive materials, three-dimensional visualization, game-based exercises, and immediate formative feedback was executed to a high standard of instructional and technical quality. Practicality testing across three sequential stages—one-to-one evaluation (87.88%), small-group evaluation (78.86%), and field trial (87.50%) showed that Edumatika.id was consistently practical to very practical, with the temporary dip observed during small-group testing recovering fully once students used the platform individually at home, suggesting that the product is particularly well suited to independent, self-paced use. Parents reported an overall positive perception of home implementation (78.45%), with especially strong ratings for parental support (81.82%) and student motivation (80.00%), though independent learning was rated comparatively lower (73.81%), reflecting a gap between children's engagement with the platform and their capacity to work through it entirely unaided. Finally, students' mathematics achievement improved meaningfully from pretest ($M = 7.00$) to posttest ($M = 8.18$), with 81.8% of students showing gains and a moderate N-gain of approximately 0.39, indicating that even a short, one-week home-based implementation produced a measurable improvement in learning outcomes. Taken together, these results confirm that Edumatika.id addresses a genuine gap in the existing e-Worksheet landscape by integrating features that are typically studied and implemented in isolation within a single, coherent, cross-device-accessible platform explicitly designed for, and validated in, an authentic home-based learning context.

Despite these encouraging results, several limitations should be acknowledged. The number of participants involved at each stage of testing was small, particularly in the field trial ($n = 11$), which limits the statistical power of the achievement analysis and constrains the generalizability of the findings to broader populations of Grade II students. The field trial was also limited to a single one-week implementation period, which, while sufficient to detect a moderate short-term achievement gain, cannot establish whether these gains are retained over time or whether the observed patterns of parental support, motivation, and independent learning would shift with more prolonged exposure to the platform. In addition, this study did not include a control group using a conventional or printed worksheet, which limits the strength of causal claims that can be made about the specific contribution of Edumatika.id's interactive features relative to standard instructional

practice. Finally, data on students' independent learning and self-regulation were derived solely from parental perception questionnaires, which, however informative, are inherently subject to observational limitations and may not fully capture children's actual cognitive and behavioral processes during unsupervised platform use.

Future research should therefore pursue larger-scale, quasi-experimental or randomized controlled studies involving greater numbers of participants and an explicit comparison group, in order to more rigorously establish the causal effectiveness of Edumatika.id relative to conventional e-Worksheets. Longitudinal designs extending implementation across a full semester or academic year would help determine whether the achievement gains observed here are sustained, and whether the gap between parental-perceived motivation/support and independent learning narrows as children gain familiarity with the platform. Future studies would also benefit from incorporating objective behavioral or log-data measures of self-regulation to complement and validate parental perception data. Further research might also examine how Edumatika.id performs across other grade levels and mathematical topics, explore the specific contribution of each individual feature (feedback, gamification, three-dimensional visualization) through dismantling or factorial designs, and investigate strategies for actively strengthening children's independent learning capacity during home-based digital mathematics instruction, such as embedded self-monitoring prompts or parent-guidance modules designed to gradually reduce the level of external scaffolding required.

ACKNOWLEDGMENTS

The authors thank the material and media experts for validating the Edumatika.id prototype, and the Grade II students and their parents for their participation in the one-to-one, small-group, and field trial stages. Appreciation is also extended to the participating elementary school for granting permission and facilities, and to Universitas PGRI Madiun for its institutional support throughout this study.

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