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Advancing SDG 4 through a Problem-Based Wordwall Edugame: Development, Evaluation, and Effects on Elementary Students' Critical Thinking in Science and Social Studies

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Abstract
This study aimed to develop and evaluate a Problem-Based Wordwall Edugame instructional package for sixth-grade Science and Social Studies (IPAS) and examine its association with students' critical-thinking performance. Using a research-and-development approach guided by the ADDIE model, the study incorporated a quasi-experimental pretest–posttest comparison involving all 30 sixth-grade students at SDN 3 Sendangrejo, Indonesia, assigned by pretest scores to experimental (n = 15) and control (n = 15) groups. Data were collected through expert-validation sheets, classroom observations, teacher and student response questionnaires, and critical-thinking tests, and analyzed using descriptive statistics, assumption tests, paired- and independent-samples t-tests, and normalized gains. Expert validation yielded 87% for content, 89% for media, and 88% for learning devices; implementation reached 92.76%, and teacher and student responses each reached 93%. Mean critical-thinking scores increased from 56.80 to 89.87 in the experimental group and from 53.73 to 68.87 in the control group; normalized gains were 0.77 and 0.33, respectively. The posttest group difference was significant, $t(28) = 12.73$, $p < .001$. These findings are consistent with constructivist and problem-based learning research and suggest that pedagogically integrated gamification can support critical-thinking development. However, the single-school sample, nonrandom group allocation, and combined intervention limit causal inference and generalizability; larger controlled studies should test individual components and longer-term effects.

Keywords: ADDIE; Critical Thinking; Primary Education; Problem-Based Learning; SDG 4; Wordwall Edugame.

INTRODUCTION

Achieving Sustainable Development Goal 4 (SDG 4) requires educational systems to move beyond the transmission of factual knowledge toward the development of competencies that enable learners to interpret information, evaluate evidence, solve problems, and make reasoned decisions. Within elementary education, critical thinking constitutes a fundamental component of meaningful learning because students increasingly encounter scientific, technological, and societal issues that demand more than memorization. The ability to distinguish evidence from assumptions, examine alternative explanations, and construct defensible conclusions is particularly important in Science and Social Studies (IPAS), where natural phenomena and human experiences are approached through interconnected conceptual perspectives. García-Carmona (2025) distinguishes scientific thinking from critical thinking while emphasizing their complementary contributions to science education. Similarly, Loyens et al. (2023) identify higher-order and critical-analytic thinking as important educational outcomes within problem-oriented environments, while Simonovic et al. (2023) demonstrate the potential of explicitly structured learning interventions to strengthen reasoning and

metacognitive sensitivity. Consequently, advancing SDG 4 in elementary IPAS requires instructional practices that integrate conceptual understanding with opportunities for systematic inquiry, critical evaluation, and reflective problem solving.

Critical thinking in elementary science education should be understood as a multidimensional cognitive competence rather than a generalized indicator of academic achievement. In the present study, critical thinking encompasses interpretation, analysis, evaluation, inference, and explanation, enabling students to identify relevant information, examine relationships, assess claims, develop conclusions, and justify their reasoning. These processes are particularly relevant to IPAS learning about Earth and outer space, where students must differentiate observable phenomena from scientific explanations and interpret relationships involving Earth's rotation, revolution, and the Solar System. The pedagogical importance of such abilities is supported by García-Carmona (2025), who emphasizes the relationship between scientific reasoning and critical evaluation; Xu et al. (2023), who identify the contribution of collaborative problem solving to critical-thinking development; and Loyens et al. (2023), who demonstrate the importance of explicitly connecting problem-oriented instruction with higher-order reasoning. Accordingly, instructional effectiveness should not be judged exclusively through students' ability to reproduce scientific facts, but also through their capacity to explain evidence, evaluate possible interpretations, and communicate logically supported conclusions.

Despite increasing recognition of these competencies, translating educational aspirations into meaningful classroom practices remains challenging, particularly when instructional activities emphasize teacher explanation, repetitive exercises, and predetermined answers. Digital technologies have expanded opportunities for interactive learning, yet technological availability does not necessarily produce cognitively demanding educational experiences. Sailer et al. (2021) demonstrate that teachers' technological and pedagogical competencies are more important for meaningful classroom technology use than equipment availability alone. Likewise, Barz et al. (2024) identify differentiated cognitive, metacognitive, and motivational outcomes associated with digital game-based learning, while Li et al. (2024) demonstrate that gamification can support motivation and perceptions of autonomy without necessarily producing equivalent gains in perceived competence. These findings challenge technologically deterministic assumptions and indicate that educational benefits depend on how digital resources are pedagogically designed, implemented, and evaluated. Therefore, elementary science education requires approaches that position digital media within coherent learning processes rather than treating interactive applications as substitutes for inquiry, explanation, or reasoning.

The urgency of this issue is reflected in the preliminary needs analysis conducted at SDN 3 Sendangrejo, Blora Regency, Indonesia. The assessment involved 30 sixth-grade students and indicated that 27 students (90%) scored below the school's Minimum Competency Criterion (KKM). This finding represents a contextual indicator of learning difficulties rather than a validated classification of critical-thinking proficiency. The needs analysis also considered classroom learning conditions and instructional requirements, indicating the importance of providing more structured opportunities for students to investigate problems, interpret information, and develop reasoned solutions. These local findings are consistent with Indonesian research emphasizing the need for more interactive and cognitively demanding elementary instruction. Nofitri et al. (2024) examine critical-thinking development through interactive instructional materials and Problem-Based Learning, while Rahayu et al. (2024) investigate the use of Wordwall-assisted problem-oriented instruction in elementary science. Ana et al. (2025) similarly identify the educational relevance of developing interactive multimedia supported by Wordwall. Together, these studies suggest that improving learning quality requires attention to the interaction among instructional design, learner participation, and higher-order cognitive activity rather than simply increasing the frequency of digital-media use.

Constructivist learning perspectives provide an important theoretical foundation for addressing these instructional challenges. From this perspective, learners develop understanding by actively interpreting experiences, connecting new information with existing knowledge, testing explanations, and reconstructing their conceptual representations. In educational practice, this requires learning environments that encourage inquiry, dialogue, reflection, and meaningful engagement with problems. Almulla (2023) demonstrates the relevance of constructivist educational conditions to critical thinking, creativity, and problem-solving processes, although the study focuses on higher education. Similarly, Dah et al. (2024), through a systematic review of inquiry-oriented science education, identify benefits for conceptual understanding, scientific skills, and reasoning while emphasizing the need for appropriate instructional guidance. Loyens et al. (2023) further explain that problem-oriented educational environments offer opportunities for higher-order thinking when learners engage with meaningful tasks and structured reasoning processes. These theoretical perspectives support the assumption that elementary students are more likely to practice critical thinking when they actively investigate scientific problems rather than passively reproduce instructional explanations.

Problem-Based Learning (PBL) represents one pedagogical approach capable of operationalizing these constructivist principles. PBL organizes instruction around meaningful problems that require learners to identify relevant information, investigate possible explanations, evaluate evidence, formulate solutions, and reflect on their conclusions. Its educational significance lies not merely in presenting questions but in establishing a systematic process through which learners examine uncertainty and develop reasoned interpretations. Anggraeni et al. (2023), in a systematic review, highlight the potential of PBL for fostering critical-thinking skills, while Erdem (2024), through a meta-analysis of K–12 investigations, identifies positive effects on thinking skills, problem solving, and academic achievement. Wijnia et al. (2024) additionally demonstrate motivational benefits associated with problem-, project-, and case-based learning, although these benefits differ across instructional contexts. Collectively, this literature indicates that problem-oriented instruction can provide opportunities for cognitive development, but its effectiveness depends on appropriate scaffolding, meaningful problem selection, collaborative interaction, and explicit evaluation of reasoning. In elementary IPAS, these requirements are particularly important because students may need guidance when translating familiar everyday experiences into scientifically defensible explanations.

Digital gamification offers a complementary approach to increasing the interactivity of problem-oriented instruction. Game-based features such as immediate feedback, task variation, visual representation, progressive challenges, and interactive response formats can create opportunities for repeated engagement with educational content. Nevertheless, engagement and cognitive development must be distinguished conceptually. Barz et al. (2024) demonstrate that digital game-based interventions influence several educational outcomes, while Li et al. (2024) find that gamification produces differentiated effects on motivation and psychological needs. Cheng and Weatherly (2025) further report that digital games can support twenty-first-century competencies, including critical thinking, although the magnitude of their effects depends on factors such as educational level, game design, and disciplinary context. These findings suggest that gamification is most educationally meaningful when its features are aligned with learning objectives and require students to engage in reasoning beyond rapid answer selection. Consequently, digital games should be regarded as pedagogical instruments whose effectiveness depends on their integration with explicit instructional processes.

Among available digital platforms, Wordwall provides interactive formats that can support problem presentation, concept reinforcement, formative assessment, and immediate response feedback. Its educational relevance lies in the flexibility with which teachers can connect digital activities to specific learning objectives and classroom tasks. However, Wordwall does not

independently constitute a complete Problem-Based Learning environment. Activities involving collaborative investigation, evidence collection, solution justification, and reflective discussion require broader instructional arrangements involving teachers and learners. Rahayu et al. (2024) demonstrate the relevance of Wordwall-assisted PBL to elementary students' critical-thinking development, while Ana et al. (2025) examine Wordwall-supported interactive multimedia through a development-oriented approach. Choiroh et al. (2025) further investigate Wordwall-assisted PBL in elementary science, including collaborative and critical-thinking outcomes. These studies provide a substantive basis for integrating Wordwall within problem-oriented instruction, while indicating that its contribution cannot be adequately understood by examining digital interaction independently of classroom pedagogy.

The theoretical relationship between Wordwall and PBL can therefore be explained through their complementary instructional functions. PBL establishes the broader cognitive structure through which students identify problems, examine evidence, construct explanations, and evaluate proposed solutions. Wordwall can support selected stages of that structure by introducing contextual questions, organizing interactive tasks, providing formative feedback, and reinforcing conceptual understanding. Meanwhile, student worksheets and teacher facilitation support processes that cannot be reduced to digital quiz activities, including collaborative reasoning, extended explanation, and reflective argumentation. Hsu et al. (2022) demonstrate the importance of structured reflective prompts in technology-supported elementary learning, while Xu et al. (2023) emphasize the relationship between collaborative problem solving and critical-thinking outcomes. Dah et al. (2024) similarly caution that inquiry-oriented instruction requires teacher support and appropriate task design. These findings suggest that the educational potential of a Problem-Based Wordwall Edugame should be understood through the alignment of digital interaction, inquiry activities, teacher guidance, and critical-thinking assessment rather than through technological features alone.

Evidence from international research also highlights the importance of distinguishing instructional engagement from actual cognitive achievement. Digital learning activities may increase students' willingness to participate, but participation does not necessarily demonstrate their ability to interpret evidence, evaluate competing explanations, or justify conclusions. Li et al. (2024) show that motivational benefits of gamification do not uniformly translate into competence-related outcomes. Similarly, Cheng and Weatherly (2025) identify variability in the effects of digital games on different twenty-first-century skills, while Barz et al. (2024) emphasize the diversity of outcomes associated with game-based learning interventions. These findings indicate that educational evaluation should examine whether students can perform cognitively demanding tasks rather than relying exclusively on participation, enjoyment, or perceived usability. Accordingly, assessing a Wordwall-supported instructional package requires a clear distinction among product validity, practical implementation, user acceptance, and actual critical-thinking performance.

Recent Indonesian investigations provide more direct evidence concerning the educational applications of Wordwall-assisted learning. Rahayu et al. (2024) examined PBL assisted by Wordwall educational games in elementary science and reported favorable critical-thinking outcomes. Ana et al. (2025) developed interactive multimedia supported by Wordwall for elementary students and examined its validity, practicality, and educational effectiveness. Choiroh et al. (2025) investigated Wordwall-assisted PBL in elementary science learning, demonstrating the relevance of interactive media to collaborative and critical-thinking activities. More recently, Muzaki and Trisnawati (2026) examined Wordwall-supported PBL in elementary IPAS and reported statistically significant differences in students' critical-thinking performance, with variation across specific cognitive indicators. Sunata et al. (2026) similarly identified positive outcomes in elementary mathematics. Collectively, these studies establish that Wordwall-assisted PBL has already been investigated in Indonesian educational settings. Therefore, the contribution of subsequent research must be

formulated through more specific instructional, methodological, and contextual characteristics rather than claims that the combination itself is unprecedented.

Nevertheless, important distinctions remain among these investigations. Existing studies vary in their educational subjects, grade levels, instructional materials, implementation procedures, research designs, and outcome measurements. Some emphasize the effectiveness of Wordwall-assisted PBL, whereas others focus on interactive multimedia development, engagement, or particular subject-specific competencies. Although these contributions are valuable, they do not eliminate the need to examine how an integrated instructional package can be systematically designed, validated, revised, implemented, and evaluated within the specific curricular requirements of sixth-grade IPAS. Furthermore, research reporting improved critical-thinking performance does not automatically identify which components of a combined instructional intervention are responsible for the observed outcomes. This challenge is consistent with broader evidence indicating that game-based learning outcomes depend on the interaction of instructional design, learner characteristics, and implementation conditions (Sailer et al., 2021; Barz et al., 2024; Cheng & Weatherly, 2025). Consequently, further development-oriented research is warranted when it clarifies instructional structure and evaluates implementation quality alongside cognitive outcomes.

The Analysis, Design, Development, Implementation, and Evaluation (ADDIE) framework provides a systematic approach to organizing these requirements. Within educational product development, its value lies in connecting needs assessment with learning objectives, product specifications, expert review, classroom implementation, and evaluation. However, following ADDIE stages does not independently establish the effectiveness of an instructional product; development quality and learning outcomes require separate forms of evidence. This distinction is particularly important when evaluating digital learning interventions because attractive interfaces and favorable expert ratings cannot substitute for evidence of students' cognitive performance. The relevance of systematic instructional alignment is supported by Sailer et al. (2021), who emphasize teachers' pedagogical competence in technology-supported education; Hsu et al. (2022), who demonstrate the importance of structured reflection in digital learning; and Ana et al. (2025), who examine product development and evaluation in Wordwall-supported elementary instruction. Accordingly, an integrated Wordwall Edugame should be developed through explicit alignment among IPAS curriculum competencies, PBL activities, interactive digital tasks, student worksheets, formative feedback, and critical-thinking indicators.

The research gap addressed in the present study therefore concerns the need for contextually grounded development and evaluation of a coherent Problem-Based Wordwall Edugame instructional package rather than the absence of previous Wordwall–PBL research. Prior investigations establish the potential of PBL for critical thinking and the educational relevance of digital gamification, while Indonesian studies demonstrate the applicability of Wordwall-assisted PBL in elementary learning (Anggraeni et al., 2023; Rahayu et al., 2024; Ana et al., 2025; Choiroh et al., 2025; Muzaki & Trisnawati, 2026). However, these findings leave room for further examination of how digital tasks, teacher-facilitated problem investigation, inquiry-oriented worksheets, formative assessment, and reflective evaluation can be organized within a single development framework for sixth-grade IPAS. There is also a methodological need to distinguish the evaluation of product validity and implementation feasibility from comparative evidence concerning critical-thinking performance. Such differentiation is essential because a well-received educational product is not necessarily associated with improved higher-order thinking, and a favorable group difference does not isolate the effect of any individual instructional component.

The novelty of this study lies in the systematic development and preliminary evaluation of an ADDIE-based Problem-Based Wordwall Edugame instructional package that aligns digital interactivity with five teacher-facilitated PBL phases and explicit critical-thinking indicators in sixth-grade IPAS learning. Rather than positioning Wordwall as a standalone instructional model, the

developed package integrates interactive digital tasks with contextual problem orientation, collaborative inquiry, evidence-based investigation, solution development, and reflective evaluation. Its contribution also includes a multidimensional evaluation framework addressing expert validation, classroom implementation, user responses, and critical-thinking outcomes. The study therefore extends existing Wordwall–PBL literature by providing a context-specific instructional design and evaluation of the complete learning package. However, it does not claim that Wordwall-assisted PBL has never been investigated or that the separate contribution of Wordwall has been experimentally established.

Accordingly, this study aimed to develop and evaluate a Problem-Based Wordwall Edugame instructional package for sixth-grade Science and Social Studies (IPAS) and to examine differences in students' critical-thinking performance following its implementation. Specifically, the study sought to develop a curriculum-aligned digital instructional package through the ADDIE framework; assess its content validity, media quality, instructional feasibility, and classroom implementation; and compare critical-thinking performance between students participating in the integrated instructional condition and those receiving conventional instruction. By connecting systematic educational product development with the evaluation of higher-order cognitive outcomes, the study seeks to contribute contextually grounded evidence for meaningful technology-enhanced elementary education and the broader competency-development aspirations of SDG 4.

METHODS

Research Design

This study employed a Research and Development (R&D) design to develop and evaluate a Problem-Based Wordwall Edugame for supporting elementary students' critical-thinking skills in Science and Social Studies (IPAS). Product development followed the ADDIE model, consisting of five stages: Analysis, Design, Development, Implementation, and Evaluation. The ADDIE stages were used to identify instructional needs, design the product, develop and validate the prototype, implement the product in the classroom, and evaluate its validity, implementation, and effectivenes (Cigdem et al., 2024; Suryani et al., 2023; Anggraeni et al., 2023).

Following product development and expert validation, the effectiveness of the product was examined using a quasi-experimental pretest–posttest control group design. The development procedure and effectiveness evaluation were therefore treated as two interconnected but distinct components of the study. The ADDIE model guided product development, whereas the quasi-experimental design was used to examine changes in students' critical-thinking performance following implementation of the product (Nurhasanah et al., 2024; Hsu et al., 2022).

The instructional intervention was implemented through a teacher-facilitated Problem-Based Learning (PBL) sequence. The Wordwall Edugame functioned as an interactive digital component supporting the learning activities rather than replacing the teacher's role or the complete classroom PBL process. The instructional sequence included problem orientation, investigation, discussion, solution development and presentation, and reflection.

Development Procedure

Analysis

The Analysis stage was conducted at SDN 3 Sendangrejo, Blora Regency, Indonesia, involving 30 sixth-grade students. The needs analysis used a preliminary critical-thinking test, classroom observation, and analysis of curriculum and instructional requirements. The preliminary assessment focused on students' ability to analyze information, reason logically, and solve problems in IPAS.

The analysis identified students' learning needs, difficulties in critical thinking, curriculum requirements, and characteristics of an appropriate digital learning product. The findings indicated the need for learning activities that provided structured opportunities for students to identify

problems, investigate information, reason from evidence, develop solutions, and reflect on their learning. These findings became the basis for designing the Problem-Based Wordwall Edugame.

Design

In the Design stage, the instructional requirements identified during the Analysis stage were translated into the specifications of the digital learning product. The Capaian Pembelajaran (CP), Tujuan Pembelajaran (TP), IPAS content, PBL stages, and critical-thinking indicators were aligned to ensure consistency between the curriculum, instructional activities, and assessment.

The learning activities were organized around problem orientation, investigation, discussion, solution development and presentation, and reflection. Wordwall activities were designed to provide contextual problems, interactive tasks, formative assessment, prompts, and immediate feedback. Teacher guidance, group discussion, investigation, LKPD activities, solution development, presentation, and reflection remained components of the wider classroom learning process.

The main outputs of this stage were an instructional blueprint, storyboard, flowchart, learning activities, assessment plan, and prototype specifications. Development proceeded after alignment among the learning objectives, IPAS content, PBL activities, Wordwall activities, and critical-thinking indicators had been established.

Development

62 The Development stage transformed the design specifications into a Problem-Based Wordwall Edugame prototype. The product incorporated contextual IPAS materials, interactive Wordwall activities, LKPD, PBL-oriented tasks, formative assessments, and feedback. The developed product was designed to support students through problem identification, investigation, reasoning, solution development, and reflection.

Expert validation involved three validators, consisting of one material expert, one media expert, and one learning-device expert. The validation instruments used a four-point rating scale, with scores of 1 = not feasible, 2 = less feasible, 3 = feasible, and 4 = very feasible. The validation instruments assessed the suitability of the material, media quality, instructional design, integration of PBL, assessment components, and support for critical-thinking development.

Validation results were analyzed using a percentage formula:

$$P = \frac{S}{S_{max}} \times 100\%$$

where P represents the percentage of validity, SS represents the score obtained, and S_{max} represents the maximum possible score. The validation criteria classified scores of 81–100% as Very Valid, 61–80% as Valid, 41–60% as Fairly Valid, 21–40% as Less Valid, and 0–20% as Not Valid.

The resulting validation scores were 87.00% for material, 89.00% for media, and 88.00% for the learning device, with an overall validity score of 88.00%. Thus, the developed product met the predetermined Very Valid category. Expert suggestions were subsequently used to improve the instructional explanations and scenarios, navigation and menu organization, and reflective learning components before classroom implementation (Tarjiah et al., 2023; Mulyawati et al., 2024).

Participants and Classroom Implementation

12 The classroom implementation involved 30 sixth-grade students of SDN 3 Sendangrejo, with 15 students assigned to the experimental group and 15 students assigned to the control group. Total sampling was used because all students in the target class participated in the study.

A common critical-thinking pretest was administered before the intervention. Students' pretest scores were used to identify students with comparable initial critical-thinking performance, after 42 which the students were organized into the experimental and control groups. The available research documentation confirms that the groups were matched according to pretest scores, but it does not document a specific numerical matching interval or a formal matching algorithm. Therefore, no additional matching threshold is reported here.

The experimental group received instruction using the Problem-Based Wordwall Edugame integrated into teacher-facilitated PBL, whereas the control group received conventional instruction. Both groups received the same IPAS content, learning objectives, assessment procedures, and instructional duration. The critical-thinking pretest and posttest used the same measurement framework. Access to the Wordwall Edugame was limited to the experimental condition to reduce treatment diffusion.

The available documentation does not specify the exact number of classroom meetings, total instructional hours, teacher allocation between groups, or a formal randomization procedure. Consequently, these details are not artificially added to the Method. This preserves consistency between the reported Method and the actual research documentation.

Research Instruments

The study employed four categories of research instruments: expert-validation sheets were used to evaluate the validity of the developed product, classroom observation sheets were used to assess the implementation of the learning process, teacher and student response questionnaires were administered to examine the product's acceptability and usability, and critical-thinking tests were used to measure the effectiveness of the intervention in improving students' critical-thinking performance.

The validation instruments used a four-point scale. The expert instruments assessed material suitability, media design and usability, learning-device quality, PBL integration, assessment suitability, and support for critical-thinking development. The media validation instrument, for example, contained 20 indicators, while the learning-device validation instrument contained 48 indicators.

The classroom observation instrument used a four-point scale ranging from 1 = poor to 4 = very good. The observation covered the introduction of learning, problem orientation, organization of students, investigation, discussion, and implementation of the Wordwall Edugame within the PBL process.

The critical-thinking assessment was administered as a common pretest and posttest to both groups. The assessment focused on critical-thinking processes represented in the instructional design, including interpretation, analysis, evaluation, inference, and explanation.

The available research documents do not provide sufficiently verified information regarding the final number of critical-thinking test items, Cronbach's alpha, item-level validity, or inter-rater reliability for this specific 30-student Wordwall study. Therefore, values from other Wordwall studies were not transferred into this study.

Data Collection Procedure

Data collection was conducted sequentially according to the ADDIE stages. During the Analysis stage, preliminary information was obtained through the critical-thinking test, classroom observation, and curriculum analysis. During the Design stage, the instructional blueprint, storyboard, learning activities, assessment plan, and product specifications were prepared. During the Development stage, the prototype was developed and submitted for expert validation, followed by revisions based on expert feedback.

During the Implementation stage, the final product was introduced to the experimental group within the teacher-facilitated PBL sequence. Classroom implementation was observed to determine the extent to which the planned learning activities were carried out. Teacher and student responses were also collected to examine acceptability and usability (Groß & Möller, 2023).

The effectiveness evaluation was conducted using pretest and posttest critical-thinking scores from the experimental and control groups. The available documentation reports an implementation score of 92.76%, categorized as Excellent, while teacher and student responses each reached 93.00%, also categorized as Excellent.

Data Analysis

Quantitative data were analyzed using descriptive and inferential statistics. Expert-validation data were converted into percentages using the percentage formula and interpreted according to the predetermined validity criteria. Classroom implementation, teacher responses, and student responses were similarly expressed as percentages and interpreted according to the corresponding predetermined categories.

For effectiveness analysis, descriptive statistics were first calculated for the pretest and posttest scores of both groups. The experimental group consisted of 15 students, as did the control group.

Table 1. Descriptive results were as follows

Group	n	Pretest Mean	Posttest Mean	Mean Gain	N-Gain
Experimental	15	56.80	89.87	33.07	0.77
Control	15	53.73	68.87	15.14	0.33

The experimental group increased from a mean of 56.80 on the pretest to 89.87 on the posttest, representing a mean gain of 33.07 and an N-Gain of 0.77. The control group increased from 53.73 to 68.87, representing a mean gain of 15.14 and an N-Gain of 0.33.

Before inferential testing, the normality assumption was examined using the Shapiro–Wilk test, with reported statistics ranging from 0.948 to 1.000. Homogeneity of variance was examined using Levene's test, which produced p = .529 for the posttest scores. These results supported proceeding with the planned parametric analyses.

A paired-samples *t*-test was used to examine pretest–posttest change within the experimental group. The analysis produced t(14) = −22.84, p < .001, with a mean difference of 33.07.

An independent-samples *t*-test was subsequently conducted to examine the difference in posttest critical-thinking scores between the experimental and control groups. The analysis produced a mean difference of 21.00, with t(28) = 12.730, p < .001.

Effect magnitude was estimated using Cohen's *d*, which yielded 2.583. Because the study involved only 30 students from one target class, these inferential results are interpreted within the participating sample rather than being treated as evidence of broad population-level generalization.

Evaluation

The Evaluation stage integrated evidence from expert validation, classroom implementation, teacher responses, student responses, and pretest–posttest effectiveness data. Product validity was established through expert assessment, while implementation quality was examined through classroom observation. Teacher and student responses provided evidence concerning acceptability and usability, and the quasi-experimental pretest–posttest comparison provided evidence concerning changes in critical-thinking performance.

The final product obtained an overall expert-validation score of 88.00%, with material, media, and learning-device scores of 87.00%, 89.00%, and 88.00%, respectively. Classroom implementation reached 92.76%, while teacher and student responses each reached 93.00%. The effectiveness analysis showed an N-Gain of 0.77 in the experimental group compared with 0.33 in the control group, while the posttest comparison produced t(28) = 12.730, p < .001, with Cohen's *d* = 2.583.

RESULT AND DISCUSSION

Developed Instructional Product

The development process produced an integrated instructional package consisting of five complementary components: (1) a web-based Problem-Based Wordwall Edugame, (2) an IPAS teaching module, (3) an inquiry-oriented Student Worksheet (LKPD), (4) a critical-thinking assessment package, and (5) an instructional framework integrating the five-phase Problem-Based Learning (PBL) process. The product was developed for Grade VI Science and Social Studies (IPAS)

on the topic *Exploring the Earth and Outer Space* and aligned with the Learning Outcomes (CP) and Learning Objectives (TP) of the Merdeka Curriculum. Rather than functioning as a stand-alone digital platform for the entire PBL process, the Problem-Based Wordwall Edugame served as the digital component within a broader teacher-facilitated PBL instructional sequence. The developed product specifications are presented in Table 2.

Table 2. Developed Product Specifications of the Proposed Problem-Based Wordwall Edugame

Product Component	Development Output	Specification
Teaching Module	1 module	Grade VI IPAS module entitled *Exploring the Earth and Outer Space*, covering the Solar System, Earth's rotation, and Earth's revolution for two learning meetings (6 JP).
Instructional Framework	1 framework	Five-phase Problem-Based Learning sequence comprising problem orientation, collaborative inquiry, evidence-based investigation, solution development and presentation, and reflective evaluation.
Wordwall Edugame	1 web-based learning component	Interactive Wordwall activities providing learning materials, problem scenarios, inquiry prompts, formative questions, and immediate feedback as part of the broader PBL sequence.
Student Worksheet (LKPD)	1 LKPD	Inquiry-oriented LKPD containing 10 learning tasks and 1 reflective activity aligned with critical-thinking indicators and used to support collaborative inquiry and investigation.
Assessment Package	1 assessment package	Critical-thinking assessment consisting of 10 structured essay items, analytic scoring rubrics, classroom observation sheets, and response questionnaires.

Instructional Design Characteristics

The developed Problem-Based Wordwall Edugame embedded the complete five-phase Problem-Based Learning (PBL) process within a single digital learning environment. Each instructional phase was operationalized through specific Wordwall activities, contextual IPAS learning content, inquiry-oriented student worksheets (LKPD), formative assessment, and immediate feedback. The instructional design also aligned each learning activity with a corresponding critical-thinking indicator to ensure coherence between pedagogy, digital interaction, and assessment. The resulting instructional design characteristics are presented in Table 3.

Table 3. Instructional Design Characteristics of the Proposed Problem-Based Wordwall Edugame

Problem-Based Learning Phase	Instructional Implementation	Digital Learning Feature	Critical-Thinking Indicator	Development Output
Problem Orientation	Students analysed authentic IPAS problems related to the Earth and the Solar System.	Opening scenario	Interpretation	Contextual problem scenario integrated into the Wordwall Edugame.
Collaborative Inquiry	Students discussed problems, formulated hypotheses, and completed collaborative learning tasks.	Interactive learning activity	Analysis	Collaborative inquiry activities supported by digital interaction.
Evidence-Based Investigation	Students collected, analysed, and	Integrated LKPD	Evaluation	Inquiry-oriented worksheets

	interpreted information using the LKPD.			embedded into the digital learning sequence.
Solution Presentation	Students presented and justified their solutions through interactive activities.	Interactive quiz and discussion	Inference	Digital presentation and formative assessment activities.
Reflective Evaluation	Students reflected on learning outcomes and received immediate feedback.	Automated feedback	Explanation	Reflection activities integrated with immediate feedback.

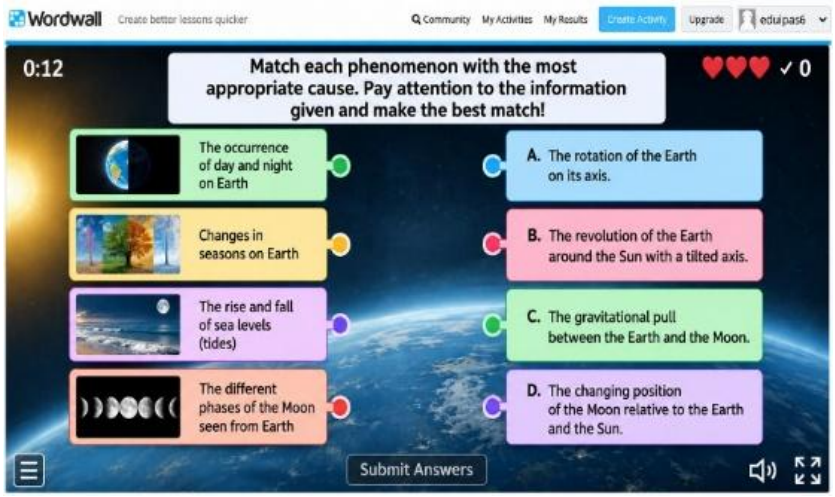


Figure 2. Wordwall "Find the Match" Activity for Analysing Earth and Space Phenomena



Figure 3. Wordwall "Quiz" Activity for Analysing the Effects of Changes in Earth–Sun Distance

Expert Validation Results

Expert validation was conducted to evaluate the instructional quality, media quality, and feasibility of the developed Problem-Based Wordwall Edugame before classroom implementation. Three independent validators, comprising a material expert, a media expert, and a learning-device expert, assessed the developed product using structured validation instruments. The material expert evaluated the accuracy and clarity of the instructional content, the media expert assessed the digital interface and usability, and the learning-device expert evaluated the suitability of the instructional components and learning activities. The validation results are presented in Table 4.

Table 4. Expert Validation Results of the Proposed Problem-Based Wordwall Edugame

Evaluation Aspect	Percentage (%)	Category
Material validity	87.00	Very Valid
Media validity	89.00	Very Valid
Learning-device validity	88.00	Very Valid
Overall validity	88.00	Very Valid

As presented in Table 4, the validity percentages ranged from 87.00% to 89.00%. Media validity obtained the highest score (89.00%), followed by learning-device validity (88.00%) and material validity (87.00%). The overall validity score was 88.00%, which was classified as Very Valid. These results indicate that the developed instructional package met the established validity criteria and was suitable for further refinement and classroom implementation.

Product Revision

Although the product achieved the Very Valid category, the validators also provided qualitative recommendations for improving the clarity, usability, and instructional quality of the product. These recommendations were used to revise the prototype before classroom implementation. Table 5 presents the specific recommendations and the corresponding product revisions.

Table 5 Expert Recommendations and Product Revisions

Evaluation Aspect	Expert Recommendation	Product Revision
Material	Simplify instructional explanations and learning scenarios.	Learning scenarios and instructional explanations were revised to improve clarity and reduce unnecessary textual complexity.
Media	Improve menu organization and navigation.	The navigation structure and menu layout were redesigned to improve usability and ease of access.
Learning device	Strengthen reflective learning activities.	Reflection activities were expanded and integrated more explicitly into the final learning sequence.

Classroom Implementation and User Response

Classroom implementation demonstrated a high level of product practicality. Observation of the learning process produced an implementation score of 92.76%, which was classified as Excellent. This result indicates that the planned instructional sequence could be implemented during classroom learning. The observation results are presented in Table 6.

Table 6. Classroom Implementation Results

Observed Aspect	Percentage (%)	Category
Learning implementation	92.76	Excellent

As presented in Table 6, the implementation score of 92.76% indicates that the instructional sequence, including problem orientation, collaborative inquiry, evidence-based investigation,

solution development and presentation, and reflective evaluation, was implemented consistently during the learning process. The high score suggests that the developed instructional package could be practically implemented within the classroom context. The implementation was supported by the complementary use of the Problem-Based Wordwall Edugame, inquiry-oriented LKPD, and teacher-facilitated learning activities.

Critical-Thinking Learning Outcomes

Students' critical-thinking outcomes were evaluated by comparing performance before and after the learning intervention. Both groups demonstrated improvement, with a greater increase observed in the experimental group. Descriptive statistics, including the mean, standard deviation, gain, N-Gain, and 95% confidence intervals, are presented in Table 7. The difference in gain scores between the two groups was subsequently examined using an independent-samples *t*-test.

Table 7. Critical-Thinking Learning Outcomes

Group	*n*	Pretest *M* (SD)	95% CI	Posttest *M* (SD)	95% CI	Gain *M* (SD)	95% CI	N-Gain *M* (SD)	95% CI	Category
Experimental	15	56.80 (6.03)	53.46–60.14	89.87 (4.09)	87.60–92.13	33.07 (2.46)	31.70–34.43	0.77 (0.07)	0.74–0.81	High
Control	15	53.73 (5.66)	50.60–56.87	68.87 (4.91)	66.15–71.59	15.13 (1.41)	14.35–15.91	0.33 (0.03)	0.31–0.35	Medium

The independent-samples *t*-test indicated a statistically significant difference in gain scores between the experimental and control groups, $t(28) = 24.48$, $p < .001$, with a mean difference of 17.93 points (95% CI [16.43, 19.43]). Thus, the improvement in critical-thinking scores differed significantly between the two groups. N-Gain was treated as a descriptive indicator of improvement rather than as the sole basis for the effectiveness claim.

Discussion

The findings demonstrate that the developed Problem-Based Wordwall Edugame was positively evaluated for instructional validity and practicality and was associated with higher critical-thinking performance among sixth-grade students in Science and Social Studies (IPAS). The instructional package achieved an overall expert-validation score of 88.00%, classroom implementation of 92.76%, and positive teacher and student responses of 93.00%. Furthermore, the experimental group's mean critical-thinking score increased from 56.80 to 89.87, compared with an increase from 53.73 to 68.87 in the control group. The reported between-group posttest difference was statistically significant, $t(28) = 12.730$, $p < .001$, with higher normalized gains in the experimental group (0.77) than in the control group (0.33). These results address the study's objectives concerning product development, instructional feasibility, and preliminary effectiveness. Nevertheless, the observed differences should be attributed to the integrated instructional condition rather than to Wordwall independently.

The findings correspond with international research emphasizing the potential of digital game-based learning to support cognitive development when embedded within purposeful instructional activities. Barz et al. (2024) demonstrated that digital game-based learning can positively influence cognitive, metacognitive, and affective-motivational outcomes in school settings. Similarly, Zeng et al. (2024), synthesizing experimental studies, reported favorable effects of gamification on academic performance, although the magnitude varied across educational environments. More recently, Cheng and Weatherly (2025) identified positive effects of digital games on twenty-first-century competencies, with particularly relevant findings concerning critical thinking. These studies provide theoretical and empirical support for integrating interactive digital activities into meaningful instructional processes. However, their findings also suggest that educational outcomes depend on game characteristics, instructional design, learning objectives, and learner differences rather than technological exposure alone.

The central pedagogical explanation concerns the complementary relationship between Problem-Based Learning (PBL) and the interactive affordances of Wordwall. PBL organizes learning around authentic problems, evidence-based investigation, collaborative reasoning, solution development, and reflection, whereas Wordwall provides interactive exercises, immediate feedback, and opportunities for formative assessment. The systematic review by Loyens et al. (2023) emphasized the relevance of problem-oriented learning environments for higher-order and critical-analytic thinking. Erdem (2024) similarly identified favorable cognitive outcomes associated with PBL among K–12 learners. Furthermore, Wijnia et al. (2024) demonstrated that problem-driven instructional approaches can strengthen learning motivation, although implementation conditions influence outcomes. Collectively, these findings suggest that interactive digital tasks become educationally meaningful when students are required to explain evidence, examine alternatives, and justify conclusions. The present intervention reflects this instructional logic, but its design does not permit the independent effects of Wordwall and PBL to be distinguished.

International research also introduces important qualifications regarding the relationship between engagement and cognitive competence. Li et al. (2024) found that gamification can strengthen intrinsic motivation, autonomy, and relatedness while producing comparatively limited effects on perceived competence. Similarly, Cai et al. (2025), examining digital game-based learning and problem-solving abilities, emphasized considerable variability in intervention outcomes. Giannakoulas and Xinogalos (2024) further highlighted both the educational potential and methodological limitations of game-based interventions among primary-school learners. These findings challenge the assumption that interactive activities necessarily produce deeper reasoning. Students may remain highly engaged in completing digital challenges without consistently demonstrating the interpretation, analysis, evaluation, inference, and explanation required for critical thinking. Consequently, the observed performance differences in the present study should be interpreted in relation to the complete problem-oriented instructional sequence rather than students' enjoyment of digital activities.

The findings also align with international evidence concerning formative feedback and collaborative learning. Hsu et al. (2022) demonstrated the relevance of structured reflection prompts for developing elementary students' critical-thinking skills in technology-supported learning environments. Xu et al. (2023) likewise reported positive relationships between collaborative problem solving and critical-thinking performance. These investigations suggest that feedback becomes most valuable when it encourages learners to reconsider explanations, identify errors, and refine reasoning. In the present instructional package, Wordwall's immediate response features complemented teacher facilitation and inquiry-oriented student worksheets. Nevertheless, automated feedback cannot independently determine the validity of students' scientific reasoning. Teacher-guided explanation and reflection remain necessary, particularly when questions involve causal relationships, alternative explanations, or scientific misconceptions.

Indonesian research provides particularly relevant comparisons. Rahayu et al. (2024) examined PBL assisted by Wordwall educational games in elementary science and reported favorable critical-thinking outcomes. Ana et al. (2025) similarly investigated Wordwall-assisted interactive multimedia for developing elementary students' critical thinking. More directly, Sunata et al. (2026) identified significant differences in mathematical critical-thinking performance following Wordwall-assisted PBL among third-grade students. Muzaki and Trisnawati (2026) also reported higher critical-thinking performance in elementary IPAS through PBL supported by Wordwall. Their more moderate standardized effect, however, illustrates that the magnitude of instructional differences varies across educational settings and assessment procedures. These convergent findings support the potential relevance of Wordwall-assisted problem-oriented learning while demonstrating that the present approach is not entirely unprecedented.

Further Indonesian evidence reinforces the significance of aligning digital media with coherent learning models. Aisah et al. (2026) investigated storybooks and Wordwall within PBL and reported significant differences in critical thinking and environmental awareness. Aminingsih et al. (2026), examining Canva-assisted project-based learning in elementary IPAS, similarly identified higher critical-thinking gains under technology-supported instruction. Mahfud et al. (2026) developed a PBL-based science e-module incorporating local wisdom and reported promising validity, practicality, and critical-thinking results. Meanwhile, Witavia et al. (2026) examined a virtual-world quiz application embedded within inquiry-based learning and identified favorable cognitive and participation outcomes. Although these studies differ in educational level, media platform, assessment method, and instructional model, their common implication is that digital resources should function as components of cognitively demanding learning activities. The distinctive contribution of the present study concerns the development and evaluation of a Wordwall-supported instructional package for elementary IPAS through the ADDIE framework.

Evidence from digital-learning research further clarifies the importance of implementation quality. Sari et al. (2025) documented favorable critical-thinking outcomes using multimedia-based instruction, while Hariandini et al. (2026) found that digital technologies in school settings were frequently used for presentation rather than higher-order inquiry, collaboration, and formative assessment. Sidik et al. (2025) similarly emphasized the relevance of problem-oriented learning strategies for analytical and problem-solving competencies, although their review focused on programming education. These findings suggest that instructional coherence may be more consequential than technological sophistication. The present product's favorable expert evaluation and classroom implementation results support its preliminary feasibility; however, high validation percentages do not independently establish measurement validity or instructional effectiveness. Product quality, implementation fidelity, and learning outcomes represent related but analytically distinct evaluation dimensions.

From a methodological perspective, the observed critical-thinking differences require careful interpretation. The substantial posttest separation between groups is consistent with the

reported statistical significance, but the relatively small sample makes standardized effect estimates sensitive to score dispersion and sampling variability. Furthermore, assigning students to instructional groups according to pretest performance does not provide the protection against selection bias associated with randomized allocation. The reported analyses also compare a comprehensive instructional package with conventional instruction rather than isolating its individual components. Therefore, the findings provide preliminary evidence of a favorable instructional difference within the participating school, but they cannot determine whether equivalent results would occur across different teachers, student populations, IPAS topics, or implementation conditions.

Theoretically, the findings are compatible with constructivist and problem-oriented learning perspectives, in which students develop understanding through meaningful interaction with problems, evidence, feedback, and reflection. They also suggest that gamified learning is most educationally defensible when its interactive features support higher-order cognitive processes rather than rewarding rapid responses alone. Pedagogically, teachers should integrate Wordwall activities into structured problem orientation, evidence investigation, collaborative explanation, and reflective evaluation while ensuring that students justify their reasoning beyond selecting correct answers. The use of accessible digital tasks may support engagement, learning confidence, and constructive classroom interaction, although emotional well-being was not measured directly. Critical media literacy can be incorporated through the evaluation of online scientific information, responsible digital participation, and discussion of misleading information, consistent with Jumakulova and Kushieva (2025). At the policy level, schools should prioritize teacher professional development, equitable digital access, age-appropriate online safety, student-data protection, and the pedagogical evaluation of educational technologies. Henriksen-Bulmer et al. (2024) further demonstrated the educational relevance of game-based approaches to privacy and online safety. Connections with SDG 4 may support institutional commitments to inclusive and meaningful learning, consistent with the broader policy orientation discussed by Febriani et al. (2026). Nevertheless, social-media behavior, mental health, and digital identity were not direct outcomes of this investigation and require separate evaluation.

The novelty of the study lies in the systematic development and preliminary evaluation of an ADDIE-based instructional package integrating Wordwall's interactive and formative-feedback features within teacher-facilitated PBL for sixth-grade IPAS learning. Unlike interventions that use Wordwall predominantly for isolated quizzes or reinforcement activities, the developed package aligns digital interactions with authentic problem orientation, collaborative inquiry, evidence-based investigation, solution presentation, and reflective evaluation. Its methodological contribution involves examining expert validation, implementation quality, user responses, and critical-thinking outcomes within one development-and-evaluation framework. Nevertheless, previous studies have already investigated Wordwall-assisted PBL; the present contribution therefore concerns its particular instructional design, curriculum alignment, learning context, and integrated evaluation rather than the invention of an entirely new pedagogical combination.

Several limitations constrain the interpretation and generalizability of these findings. First, the study involved only 30 sixth-grade students from one elementary school, restricting statistical precision and external validity. Second, the available documentation does not establish random assignment, limiting causal attribution. Third, the intervention combined PBL, Wordwall, LKPD, teacher facilitation, and feedback, preventing identification of the independent contribution of each component. Fourth, the limited documentation of intervention duration and psychometric characteristics of the critical-thinking assessment restricts evaluation of instructional fidelity and measurement quality. In addition, inconsistent standardized effect-size reporting requires reconciliation with the original statistical output. Future investigations should employ larger multisite samples, randomized or carefully matched comparison groups, transparent intervention-fidelity measures, and independently validated critical-thinking

instruments. Factorial designs could distinguish the effects of PBL and Wordwall, while longitudinal studies should examine knowledge retention, transfer of critical-thinking skills, learner motivation, accessibility, and responsible digital participation. Such investigations would strengthen the evidence base for scalable, inclusive, and cognitively meaningful digital science education.

CONCLUSION

This study developed and evaluated a Problem-Based Wordwall Edugame as part of an integrated instructional package designed to strengthen sixth-grade students' critical-thinking skills in Science and Social Studies (IPAS). Employing the ADDIE development framework and a pretest–posttest comparison, the study examined product validity, classroom practicality, and differences in critical-thinking performance between experimental and control groups. Expert evaluations indicated satisfactory instructional validity, with an overall score of 88.00%, while classroom implementation reached 92.76% and teacher and student responses each reached 93.00%. Students receiving the integrated instructional package demonstrated greater critical-thinking gains than those receiving conventional instruction, with experimental-group scores increasing from 56.80 to 89.87 compared with 53.73 to 68.87 in the control group. The reported between-group posttest comparison was statistically significant ($p < .001$). These findings indicate that integrating interactive digital activities, structured problem investigation, collaborative inquiry, and reflective feedback constitutes a feasible instructional approach associated with favorable critical-thinking outcomes within the participating school.

Theoretically, the findings reinforce the relevance of constructivist and problem-oriented learning principles while emphasizing that digital games acquire educational significance through purposeful pedagogical integration. Practically, the developed package offers teachers an adaptable framework for combining interactive assessment, evidence-based reasoning, and collaborative problem solving in elementary IPAS instruction. Nevertheless, the small sample, single-school context, nonrandomized group allocation, and combined instructional components restrict causal interpretation and generalizability. In addition, inconsistencies in standardized effect-size reporting and incomplete documentation of assessment reliability require further methodological verification. Future research should employ larger multisite samples, rigorous comparison designs, independently validated instruments, and longitudinal assessment to examine the sustainability and transferability of critical-thinking development. Further investigation should also distinguish the contributions of Wordwall, PBL, and teacher facilitation. By connecting digital interaction with cognitively demanding instructional processes, this study provides a preliminary foundation for developing inclusive, evidence-informed, and competency-oriented elementary science education consistent with the broader aspirations of SDG 4.

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