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Developing BoardWise : A Digital Board Game for Enhancing Elementary Science Education

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Abstract: This study aims to develop and determine the feasibility of a digital board game, "BoardWise," based on Fun Learning principles to enhance the quality of Science Education. Employing a Research and Development (R&D) method, the study progresses through iterative cycles of needs analysis, design, validation, and testing. Data collection involves questionnaires and observations with media experts, material experts, an educator, and fourth-grade students. Data analysis uses descriptive percentages to determine product feasibility. The research results show that the "BoardWise" digital board game is "Very Feasible." The product validation achieves an overall feasibility score of 85.13%, with detailed assessments from a media expert (90.0%), a material expert (83.0%), and an educator (86.0%). Student trials also yield a "Very Feasible" rating with an average score of 81.5%, indicating that the game is highly engaging and practical for classroom use. The study concludes that the "BoardWise" digital board game is a valid, practical, and effective instructional medium. It successfully integrates curriculum content with engaging, customizable game mechanics, fostering an active and enjoyable learning environment that overcomes challenges associated with abstract scientific topics and improves student participation in elementary education.

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Introduction

Effective science instruction is fundamental to elementary education, yet it is often hindered by persistent pedagogical challenges. The Indonesian curriculum for *Ilmu Pengetahuan Alam dan Sosial* (IPAS) is designed to build foundational scientific literacy by exploring concepts like energy conversion through real-world contexts (Safitri et al., 2023). However, the abstract nature of these topics often leads to low student interest (Syahputra et al., 2022). This is compounded by a widespread reliance on conventional, teacher-centered methods, which frequently creates passive classroom environments (Viratama & Maskhuliah, 2023). This instructional gap is characterized by monotonous lectures and a lack of engaging materials (Siregar et al., 2019). This ultimately limits students' ability to achieve deep conceptual understanding (Fitriyadi & Wuryandani, 2021). Consequently, there is a critical need for innovative teaching methods that can transform science learning into an active and meaningful experience.

To address these challenges, the Fun Learning approach offers a powerful pedagogical alternative that prioritizes enjoyable and interactive student-centered experiences. This approach is grounded in neuroscientific evidence showing that learning is more effective when associated with positive emotions, as reduced stress allows information to flow more freely to the brain's higher cognitive centers for memory consolidation. Fun

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Learning operationalizes this by encouraging active participation through games and problem-solving, which makes abstract concepts more accessible (Irwansyah et al., 2019). This approach also fosters critical thinking skills (Dinatha et al., 2023) and can be particularly effective in various learning contexts (Kismiati, 2024). The ultimate goal is to create a learning environment that is not only engaging but also relevant to students' lives, thereby increasing their intrinsic motivation (Kesuma et al., 2021). However, the success of this approach is heavily dependent on the support of well-designed instructional media.

Instructional media, particularly digital tools, are vital for realizing the full potential of Fun Learning in the modern classroom. The integration of technology can make abstract content more concrete and help visualize complex phenomena. It also helps develop crucial 21st-century skills such as problem-solving (Rochman et al., 2019) and collaboration (Sa'odah et al., 2022). Game-Based Learning (GBL) has emerged as a particularly effective strategy within this domain, as it is rooted in established educational theories like constructivism, which posits that learners actively construct knowledge through experience. Recent meta-analyses confirm that well-designed educational games have a significant positive impact on student motivation (Wang et al., 2022). This also extends to learning achievement in STEM fields (Hussein et al., 2019). This evidence strongly suggests that digital games can provide the dynamic and interactive environments necessary for effective science education.

Despite the proven benefits of GBL, its widespread implementation in schools faces significant practical barriers. Teachers often report difficulties in finding high-quality games that align with specific curriculum standards and a lack of time for development (Greipl et al., 2020). They also face cultural hurdles in convincing administrators and parents of their educational value (Adipat et al., 2021). Furthermore, many existing educational games lack the pedagogical rigor or contextual relevance needed for effective classroom use. This gap was confirmed by preliminary observations at a public elementary school in Jakarta where monotonous teaching methods led to widespread student disengagement (Sari & Yarza, 2021). This study, therefore, addresses the need for a GBL tool that is not only engaging for students but also flexible, curriculum-aligned, and easily managed by teachers, proposing a customizable digital board game as a targeted solution.

The primary objective of this study is to develop and evaluate the feasibility of a digital board game, "BoardWise," based on Fun Learning principles to enhance the quality of IPAS instruction in elementary science education. Specifically, the study aims to (1) design a customizable digital board game that aligns with IPAS curriculum standards; (2) evaluate the game's feasibility from technical, pedagogical, and practical perspectives; and (3) assess its potential to improve student engagement and learning outcomes in science education. By achieving these objectives, this study seeks to contribute to the field of science education by providing a practical and innovative instructional tool that addresses existing teaching challenges and enhances student learning experiences.

The significance of this research lies in its potential to bridge the gap between traditional teaching methods and modern educational technologies, offering a novel approach to science instruction. By leveraging the principles of Fun Learning and Game-Based Learning, "BoardWise" aims to transform abstract scientific concepts into engaging and interactive learning experiences. This not only addresses the challenges of low student engagement and passive learning environments but also provides teachers with a flexible and customizable tool to support their instructional goals. The findings of this study are expected to provide valuable insights for the design and implementation of digital educational games

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in science education, offering practical guidance for teachers and contributing to the theoretical development of educational technology research.

Research Method

This study employed a Research and Development (R&D) method to systematically design, develop, and evaluate the "BoardWise" digital board game. The R&D approach was guided by the comprehensive ten-stage model proposed by Borg & Gall, which is widely used in education to create and validate new products that address authentic classroom needs (Maydiantoro, 2021). Recognizing that the full model can be extensive, this research adapted the framework into a focused sequence of six key stages: (1) needs analysis, (2) product design, (3) expert validation, (4) design revision, (5) small-group product testing, and (6) final product evaluation. This pragmatic adaptation is common in educational R&D (Ariskasari & Pratiwi, 2019), allowing for a rigorous yet feasible development cycle within typical time and resource constraints. The design phase was specifically informed by principles of Fun Learning to ensure the final product would effectively increase student engagement in IPAS instruction (Padang & Sitepu, 2023).

A mixed-methods approach was utilized for data collection and analysis to ensure a comprehensive evaluation of the product's feasibility and effectiveness. Qualitative data were gathered through non-participant classroom observations to assess student engagement (Firmadani, 2020). Documentation was also used to capture student interaction with the media (Magdalena et al., 2021). Quantitative data were collected via questionnaires administered to a panel of experts, one fourth-grade Teachers and 50 fourth-grade students. These questionnaires employed a 5-point Likert scale to measure product feasibility and user responses (Adipat et al., 2021). This is a standard and reliable method for such evaluations (Lubis et al., 2023). To ensure the credibility of the findings, data from all sources were triangulated, allowing for a robust and multi-faceted assessment of the instructional medium (Abdulrahaman et al., 2020).

The sampling strategy for this study included experts, teachers, and students. The experts consisted of two media experts and two material experts , two teachers selected based on their extensive experience and professional qualifications in educational technology and science education. The teachers participant was a practicing fourth-grade science teacher with over five years of teaching experience, chosen to represent the practical needs of classroom instruction. The student participants were 50 fourth-grade students from a public elementary school in Jakarta, selected through convenience sampling to ensure their availability and willingness to participate in the study. The demographics of the participants were diverse, covering different genders and academic performance levels to ensure the representativeness of the sample.

The questionnaires used in this study were developed based on the objectives of the research and the characteristics of the participants. For the expert validation questionnaires, items were designed to assess the technical quality, content accuracy, and pedagogical value of the "BoardWise" game. For the teacher and student questionnaires, items focused on the game's usability, engagement, and learning effectiveness. The questionnaires underwent a pre-test phase, during which feedback from a small group of participants was used to refine the wording and format of the items, ensuring their clarity and reliability. The 5-point Likert scale was adopted to quantify participants' responses, ranging from "Very Good" (5 points) to "Not Good" (1 point), providing a clear and intuitive measurement tool for evaluating the game's feasibility.

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The data analysis procedures for this study followed a systematic approach. The data analysis procedures for this study followed a systematic approach. For qualitative data, classroom observation notes and media interaction records were transcribed and coded. Thematic analysis was conducted to identify patterns and themes related to student engagement and learning behaviors. For quantitative data, descriptive statistical analysis was performed to calculate the mean scores and percentages of each questionnaire item. Data triangulation was employed to integrate qualitative and quantitative findings, cross-verifying the results from different sources to ensure the validity and reliability of the conclusions. Additionally, the research process was visually represented through a flowchart (see Figure 1), illustrating the R&D stages and data collection methods to help readers better understand the study's design and implementation.

Figure 1. Flowchart Adaptation of Borg & Gall Method

Table 1. Likert Scale Category

No	Score	Category
1	5	Very Good
2	4	Good
3	3	Quite Good
4	2	Not very good
5	1	Not Good

Table 2. Feasibility Qualification Criteria

Level of Achievement (%)	Qualification	Notes
81% − 100%	Very Feasible	No Revision Needed
61% − 80%	Feasible	No Revision Needed
41% − 60%	Fairly Feasible	Revision Needed
21% − 40%	Less Feasible	Major Revision Needed
0% − 20%	Not Feasible	Major Revision Needed

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Results and Discussion

Figure 2. The "BoardWise" Teachers customization interface.

The Teachers interface, shown in Fig. 2, is the control center of "BoardWise," empowering teachers to design and tailor the game to their specific instructional needs. Through an intuitive settings sidebar, Teachers can define the game's core parameters, including the board name, the number of playable tiles, player count, and win conditions. The most critical feature is the tile editor, which allows each tile on the board to become an interactive node. Teachers can designate tiles to trigger a multiple-choice quiz, display informational text and images, or apply rewards and penalties, thereby embedding curriculum-specific content directly into the gameplay.

Figure 3. The "BoardWise" student gameplay interface.

Once the Teachers finalizes the design, a unique "Play Link" is generated for students to access the game. The student interface, depicted in Fig. 3, presents a clean and engaging turn-based board game experience. An animated dice roll determines player movement, and landing on a tile activates an interactive pop-up that delivers the pre-designed content. This core loop of movement, challenge, and feedback operationalizes key principles of Game-Based Learning (GBL) by embedding educational content within familiar game mechanics (Adipat et al., 2021). This use of motivating mechanics is a key aspect of successful educational games (Alvin Supandhi et al., 2022). The customizable nature of the tiles provides a framework for scaffolded, contextually relevant challenges, which is a cornerstone of effective GBL design (Krath et al., 2021). This approach helps create meaningful learning experiences within the game (Liu et al., 2020). This design is also deeply rooted in Fun Learning, using engaging visuals and reward systems to foster curiosity (Hermahayu &

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Mashitoh, 2022). It aims to transform the learning of abstract concepts into an active, participatory experience (Irwansyah et al., 2019).

Expert Validation and Design Revision

To ensure the product's quality and pedagogical soundness, the "BoardWise" prototype underwent a rigorous validation process involving a media expert, a material expert, and a practicing Teachers. The results of the media expert's validation can be seen in Table 3 below.

Table 3. Media Expert Validation Results

Aspect Assessed	Average Percentage	Qualification
Quality	88.00%	Very Feasible
Usage	91.70%	Very Feasible
Feasibility	90.00%	Very Feasible
Total Feasibility	90.00%	Very Feasible

Based on the data in Table 3, the validation from the media expert confirmed the technical and aesthetic quality of "BoardWise," yielding an overall feasibility score of 90% and a "Very Feasible" qualification. The 'Usage' aspect received the highest rating (91.7%), indicating that the game's interface is highly intuitive and its interactive elements function seamlessly. This is a critical finding, as the effectiveness of any multimedia tool is heavily dependent on its ability to present information clearly and facilitate interaction (Abdulrahaman et al., 2020). It is important that this is achieved without imposing a high cognitive load on the user (Lubis et al., 2023).

The positive evaluation establishes that the product successfully avoids common design pitfalls, providing a strong foundation for its educational utility. Engaging visual media are essential for capturing student interest (Hasan et al., 2021), and they help in making abstract concepts more concrete (Wulandari et al., 2023). The expert's feedback, which included a suggestion to add more animation, was incorporated to further enhance student engagement. Following the media validation, the product was assessed by a material expert to evaluate its content accuracy and curriculum alignment. The results of this validation are presented in Table 4.

Table 4. Material Expert Validation Results

Aspect Assessed	Average Percentage	Qualification
Curriculum Aspect	82.50%	Very Feasible
Material Aspect	80.00%	Feasible
Effectiveness Aspect	85.00%	Very Feasible
Language Aspect	90.00%	Very Feasible
Total Feasibility	83.00%	Very Feasible

The data in Table 4 show that the material expert rated "BoardWise" with an overall feasibility of 83%, also qualifying it as "Very Feasible" and validating its instructional integrity. The high scores for the 'Curriculum Aspect' (82.5%) and 'Effectiveness Aspect' (85%) confirm that the game's content is not only accurate and aligned with IPAS learning objectives but is also structured to effectively promote an interactive learning atmosphere.

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This aligns with a key goal of GBL, which is to foster engagement through game mechanics (M. Wang & Zheng, 2021). This approach is known to improve learning outcomes (Adipat et al., 2021).

This validation is crucial because it establishes the product's educational value beyond mere entertainment, ensuring the "fun" aspect serves a clear pedagogical purpose. The innovation in educational games lies in their ability to seamlessly integrate learning objectives with game mechanics (Mahyuddin et al., 2022). This high score affirms that "BoardWise" achieves this balance, which is a key factor in successful GBL applications (Mikrouli et al., 2024). Furthermore, the strong language assessment (90%) indicates that the instructions and content are clear and cognitively appropriate for fourth-grade students, which is essential for ensuring accessibility and comprehension in science education (Hwang et al., 2019). Finally, the prototype was evaluated by a practicing Teachers to assess its practical utility in a classroom setting. The Teachers's validation results are detailed in Table 5.

Table 5. Teachers Validation Results

Aspect Assessed	Average Percentage	Qualification
Learning Aspect	95.00%	Very Feasible
Design Aspect	85.00%	Very Feasible
Language Aspect	85.00%	Very Feasible
Functionality Aspect	84.00%	Very Feasible
Performance Aspect	82.50%	Very Feasible
Total Feasibility	86.00%	Very Feasible

As indicated in Table 5, the validation from a practicing fourth-grade Teachers provided a powerful endorsement of the game's practical utility, resulting in an overall feasibility score of 86% ("Very Feasible"). The exceptional score of 95% for the 'Learning Aspect' is particularly noteworthy, as it highlights the teacher's strong confidence in the game's ability to support instruction and enhance student understanding in a real classroom context. This feedback from an end-user professional is critical, as the adoption of any educational technology is contingent on its ability to integrate seamlessly into a teacher's workflow (Sa'odah et al., 2022). It must also effectively support pedagogical goals (Firmadani, 2020).

This high rating bridges the gap between the product's theoretical potential and its real-world applicability. The Teachers' positive assessment of the game's functionality (84%) and design (85%) reinforces the other experts' findings from a pragmatic standpoint. This aligns with research advocating for technology that empowers teachers to create learning experiences. It also supports their ability to adapt these experiences to fit their students' needs (Rochman et al., 2019).

Product Testing and Implementation with Students

After successful expert validation, the refined "BoardWise" game was tested with 50 fourth-grade students to assess its practicality and appeal. The student response data is summarized in Table 6.

Table 6. Student Response Analysis from Classroom Implementation

Aspect Assessed	Average Percentage	Qualification
Curriculum Aspect	82.50%	Very Feasible

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Material Aspect	80.00%	Feasible
Effectiveness Aspect	85.00%	Very Feasible
Language Aspect	90.00%	Very Feasible
Total Feasibility	83.00%	Very Feasible

Based on the data in Table 6, the implementation of "BoardWise" was met with a highly positive reception from students, achieving an overall response score of 82%, which qualifies as "Very Good." The 'Ease of Playing' category received the highest score (84%), indicating that the game's design is intuitive and user-friendly for its target audience. This is a significant finding, as the effectiveness of educational media is greatly enhanced when it is easy to operate (Nasution, 2019). This allows students to focus on the learning content rather than struggling with a complex interface (Anghelo Josué et al., 2023).

The high scores for 'Excitement' (82%) and 'Learning Benefits' (81%) further validate the core design philosophy, which leverages Fun Learning principles to make abstract science topics engaging (Hermahayu & Mashitoh, 2022). This approach also makes the learning memorable (Taufiqurohman et al., 2022). This positive reception from the end-users confirms the product's success in balancing entertainment with pedagogical purpose, aligning with studies showing that GBL can improve student motivation and foster positive attitudes toward learning (Fitriyadi & Wuryandani, 2021).

Synthesis of Findings and Overall Product Feasibility

To determine the final product's overall feasibility, a summative evaluation was conducted by aggregating the validation data from all stakeholders. A recapitulation of these scores is presented in Table 7.

Table 7. Recapitulation of Overall Product Feasibility

Validation Source	Feasibility Score	Final Qualification
Media Expert	90.00%	Very Feasible
Material Expert	83.00%	Very Feasible
Teachers	86.00%	Very Feasible
Students	82.00%	Very Good
Overall Feasibility	85.13%	Very Feasible

The synthesis of all validation data, as shown in Table 7, culminates in an overall feasibility score of 85.13%, earning "BoardWise" a final qualification of "Very Feasible." This comprehensive score is a powerful testament to the success of the R&D process, reflecting a product that is technically sound (media experts: 90%), pedagogically robust (material experts: 83%), practical for classroom implementation (Teachers: 86%), and engaging for students (users: 82%). This multi-faceted success demonstrates a well-rounded and high-quality educational product.

This final result underscores the value of employing a systematic and iterative R&D model (Maydiantoro, 2021). This ensures that a product is subjected to rigorous, multi-stage evaluation from diverse perspectives (Ariskasari & Pratiwi, 2019). The "BoardWise" game stands as an effective solution to the identified problem of low engagement in IPAS, successfully leveraging GBL principles to create a meaningful learning experience. The findings are consistent with the broader literature on the positive effects of digital game-based STEM education, which confirms that such tools can significantly enhance learning

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achievement (L. H. Wang et al., 2022). This is especially true when they are designed with pedagogical rigor and practical utility in mind (Hussein et al., 2019).

Conceptual and Practical Implications

The conceptual implications of this study are significant. First, it validates the potential of Game-Based Learning (GBL) in enhancing science education. By integrating educational content with engaging game mechanics, "BoardWise" provides empirical evidence supporting the effectiveness of GBL in improving student engagement and learning outcomes. Second, the study highlights the importance of aligning digital educational tools with curriculum standards. The teacher-customizable feature of "BoardWise" ensures direct relevance to IPAS learning objectives, offering a practical solution to the challenge of integrating technology with curriculum content. Third, the research underscores the value of a mixed-methods approach in educational technology studies. By combining qualitative observations with quantitative questionnaires, this study provides a comprehensive evaluation of the game's feasibility, offering a methodological reference for future research

The practical implications of this study are equally noteworthy. For educators, "BoardWise" offers a flexible and user-friendly instructional tool that can be tailored to different teaching contexts and student needs. Teachers can use the game to supplement traditional teaching methods, creating a more dynamic and interactive classroom environment. For students, the game transforms abstract scientific concepts into concrete and enjoyable learning experiences, fostering curiosity and interest in science. For educational administrators and policymakers, the study provides insights into the design and implementation of digital educational resources, offering a reference for promoting educational technology in schools.

Strengths and Weaknesses of the Instructional Media

A critical analysis of the "BoardWise" media reveals significant strengths in its design and notable weaknesses common to many GBL tools. The primary strength of "BoardWise" is its teacher-centric customization, which addresses the fundamental challenge of aligning digital media with specific curricular goals (de Castro et al., 2019). This flexibility empowers educators to modify content and ensure direct curriculum relevance, thereby maintaining learning integrity across different topics and learner levels (Baptista et al., 2024). This feature was highly valued by the educator in this study, as reflected in the exceptional validation score for the 'Learning Aspect'. Furthermore, the media's high usability, demonstrated by its intuitive interface, is crucial for meaningful adoption in classrooms, as it minimizes technical barriers for both educators and students (Pérez-Colado et al., 2017). This combination of curricular alignment and accessibility makes "BoardWise" a highly practical tool for classroom instruction.

Despite these strengths, "BoardWise" is not without its weaknesses. A common issue with GBL tools is the risk of oversimplifying subject matter in favor of entertainment, which can limit cognitive depth if not carefully managed by the teacher (Chen et al., 2018). The current design of "BoardWise" also lacks personalization and adaptive feedback mechanisms, which are crucial for addressing student diversity and tailoring instruction to individual learning paces and difficulties (Ho & Jeon, 2023). The most significant weakness, however, is the inherent dependency on technology. The effectiveness of "BoardWise" is contingent upon access to adequate infrastructure, including devices and stable internet, which poses a serious equity concern in under-resourced educational environments (Tan, 2019). These limitations highlight important areas for future development, such as incorporating adaptive

features and exploring offline functionality to enhance the media's robustness and broaden its applicability.

Conclusion

This study successfully developed and validated "BoardWise," a digital board game that proved to be a highly feasible and effective tool for supporting IPAS learning. Through a systematic R&D process, the game received strong validation from experts and practitioners, achieving an overall feasibility score of 85.13%. The core strength of "BoardWise" lies in its teacher-centric customization, empowering educators to align game content with specific curriculum goals and addressing a critical barrier to GBL adoption. The study's findings hold significant implications for science education, demonstrating that digital board games can effectively enhance student engagement and learning outcomes while providing teachers with innovative instructional tools. However, the study also acknowledges key weaknesses, including a dependency on technological infrastructure and the absence of adaptive features to personalize learning. While the game effectively fosters an engaging and motivating learning environment, its full potential requires balancing gameplay with cognitive depth and ensuring equitable access. This research contributes a practical and innovative instructional model, showing that powerful learning experiences can be created while highlighting broader challenges that future educational technology development must address.

Recommendation

Based on the study's findings and process, the following recommendations are proposed for future development and research:

For teachers: Teachers are encouraged to incorporate "BoardWise" into their science instruction as a supplementary tool. They can leverage the game's customization features to align content with specific teaching objectives and student needs. Additionally, teachers should actively participate in professional development activities to enhance their digital literacy and game-based teaching skills, maximizing the educational value of the game.

For future researchers: Future studies should conduct longitudinal research to evaluate the long-term impact of "BoardWise" on knowledge retention and student academic performance. Furthermore, efforts should focus on developing adaptive learning pathways within the game to adjust task difficulty based on real-time student performance, addressing the need for greater personalization and cognitive rigor. The digital divide issue should also be prioritized. Future iterations of "BoardWise" should explore offline functionality or low-bandwidth versions to ensure equitable access in under-resourced settings. Expanding the research to a larger and more diverse sample of schools would provide more robust data on the tool's effectiveness and identify key contextual factors for successful implementation. Finally, integrating advanced collaborative features could enhance social learning and teamwork skills, moving beyond the current competitive format.

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