

Developing an Interactive Digital Book for Mathematics Learning Using Pedagogical Deep Learning Approach and Character Education

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ABSTRACT

Integrating digital technology into mathematics education is essential for improving academic achievement and character development. This study aims to develop and evaluate an interactive digital module using a pedagogical deep-learning approach to enhance students' critical thinking and character formation in learning statistics, particularly regression analysis. The research used a Research and Development (R&D) method with the ADDIE model at SMA Muhammadiyah Al Amin Sorong, involving 20 students in a small-group trial and 70 students in a large-group trial. Data were collected through expert validation sheets, student response questionnaires, classroom observations, and pre- and post-tests. Data analysis covered validity, practicality, and effectiveness using descriptive statistics, the Shapiro-Wilk test, paired sample t-tests, and N-Gain analysis. The findings showed that the developed module was valid, practical, and effective. Expert validation confirmed its feasibility, and student responses rated it "Very Practical" at 88.09 percent. The paired sample t-test demonstrated significant improvement between pre- and post-test scores ($p < 0.001$), supported by an average N-Gain of 0.3161 in the medium category. These results indicate that the module enhances students' critical thinking and strengthens character values such as honesty, responsibility, and discipline, providing a meaningful and engaging learning experience aligned with 21st-century educational demands.

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Introduction

Mathematics is one of the fundamental subjects that plays an important role in developing logical, analytical, critical and systematic thinking skills. At the high school level, mathematics learning not only functions as a means of mastering numerical and symbolic concepts but also as a vehicle for equipping students with the high-level thinking skills essential for addressing the challenges of the 21st century (Huang et al., 2025). Statistics, as a core subject, is highly relevant because it provides a foundation for students in understanding, processing, and interpreting data that increasingly dominates everyday life. With a good understanding of Statistics, students are expected to be able to make decisions more rationally, critically, and based on information (Weiland, 2023). However, traditional methods of teaching statistics in schools remain largely conventional and abstract, making it less engaging and difficult for students to comprehend (Weiland, 2023). Therefore, innovative learning media are needed that can bridge conceptual understanding while increasing students' motivation and participation (Hillmayr et al., 2020; Nugroho et al., 2024).

Beyond conceptual mastery, mathematics learning in the digital age must also be directed at strengthening students' character. Values such as honesty, responsibility, and discipline are essential foundations in the learning process, especially when students are faced with data that must be processed honestly and analyzed responsibly. Integrating character values into learning not only fosters positive attitudes but also equips students with soft skills that are much needed in social life (Rina et al., 2020). Thus, learning statistics can contribute not only to students' academic development but also to the development of a strong personality and readiness to face complex challenges in the future (Tarusu et al., 2022; Mucinskas et al., 2025).

To achieve this goal, the pedagogical approach offers a relevant and effective strategy because it encourages students to learn meaningfully, deeply, and reflectively (Kovač et al., 2025). Through the use of interactive digital books, this

approach can be realized by providing a rich learning experience, starting from understanding concepts contextually, working on real-life case-based exercises, to reflecting on learning outcomes to strengthen understanding (Brnic et al., 2024). Interactive digital books are not only a means of presenting material, but also as comprehensive learning tools that integrate multimedia elements such as videos and digital quizzes so that students are encouraged to be active, think critically, and have character in the learning process (Pepin et al., 2017; Setyo et al., 2024; Buria et al., 2024).

Recent research shows that the integration of digital technology can improve the quality of mathematics and science learning (Hillmayr et al., 2020). For instance, Hillmayr et al. conducted a meta-analysis showing that the use of digital tools has a significant positive impact on learning outcomes, especially when the design is appropriate for the secondary school context. Similar findings were also conveyed by Wijaya et al., who through a meta-analysis found that e-books have a significant influence on students' mathematics achievement. In line with this, other studies emphasized that e-books have a significant influence on mathematics learning achievement, so digital-based media is worth considering as a primary alternative in delivering material (Wijaya et al., 2022a). Other studies highlight pedagogical aspects who found that automatic feedback on digital books can help strengthen students' conceptual development (Rezat, 2021). In terms of learning engagement, Mamolo showed that interactive digital teaching materials in the form of mathematical comics can increase motivation and conceptual understanding (Mamolo, 2019). Similarly, Trisnawati et al. demonstrated the development of an interactive mathematics module integrating problem-based learning and Islamic values, highlighting the potential of interactive digital materials to combine pedagogical approaches with value-based learning (Trisnawati et al., 2026). Meanwhile, Lohr et al. emphasized that the success of using digital media in schools is highly dependent on teachers' skills in designing interactive activities (Lohr et al., 2024).

Conceptually, Kovač et al. emphasized the urgency of deep learning which emphasizes meaningful, conscious, and enjoyable learning as an important basis for encouraging deep understanding, not just procedural memorization (Kovač et al., 2025).

Although these studies have demonstrated the effectiveness of digital media, several gaps remain that need to be addressed. First, previous studies have examined interactive digital textbooks and e-books in mathematics learning, including statistics, but their integration into high school statistics learning with a specific focus on data-based reasoning and interpretation remains limited (Brnic et al., 2024; Nugroho et al., 2024). Second, although pedagogical deep learning and digital learning have been discussed in previous research, their integration into digital media design remains limited, particularly in providing meaningful, attentive, and enjoyable learning experiences (Kovač et al., 2025; Fathurrahman et al., 2024). Third, although character education has been incorporated into mathematics learning and digital learning media, its integration with interactive digital textbooks for statistics learning, particularly through explicit values such as honesty in data reporting, responsibility in the analysis process, and collaboration in completing assignments, remains limited (Rina et al., 2020; Tarusu et al., 2022).

Based on these gaps, this study proposes a new approach: developing an interactive digital textbook for high school statistics that combines pedagogical deep learning principles with explicit character education components. This digital textbook not only presents interactive materials and exercises but also provides adaptive automated feedback designed to address common misconceptions in statistics (Barana et al., 2021; Rezat, 2021). Furthermore, the activities in this digital textbook are aimed at fostering character values, ensuring the balanced development of cognitive and affective competencies. This innovation also includes teacher orchestration guidance to ensure classroom implementation aligns with the principles of effective interactive digital learning (Setyo et al., 2023; Yang, 2017).

This research has two important implications. From a student perspective, this product is expected to improve students' understanding of statistics concepts, increase their learning motivation, and foster positive character through contextual and enjoyable learning experiences (Trisnawati et al., 2024). From a teacher perspective, this research offers an interactive digital media implementation model that can be adapted to classroom conditions and available devices (Wijaya et al., 2022b). Thus, the results of this research can make a tangible contribution to the development of mathematics learning practices in the digital age.

The purpose of this research is to develop and assess the validity, practicality, and effectiveness of an interactive digital book based on pedagogical deep learning and character development for statistics at the high school level. Specifically, this product is expected to address gaps in previous research and provide innovative solutions relevant to the needs of 21st-century learning.

2. Methodology

Research Design

This research used the Research and Development (R&D) approach, highlighting not only the creation of an innovative educational product, but also the empirical evaluation of its effectiveness. Specifically, the ADDIE (Analyze, Design, Development, Implementation, and Evaluation) development model was applied, from the identification of needs to the creation and testing of products. The model was chosen because of its systematic stages with continuous evaluation and revision until the developed product met the criteria for validity, practicality, and effectiveness. In this framework, the objective of the study was to determine the validity, practicality and effectiveness of the interactive digital book developed for teaching statistics, particularly regression analysis, integrated with pedagogical deep learning and character education.

Research Site and Participants

The study was conducted at SMA Muhammadiyah Al Amin High School in Sorong City, Indonesia, in April 2024. Among the participants were tenth-grade students who were the main users of the interactive digital book. The trials were conducted in two stages: a small-group trial with 20 students and a large-group trial with 70 students. In addition, experts participated as product validators: material experts, media experts, and linguists. The involvement of these diverse stakeholders ensured a balanced consideration of pedagogical, technical, and learner-centered perspectives. Student participants represented different levels of prior knowledge in statistics.

Data Collection Instruments

A variety of instruments were employed to gather comprehensive data across the different phases of the study. A needs analysis questionnaire was distributed to students to identify challenges and preferences in mathematics learning, with a focus on statistics and critical thinking skills. Expert validation sheets, structured with Likert-type scales, were used by the material, media, and language experts to assess the prototype's content suitability, design, usability, linguistic relevance, and engagement. During the trial phase, student response questionnaires captured learners' perceptions of practicality and attractiveness, while classroom observation sheets assessed student activities related to discussion, collaboration, presentation, and character values (honesty, responsibility, and discipline). To measure performance improvement, pre- and post-tests were conducted, focusing on critical thinking indicators in regression analysis. Classroom observations and field notes were also recorded to document learning interactions and technical challenges.

Development Procedures (ADDIE Model) (Deák et al., 2021)

The ADDIE model was implemented sequentially. In the Analyze stage, a curriculum and materials analysis was conducted to determine relevant statistical topics, particularly

regression analysis. An analysis of student characteristics was also performed to identify their background knowledge, skills, and attitudes, while learning conditions analysis was used to understand teaching techniques commonly applied by teachers. The results showed that 58.1% of students stated that the teaching materials rarely support critical thinking and character development, and interactive media such as flipbooks were used by only 8.8% of respondents.

In the Design stage, an interactive digital book prototype was designed based on pedagogical deep learning approach (meaningful, mindful, and enjoyable learning) integrated with character development content focusing on honesty, responsibility, and discipline. The product was designed in an interactive flipbook format with supporting features such as video explanations, audio narration, interactive questions connected through the Wordwall platform, and a dedicated link for assignment submission. (Setyo et al., 2024; Trisnawati et al., 2024; Barana et al., 2021)

In the Development stage, the prototype was developed using supporting software that integrates text, illustrations, explanatory videos, audio narration, interactive exercises, and Wordwall-based activity links. The product was validated by subject matter experts, media experts, and linguists, followed by revision based on their feedback. In the Implementation stage, the product was tested on a small group, followed by subsequent revisions and trials on a larger group of students. The final phase was Evaluation, which involved assessing the product's validity, practicality, and effectiveness based on data triangulation from validation results, observations, tests, and questionnaires.

Validation Procedures

Validation was carried out by three groups of experts to ensure the quality of the interactive digital book. The material experts assessed the suitability of the statistics content—particularly the topic of regression—with the curriculum and the level of understanding of high school students. The media experts evaluated technical aspects, visual presentation, interactivity, and the

appropriateness of using digital features to support deep learning. Meanwhile, the linguists reviewed the clarity of the narrative, the correctness of terminology, and the readability of the text for students. The validation results showed media experts scored 4.30 (Valid), language experts scored 4.82 (Valid), and material experts scored 4.15 (Valid). Input from the validators was used to revise the product, including content improvements, design refinements, clearer instructions for interactive questions, and improvements to audio and video quality.

Trial Implementation

Trials were conducted in two phases. The small-scale trial involved 20 students who tested the prototype, resulting in an average practicality rating of 84% (Practical category). Students reported that the media was engaging and supportive of conceptual understanding. After improvements, the large-scale trial was conducted with 70 students, yielding an average practicality score of 92.5%, indicating that the interactive digital book was highly practical for use in learning. Teachers and researchers observed increased student engagement through group discussions, data analysis, and presentation of results, while character values such as honesty, responsibility, and discipline were fostered through independent work, timely submission, and active participation. (Mamolo, 2019; Nugroho et al., 2024)

Data Analysis

Both quantitative and qualitative techniques were used. Quantitative data from validation scores, student responses, and pre-test/post-test results were analyzed using descriptive statistics. The Shapiro-Wilk test was applied to check normality, followed by paired-sample t-tests to assess significant improvements in learning outcomes. N-Gain analysis was used to measure the magnitude of improvement. Qualitative data from observation notes and open-ended responses were thematically coded to identify patterns related to student engagement, critical thinking processes, and character development. This integrated approach ensured both statistical

rigor and rich contextual insights into the experiences of students. (Yang, 2017; Olop et al., 2024)

Ethical Considerations

Ethical standards were rigorously upheld throughout the research process. Informed consent was obtained from the school management, teachers, and students. Confidentiality was maintained by anonymizing the data collected in the reports and publications. The research related to human use has complied with all the relevant national regulations and institutional policies in accordance with the tenets of the Helsinki Declaration and has been approved by the authors' institutional review board or equivalent committee. These actions ensured compliance with scientific standards and increased trust among all stakeholders.

3. Results

This section presents the results of the development, validation and implementation of the interactive digital book for mathematics learning (statistics–regression analysis) based on a pedagogical deep learning approach and character education at SMA Muhammadiyah Al Amin Sorong. The results are explained in several parts: needs analysis, expert validation, small- and large-scale trials, student activity observations, learning outcome improvement, and overall findings. Quantitative and qualitative findings are integrated to provide a holistic view of product validity, practicality, and effectiveness.

Needs Analysis

The needs analysis focused on three aspects: material analysis, student characteristics analysis, and learning conditions and situations. The material analysis focused on regression analysis, a key topic in statistics at the high school level, selected because it is applicable and closely related to real-life situations such as predicting data or trends. This topic supports the application of deep learning principles emphasizing meaningful, mindful, and enjoyable learning. (Weiland, 2023; Huang et al., 2025)

The analysis of student characteristics showed that the teaching materials currently used were not optimal in developing students' critical thinking skills and character. A total of 58.1% of students stated that the teaching materials rarely support these two aspects, 22.3% said that they often support them, and only 19.6% stated that they always support them. This demonstrates the need for teaching materials that not only enhance cognitive understanding but also facilitate character values such as honesty, responsibility, and collaboration skills.

An analysis of learning conditions revealed that the media commonly used by teachers are still dominated by PowerPoint (28.3%), the internet (29.9%), and PDF/printed books (21.9%). Meanwhile, the use of interactive media such as flipbooks was limited, used by only 8.8% of

respondents. This indicates that students' learning experiences remain relatively monotonous, impacting low student participation. Therefore, the development of interactive digital textbooks based on deep learning is an innovative solution to create more dynamic, contextual, and student-centered learning.

Expert Validation

The interactive digital book prototype was evaluated by three groups of experts. The media expert assessed design quality, usability, and interactivity, while the material expert focused on content accuracy, curriculum alignment, and pedagogical effectiveness, and the language expert reviewed clarity and readability.

The validation results are presented in Table 1.

Table 1. Expert Validation Results

Validation	Results	Category
Media	4.30	Valid
Language	4.82	Valid
Material	4.15	Valid

Source: Prepared by the authors (2024)

Both validations confirmed that the digital media were suitable for classroom implementation after minor improvements related to content organization, visual design, instructions for interactive questions, and audio-video quality. (Hillmayr et al., 2020; Lohr et al., 2024)

Small-Scale Trial

The revised prototype was tested with 20 students from Muhammadiyah Al Amin High School in Sorong who had previously studied regression analysis material. The questionnaire results showed that most students responded in the "very good" category, with the remainder in the "good" category. Overall, the practicality level of this small-group trial reached an average of 84%, which falls within the "practical" category. These results confirm that the product can be successfully implemented in learning, although it still required some refinement before wider

implementation. Students particularly appreciated the video explanations, interactive Wordwall exercises, and the contextual presentation of regression concepts linked to real-life data prediction.

Large-Scale Trial

Following the small-group trial, the product was implemented with 70 students. Students were given access to the interactive flipbook and participated in learning activities using the deep learning approach (meaningful, mindful, and joyful learning). After the activities were completed, students filled out a questionnaire to assess the product's practicality. The analysis showed that most students rated the interactive digital book as "very good," while the remainder rated it as "good." The average practicality score was 92.5%, indicating that the interactive digital book—based on deep learning and character

building—was highly practical for use in learning, both in terms of ease of access, clarity of material, and active student engagement.

Table 2. Student Response Questionnaire Results

Assessment Aspects	Percentage (%)	Category
Appearance appeal	88.57%	Very Practical
Ease of use	85.71%	Very Practical
Material usefulness	90.00%	Very Practical
Average Total	88.09%	Very Practical

Source: Prepared by the authors (2024)

Learning Outcomes Improvement

Pretest and posttest scores indicated significant improvement in student understanding of regression analysis. The average student score increased from 65.67 in the pre-test to 75.87 in the post-test. The results of the Paired Sample t-Test indicated a significant difference between students' pre-test and post-test scores ($t = 17.38$, $p < 0.001$). The average N-Gain value was 0.3161 or 31.61%, which is included in the moderate category. This indicates that the use of interactive digital modules based on the deep learning approach was effective in improving student learning outcomes.

Table 3. Paired Sample t-Test Results

Test	N	Mean	t	Sig. (2-tailed)
Pre-test vs Post-test	70	65.67 vs 75.87	17.38	<0.001

Source: Prepared by the authors (2024)

Student Activity and Character Development

Student activity observations focused on four components: (A) involvement in group discussions; (B) helping group members in working on problems; (C) presenting discussion results; and (D) demonstrating discipline and responsibility in submitting assignments. These activities reflected problem-solving abilities and character values. Observation results showed that student activity consistently increased, with scores in the "Good" category (range 80–90%) on the second and third days of learning. This improvement demonstrates that the implementation of interactive digital modules based on a deep learning approach encouraged more active student engagement. Students not only followed instructions but also engaged more in discussions, asked questions, analyzed data,

and developed solutions. Active student engagement also reflected the strengthening of positive character traits, such as honesty in data processing, discipline in completing assignments on time, and responsibility for their respective roles in the group. (Tarusu et al., 2022; Rina et al., 2020; Mucinskas et al., 2025)

Overall Findings

At all stages, the results showed that the interactive digital module developed was valid, practical and effective. Expert validation confirmed feasibility across media, language, and material aspects. Student responses rated the module as "Very Practical" with an average of 88.09%. The paired sample t-test demonstrated significant improvement ($p < 0.001$), supported by a moderate N-Gain of 0.3161. Students showed increased motivation, deeper conceptual

understanding of regression analysis, and strengthened character values of honesty, responsibility, and discipline. The combination of quantitative and qualitative evidence suggests that the product successfully addresses the needs of high school mathematics learning by aligning pedagogical deep learning principles with character education.

4. Discussion

The objective of this research was to develop, validate and implement an interactive digital book for teaching statistics (regression analysis) using a pedagogical deep learning approach integrated with character education at SMA Muhammadiyah Al Amin Sorong. The results of the study reveal findings consistent with previous literature in the field of digital mathematics learning and character education.

First, the needs analysis confirmed that existing teaching materials and media were insufficient in supporting critical thinking and character development. This finding aligns with previous research emphasizing the importance of innovative digital tools in secondary mathematics education. Students expressed the need for more interactive and contextual media, supporting the rationale for developing a flipbook-based digital module with multimedia features. (Pepin et al., 2017; Wijaya et al., 2025)

Second, the validation by experts confirmed that the digital learning media met high standards of pedagogical and technical quality. Media, language, and material experts all rated the product as Valid. These dual approaches of technical and pedagogical validation are critical to ensure effective integration of functionality and pedagogy. The high validity scores indicate that the material is effectively aligned with the existing curriculum, so teachers can adopt it without major adaptations. This discovery reinforces the importance of aligning digital learning supports with curriculum objectives. (Lohr et al., 2024; Setyo et al., 2023; Setyo et al., 2024)

Third, the results of the trials showed high practicality and effectiveness of the digital media. Students in both small- and large-scale trials

showed high satisfaction, with the large-group average reaching 92.5% practicality and overall student response at 88.09% (Very Practical). This suggests that the product not only attracted attention but also motivated students to engage in analytical tasks related to regression. These results coincide with findings that digital platforms can significantly increase engagement and reduce learning barriers in mathematics. (Mamolo, 2019; Brnic et al., 2024; Wijaya et al., 2022a; Trisnawati et al., 2026)

Fourth, the effectiveness was demonstrated through significant improvement in learning outcomes. The paired-sample t-test ($p < 0.001$) and moderate N-Gain (0.3161) indicate that the module contributed meaningfully to students' understanding of regression analysis. From a critical thinking perspective, students were encouraged to identify important information, construct simple linear regression models, complete calculations, and interpret results in real-world contexts. These activities reflected a meaningful and mindful learning process that required students to not only memorize procedures but also connect concepts to everyday problems. (Barana et al., 2021; Rezat, 2021; Nugroho et al., 2024)

Furthermore, this module played a role in strengthening students' character, particularly the values of honesty, responsibility, and discipline. These character traits were reflected in students' involvement in working on problems independently, completing assignments on time, and actively participating in group discussions. These findings support the argument that interactive digital media can be a strategic tool for integrating cognitive learning with character development. Thus, the module's success in both cognitive and affective aspects demonstrates that integrating digital technology into mathematics learning not only supports academic achievement but also strengthens character education relevant to the demands of the 21st century. (Tarusu et al., 2022; Rina et al., 2020)

Another important finding is the potential of pedagogical deep learning principles (meaningful, mindful, and joyful learning) when integrated into

digital media design. In the meaningful learning aspect, students connected regression concepts to real-world contexts. In the mindful learning aspect, students demonstrated thoroughness and awareness in data processing. In the joyful learning aspect, interactive features such as Wordwall-based exercises made the learning atmosphere more enjoyable and encouraged collaboration. This confirms that interactive digital modules based on deep learning not only improve conceptual understanding but also strengthen students' character and motivation. (Kovač et al., 2025; Jiang, 2022; Deák et al., 2021)

Despite these strengths, several limitations should be acknowledged. First, the study was limited to a single school, which may restrict the generalizability of the findings. Second, while the product was tested in classroom settings, longer-term effects on critical thinking and character development were not measured longitudinally. Third, the reliance on self-reported data and classroom observations may introduce certain biases. Future studies should involve larger and more diverse samples, longitudinal tracking of learning outcomes, and mixed-method evaluations incorporating performance-based assessments.

Finally, the findings have important pedagogical and policy implications. For teachers, the study demonstrates the value of integrating interactive digital modules based on deep learning into statistics lessons to enhance critical thinking and character. For policymakers and curriculum developers, the study highlights the need to support the development of contextually appropriate digital resources that balance cognitive and affective goals. At a broader level, the study contributes to the digital transformation of mathematics education and aligns with efforts to prepare students for 21st-century challenges. (Lohr et al., 2024; Wijaya et al., 2025; Ye et al., 2023)

5. Conclusion

The results of this study suggest that the development of an interactive digital book based on a pedagogical deep learning approach and character education is viable and effective to

improve critical thinking skills and character values of high school students in learning statistics, particularly regression analysis. Through the systematic phases of the ADDIE model (Analyze, Design, Development, Implementation, and Evaluation), the product successfully responded to the specific needs of students and teachers at SMA Muhammadiyah Al Amin Sorong. Expert validation reaffirmed the validity of the content, media, and language aspects. Trials with students demonstrated high practicality (88.09% Very Practical) and significant effectiveness, evidenced by improved pre- to post-test scores ($p < 0.001$) and a moderate N-Gain of 0.3161. Collectively, these findings confirm that carefully designed digital resources integrating deep learning principles and character education can help bridge gaps in mathematics learning, offering accessible, interactive, and context-relevant tools. (Hillmayr et al., 2020; Wijaya et al., 2022; Setyo et al., 2023)

In addition to validating the efficacy of the product, this research contributes to creating a broader discourse on integrating cognitive and affective dimensions in digital mathematics education. Focused mainly on critical thinking in regression analysis and character values (honesty, responsibility, and discipline), the research fills an important gap where previous digital media often neglected systematic character integration. Integrating contextual problems, interactive tasks, multimedia features, and reflective activities contributed not only to conceptual understanding but also to confidence, motivation, and positive character formation.

Despite its strengths, the study also acknowledges some limitations, such as the single-school sample and short implementation duration. These limits suggest that future studies should be replicated in different contexts, introduce longitudinal designs to measure long-term improvements in critical thinking and character, and use additional performance evaluations. However, the results of this study offer important pedagogical and policy implications. For teachers, the study offers a model to enhance motivation, engagement, critical thinking, and character through interactive digital modules. For

educational stakeholders, it underscores the importance of investing in digital resources that foster both academic achievement and character education. In short, the interactive digital book

developed constitutes a practical and innovative contribution to improving students' mathematics learning outcomes while supporting 21st-century educational goals.

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8. Author Declaration

The authors declare that this work is original and has not been published elsewhere, in whole or in part. The authors also declare that there are no conflicts of interest related to this research or its publication.