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TPACK-Based Digital Flipbooks to Reduce Misconceptions in Newton's Second Law Materials

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ABSTRACT

Misconceptions concerning Newton's Second Law remain prevalent among secondary school students and hinder meaningful physics learning. This study aimed to develop and evaluate a Technological Pedagogical and Content Knowledge (TPACK)-based digital flipbook designed to improve conceptual understanding and reduce misconceptions. The study employed a research and development approach using the 4D model (Define, Design, Develop, and Disseminate). Product feasibility was assessed through expert validation, while practicality was examined through limited field trials. Effectiveness was evaluated using a quasi-experimental non-equivalent control group design involving 60 eleventh-grade science students. Data were collected using validation instruments, student response questionnaires, and a four-tier diagnostic test administered as a pretest and posttest. The digital flipbook achieved a high feasibility score (89.51%) and demonstrated increased practicality after revision (from 57.13% to 89.27%). The experimental group showed substantially higher conceptual understanding (64.76%) and lower misconceptions (5.71%) compared to the control group (17.14% understanding; 27.86% misconceptions). Normalized N-Gain analysis indicated medium-to-high improvement in the experimental group, and an independent sample t-test revealed a significant difference between groups ($t = 12.572$; $p < 0.001$). These findings indicate that the TPACK-based digital flipbook is feasible, practical, and effective, contributing an evidence-based instructional model for reducing physics misconceptions through integrated technology-enhanced learning.

ARTICLE INFORMATION

Keywords:
flipbooks; fourtier diagnostic test; misconceptions; TPACK

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INTRODUCTION

Newton's Second Law is a fundamental principle of physics that describes the relationship between force, mass, and acceleration. Still, many students misunderstand this concept. Research shows that these misunderstandings go beyond simple calculation errors and include strong beliefs that do not align with scientific ideas (Landusa & Ali, 2021; Sitepu & Yakob, 2019). A preliminary observation was conducted at SMA N 2 Timang Gajah through interviews with one physics teacher and three twelfth-grade students, along with an analysis of students' responses to five four-tier diagnostic questions on Newton's Second Law concepts. The results of the diagnostic test indicated that there was a fairly high misconception where as many as 52% of students had a misconception about the friction force with the reason why the object remained stationary even though the next force was given 41.38% of the students indicated a misconception related to the relationship between doubling the force and acceleration where in the other question it indicated a misconception rate

between 7% and 21%. This result was reinforced by interviews with students, in which three reported difficulty understanding Newton's second law, especially in calculating and understanding the relationship between force, mass, and acceleration. Interestingly, all the students interviewed expressed a strong interest in using interactive digital flipbooks accessible on mobile devices, while teachers stated that flipbooks had never been used as a learning medium. For example, some students considered that heavier objects fell faster or that it always took force to keep moving. This view often stems from everyday experiences that can pose difficulties in physics learning (Halim et al., 2021; Landusa & Ali, 2021; Sitepu & Yakob, 2019). Observations in the classroom indicate that even though the method used, for example, *Problem-Based Learning* (PBL) with hands-on activities is directly determined, students still experience difficulties in understanding and establishing physics concepts, where one of the causes is the decline in diverse learning media with interactive features, and the basis is technology.

The four levels of diagnostic tests are often widely recognized as highly valid and reliable instruments for analyzing students' misconceptions and their level of confidence in physical concepts. Systematic research by Ma et al. (2025) indicates that diagnostic technology at four levels is the most accurate method for analyzing misconceptions because it simultaneously captures the accuracy of students' answers, the reasons they give, and their epistemic beliefs. Strong empirical support can therefore drive this conclusion, where a study conducted by Istiyono et al. (2023) developed and validated the *Four-Tier Diagnostic Test* (FTDT), which showed more than 700 high school students who indicated high content validity (Aiken's V = 0.85–0.94) with a good reliability level of (α = 0.90). This is in line with research conducted by Mi et al. (2023) to validate diagnostic instruments at four levels, whose content is 20 questions on a large sample of 1,850 students, which indicates that the ability of this instrument can produce detailed and in-depth profiles of students' conceptual understanding and misconception patterns on several physics topics.

An accurate diagnosis of misconceptions is essential, where effective interventions in learning are equally crucial to facilitate conceptual change. These *interactive digital flipbooks have shown great potential to improve conceptual understanding and reduce* misconceptions in science learning. Misconceptions among students are reduced by 88% through interactive e-flipbooks based on a concept change strategy (Nurrahmah & Sukarmin, 2023). Therefore, another study found a significant increase in science literacy, with the experimental group achieving an N-Gain score of 0.68 compared to the control group's score of 0.31 (Hanik et al., 2025). To support these results, Thomas and Kumar (2024) reported a significant increase in student engagement and understanding through interactive digital learning resources, while Marisda et al. (2020) found that interactive multimedia can drastically reduce misconceptions, with several test questions decreasing from 81% to 18.9%. These results emphasize the importance of collaborating to develop accurate and effective diagnostic instruments and digital learning media to address misconceptions that persist, especially in physics education.

In today's modern classroom, where using the right educational technology is important, students who respond well and show a high interest in learning tools that are easy to access, for example, via mobile phones or tablets, are valued (Fikriansyah et al. 2023). One promising option is *an interactive digital flipbook* that combines text, images, animations, and simulations into a single medium to deliver abstract concepts, such as Newton's Second Law, in a clear, visual way. This tool can help to improve learning and reduce misunderstandings (Kodi et al., 2023; Nurrahmah & Sukarmin, 2023). However, creating effective digital media does not depend solely on technology; it also requires a careful balance among content, teaching methods, and technology that support each other. The Technology, Pedagogical Content Knowledge (TPACK) Framework provides a solid foundation for designing learning interventions. TPACK focuses on how teachers can combine content,

pedagogy, and technology to create meaningful learning experiences (Hayani & Sutama, 2022). By using TPACK-based flipbooks, Newton's Second Law material can be delivered accurately, tailored to students' needs, and enriched through interactive technology. This approach aims to make the material more engaging while also helping students recognize and correct misunderstandings.

The second teaching of Newton's Law in physics still faces several obstacles, as students are more likely to hold misconceptions that can make it difficult to understand the concepts (Landusa & Ali, 2021; Sitepu & Yakob, 2019). To overcome this, using digital media in learning, especially those guided from an integrative framework, which is often considered a promising approach, has been proven to increase student engagement to improve conceptual understanding and provide an interactive learning experience that cannot be provided by traditional methods (Fikriansyah et al. 2023; Kodi et al., 2023). In addition, digital tools can enable educators to present complex scientific phenomena through multiple representations, such as animations, simulations, and interactive diagrams, helping students visualize abstract concepts and develop more accurate mental models. The theory behind making and using this kind of media can be seen from three main angles: constructivist learning theory within the framework of *Technological Pedagogical Content Knowledge* (TPACK), and *the digital flipbooks* feature, which is an interactive tool.

Constructivist Learning Theory holds that students actively build their knowledge through experience and interaction with their surrounding environment (Suparno, 2013). This theory focuses on meaningful learning, in which students explore, reflect, and construct their own meaning rather than passively receiving information. In learning physics, some abstract concepts, such as the relationship between force, mass, and acceleration, require contextual experiences that allow students to test their initial understanding. Digital media, such as simulations and interactive animations, serve as virtual learning environments that support this knowledge construction by providing dynamic visual representations and exploratory experiences that are difficult to obtain through traditional teaching methods.

The learning environment is supported by technology grounded in constructivist theory, empirically proven to facilitate conceptual change through dynamic visualization and interactive simulation. Empirical evidence consistently supports this, as previous research by Fan et al. (2018) indicated that simulation-based interactive learning can significantly improve students' conceptual understanding, tracing skills, and self-confidence in learning. In line with Kaldaras et al. (2024), who found that computer simulations that provide scaffolding from the nativity can help students overcome differences in initial knowledge, even though careful instructional design is needed to increase their effectiveness. Kluge (2019) indicated that interactive representations can cause students to be able to negotiate the meaning between initial knowledge and scientific concepts with formality, while Afanasenko et al. (2022) indicate that a digitally enriched learning environment can positively develop the ability to think critically and skills in tracing students so that overall this study indicates a strong pattern and consistency that a learning environment based on technology and constructivism is very effective in encouraging conceptual change in science education.

The Technology Pedagogical Content Knowledge Framework (TPACK) provides a structured approach to integrating technology into the educational process (Koehler et al., 2013; Mishra & Koehler, 2006). Recent research continues to confirm the effectiveness of TPACK in improving the integration of educational technology while supporting innovative teaching methods (Mgeladze et al. 2024). According to TPACK itself, effective technology integration requires the ability to use technological tools (Technological Knowledge), a deep understanding of the subject matter (Content Knowledge), and the application of appropriate pedagogical strategies (Pedagogical Knowledge). These three domains interact with each other to form specialized fields of knowledge, such as Technology Content Knowledge (TCK), which together comprise TPACK: the ability to design teaching

that combines technology, pedagogy, and content. In the development of flipbook media for Newton's Second Law, TPACK can guide the creation of scientifically accurate content, the selection of presentation methods that suit students' learning preferences, and the integration of technological features such as animations and interactive quizzes for the identification and improvement of misunderstandings. Several studies indicate that the TPACK-based approach is effective in improving students' conceptual understanding, for example, Halim and Rizki (2024) providing reports of significant improvements, Baihaqi et al. (2022) achieving implementation effectiveness of 91.67%, and AlArabi et al. (2022) providing better guidance on learning outcomes than traditional face-to-face education.

Digital flip books serve as a learning medium that connects text, images, audio, video, and animation in a digital book format, with interactive elements that unfold when a page is opened (Rusnilawati & Gustiana, 2017). This media presents sequential, engaging multimodal information that supports adjustments to several learning styles, such as visual, auditory, and kinesthetic, and increases student involvement. Compared to conventional e-books, flipbooks offer greater interactivity, including links to simulations with instant feedback, facilitating independent learning and concept exploration. To address misconceptions, flipbooks can provide step-by-step visualizations of the process and direct comparisons between false and correct concepts, encouraging students to revise their concepts (Nurrahmah & Sukarmin, 2023). However, effective implementation can depend on adequate technological infrastructure and teachers' ability to use this tool.

From a constructivist perspective, the TPACK framework and the typical features of interactive digital books (flipbooks) guided this study in developing and evaluating TPACK-based interactive digital books for Newton's Second Law as a learning intervention. This intervention integrates technology, constructive pedagogy, and scientific content to create an interactive, contextual, and structured learning environment. The goal is to systematically identify, address, and correct student misunderstandings. This study assesses the feasibility, practicality, and effectiveness of media in reducing misunderstandings. The novelty of the research lies in the combination of TPACK-based interactive digital book design with a Four-Level Test diagnostic instrument to analyze conceptual understanding and student confidence. This research aims to contribute an innovative learning media model that expands the literature on the integration of TPACK in science education while offering practical solutions for educators to improve physics teaching and reduce conceptual gaps among secondary school students.

METHOD

This research uses a research and development (R&D) method, which follows a 4D model: Define, Design, Develop, Disseminate (Istiyono et al. 2023). The 4D model was chosen because it can provide a systematic and structured framework so that it can make it easier to create digital flipbook learning media based on TPACK with valid, practical, and effective so that with development starting from the Define stage which includes an analysis of initial needs to identify learning challenges, student analysis to assess cognitive profiles with learning styles in students and analysis of concepts that used to prepare the second Newton's Law material hierarchically so that at the design stage that has a focus on the development of the initial product, including the preparation of tests whose basis is criteria in selecting appropriate media and presentation formats and designing visual elements and flipbook navigation. The Develop stage includes validation from material and media experts to conduct content and design feasibility assessments, followed by a limited two-stage field trial with students to get input on media practices and clarity. In the last stage, Disseminate involves disseminating the finished product to a wider audience, including teachers and other schools, to encourage the adoption of innovation in learning.

The effectiveness of the media developed was evaluated using a quasi-experimental design with a non-equivalent control group. This approach involved two randomly selected groups: an experimental class that used a TPACK-based digital flipbook for learning and a control class that followed conventional learning with standard media such as textbooks, PPT presentations, and practical work. The research population comprised all 11th-grade science students at SMA Negeri 2 Timang Gajah, with sampling aimed at obtaining representative participants. Two classes were selected based on academic characteristics and teacher readiness, with 30 students in each. The data collection instrument consists of: 1) expert validation sheets that assess learning materials, media, and designs to assess the feasibility of the product; 2) a four-level diagnostic test given as a pretest and posttest to identify the type and degree of student misconception and measure changes in conceptual understanding; and 3) a Likert scale student response questionnaire to evaluate the practicality, usefulness, and appeal of the media. Data analysis was conducted using a comprehensive quantitative approach, supplemented by qualitative analysis of expert feedback and open-ended student responses.

Analysis of quantitative data is carried out in several stages. The first is the product's feasibility, assessed by calculating the average validation score, converting it to a percentage, and categorizing it according to the adaptation criteria from Oktaviara and Pahlevi (2019): very feasible, feasible, less feasible, and not feasible. In both profiles, misconceptions were identified using 16 answer patterns from the four-tier test (Ismail, 2015), which were grouped into concept understanding, lack of concept understanding, misconception, and error. The percentage of misconceptions was explained using the criteria outlined by Handayani (2018). The third is the effectiveness of the media in improving understanding of concepts, evaluated by calculating *normalized N-Gain* (Hake, 1998) by reducing the number of students who experience misconceptions, which are analyzed using the modified ΔM formula. The fourth is practicality, whose medium is determined from student responses analyzed using descriptive statistics to identify response trends ranging from very positive to very negative. In addition, in the inferential statistical test, it is determined to assess the significance of the results which include *the Shapiro-Wilk Test* which is used to normalize the data, namely *Levene's Test* is used for variance homogeneity with *the paired sample t-test* test which is used for the comparison of pretest and posttest scores in the experimental group so that the overall statistical analysis is carried out using SPSS in version 16 to ensure accuracy and reliability.

RESULTS AND DISCUSSION

The development of digital flipbook learning media based on Technological Pedagogical Content Knowledge (TPACK) for Newton's Second Law is implemented using the 4D research and development model, namely Define, Design, Develop, and Disseminate. At the identification stage, needs analysis, student analysis, and concept analysis were conducted to identify several main issues. The initial findings indicate that conventional teaching methods, which mostly use lectures and textbooks, are less effective at explaining the abstract relationship between force, mass, and acceleration. In addition, students also hinted at a strong interest in technology-based learning and expressed common misconceptions, such as believing that objects with greater mass fall faster or that continuous force is necessary for motion.

In the Design stage, a *digital flip-book prototype* was made that combines the three pillars *of Technological Pedagogical Content Knowledge* (TPACK). *Content Knowledge* (CK) identifies in the systematic presentation of the second law in Newton which starts from the basic concept of mathematical formulas ($\sum F = m.a$) to the determination of contexts, for example such as motion in data fields with slants*, Pedagogical Knowledge* (PK) is determined through the *Problem-Based Learning* model (PBL) where each part of the flipbook includes a guiding statement with real case

studies with investigative activities by encouraging the ability to do critical thinking. *Technological Knowledge* (TK) realized through multimedia includes interactive simulations from the PhET platform, explainer videos, and Quizizz-based evaluative quizzes that provide direct feedback, shaping the flipbook's navigation structure in a way that is intuitive and visually appealing to support independent and focused learning.

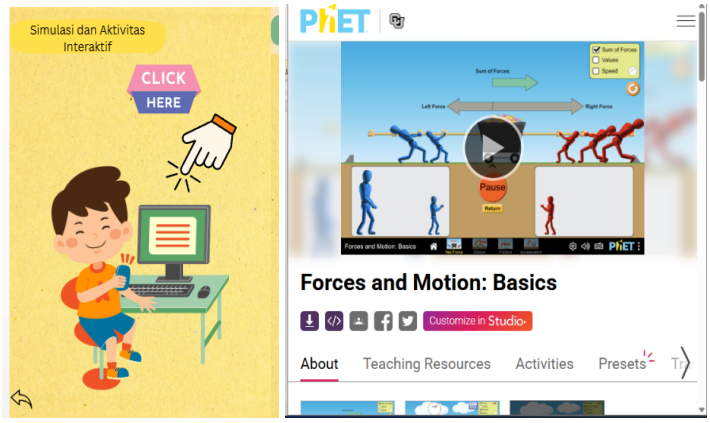

Figure 1. PhET Simulation Display

After the design phase is completed, the product proceeds to the Development stage, which includes expert validation and field tests. Validation was carried out by three material experts and three media experts, who provided very positive responses. The average eligibility percentage was 89.51%, with material experts assessing 90.76% and media experts assessing 88.26%, both categorized as "Very Valid". The validators assessed that the flipbook had met the criteria of content accuracy, pedagogical suitability, design appeal, and technological usability. The research instruments, including student response questionnaires and four-level diagnostic tests, were also found to be valid and reliable following a thorough validation process and empirical testing. Field testing was carried out in two stages, as shown in Table 1, and the results were validated by material experts and the media.

Table 1. Validation results by subject matter experts and media experts

Validator	Score	Maximum Score	Percentage (%)	Criteria
Content Expert	59	65	90.76	Highly Valid
Media Expert	110,33	125	88.26	Highly Valid
Average			89.51	Highly Valid

In *Trial I*, 23 students with a practicality score of 57.13% were selected, who had sufficient categories when the main categories were included, indicating the need for clearer instructions for use. The data from the student response questionnaire is shown in Table 2.

Table 2. Results of Student Response Questionnaire for Trial I

Average Score	57.13333333
Percentage (%)	57.13333333
Category	Adequate

After adding a clearer instruction page, Trial II, involving 20 students, showed significant improvement in instructions, with a practicality score of 89.27% (Very High category). These findings

indicate that the media is now more accessible and understandable to users. The data from the student response questionnaire is shown in Table 3.

Table 3. Results of Student Response Questionnaire for Trial II

Average Score	89.26666667
Percentage(%)	89.26666667
Category	Very High

A quasi-experimental, non-equivalent control-group design was used to assess the effectiveness of the final product, with the sample consisting of two science classes, namely class XI at SMA Negeri 2 Timang Gajah, each containing 30 students selected using the purposive sampling technique. In the experimental group that used *Digital Flipbook* The basis is TPACK while in the control group by receiving learning using traditional methods including by using lectures, discussions, and textbooks so that effectiveness is measured using *Four-tier diagnostic test* who assess not only the accuracy of the answers but also the beliefs and reasons of the students so that this approach can make the right identification of the *Concept Understanding (CU)*, *No Concept Understanding* (NCU), *Misconceptions* (MC), and *Errors* (ER). The analysis of students' answers to the diagnostic test in both groups is shown in Table 4.

Table 4. Results of analysis of diagnostic test answers

Answer Categories	Experimental (%)	Control (%)
Concept Understanding (CU)	64.76	17,14
Misconceptions (MC)	5.71	27,86
No Concept Understanding (NCU)	17.14	49,64
Errors (ER)	12.38	5,36

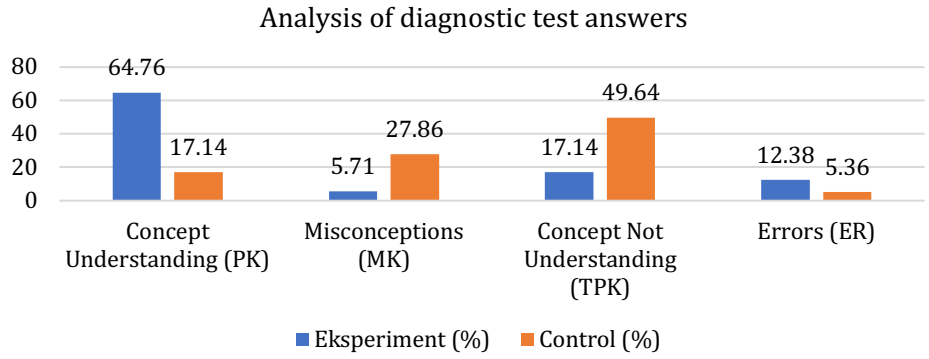

Figure 2. Results of analysis of diagnostic test answers

The posttest results showed a significant difference between the two groups. In the experimental class itself, 64.76% of students demonstrated conceptual understanding (CU), while only 5.71% experienced misconceptions (MC). In contrast, the control class recorded the lowest CU percentage (17.14%) and the highest MC percentage (27.86%). Follow-up analysis using normalized N-Gain indicated that the experimental class achieved an average N-Gain of 0.690-0.829 and was in the medium to high category. In comparison, the control class recorded an N-Gain of 0.209-0.381, which was classified as low to moderate. These findings focus on flipbook-based learning interventions that can provide a more significant improvement in conceptual understanding. The

assessment of improvements in conceptual understanding in both classes was conducted using several specific indicators.

Table 4. Results of the Concept Understanding Improvement Test

Indicator	Experimental Class	Category	Control Class	Category
1	0,690	Medium	0.2	Low
2	0,798	High	0.379032	Medium
3	0,829	High	0.381395	Medium
4	0,789	High	0.209424	Low

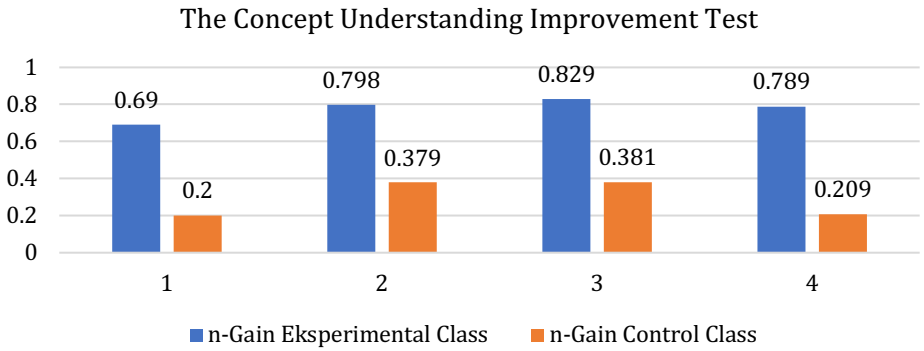

Figure 3. Results of the Concept Understanding Improvement Test

Several condition and hypothesis tests were performed to assess statistical significance of observed differences, and the Kolmogorov-Smirnov test indicated that the data were normally distributed (Experimental sig. = 0.571; Sig. control = 0.616; $p > 0.05$). The Levene test indicated that the variance between groups was homogeneous (Sig. = 0.514; $p > 0.05$). After this assumption was met, an independent t-test was carried out, which showed that the result of this t-test was 12.572 with a significance value (2-tailed) of 0.000 ($p < 0.001$). This result provides strong statistical evidence to reject the null hypothesis (H0) and accept the alternative hypothesis (Ha). Therefore, there is a clear difference in learning outcomes, which is a conceptual understanding, between students who use TPACK-based digital flipbooks and students who receive traditional learning.

The results of this study are the instructions for the TPAK-based digital flipbook, developed to be feasible to use, easy to apply, and very effective in improving conceptual understanding while reducing students' misunderstandings of Newton's Second Law. This effectiveness can arise because the media design synergistically integrates the three core components of TPACK. From the view of Content Knowledge (CK) where flipbooks indicate material with a logical structure that uses multiple representations where concepts are abstractly shown with text through style vector diagrams with contextual style examples so that in this approach students to build a schema in a stronger mentality in conducting an assessment of the dynamic relationship between styles, masses, by accelerating and being able to reduce the occurrence of misunderstandings about the concept.

From the perspective of Pedagogical Knowledge (PK), the application of the Problem-Based Learning (PBL) model in the flipbook flow transforms students from passive recipients into active inventors. Engaging in conceptual problems and guiding questions encourages students to explore, formulate hypotheses, and test their own understanding. This approach aligns with constructivist theory, which focuses on learners actively building knowledge. For example, exploratory activities in PhET simulations can create cognitive conflicts when simulation results challenge students' prejudices, thereby encouraging conceptual change.

The component of Technological Knowledge (TK) plays an important role as a catalyst and a link, where technology serves not only as a means of communication but also as a medium for providing convenience in applying pedagogical approaches that are difficult to implement conventionally. An example is the PhET simulation, which provides a virtual laboratory where students can manipulate variables such as force and mass and directly observe acceleration in real time, something that cannot be achieved by simply explaining verbally or using static images. Therefore, interactive quizzes, namely Quizizz, can provide formative feedback instantly and personally, enabling students to make corrections independently. The integration of dynamic visualization, interactivity, and direct feedback can make flipbooks more effective at overcoming and correcting misunderstandings compared to traditional lectures or group discussions.

The significant decrease in misunderstandings observed from the baseline level to 5.71% in the experimental group compared to 27.86% in the control group provides strong empirical support for the technology-based conceptual change approach. These findings hint at many misconceptions in physics arising from limited representations of concepts. By presenting the same concepts through rich, multimodal, and interactive media, students can develop more accurate mental models. These results are in line with Halim and Rizki (2024), who proved the effectiveness of TPACK in overcoming misconceptions about Newton's Law, and Nurrahmah and Sukarmin (2023), who found that interactive e-flipbooks can significantly reduce misconceptions about reaction rates. Recent studies also provide support for technology-based approaches. Mukramah et al. (2023) reported a reduction in misconceptions from 57.01% to 20.24% using flipbook-assisted modules, with an N-Gain of 0.71, and Masrifah et al. (2025) reported high expert validation (88%) and a strong increase in conceptual understanding (N-Gain 0.56-0.87) through TPACK-based e-books. Harjono et al. (2020) reported N-Gain scores of 0.79 and 0.70 using an interactive multimedia e-book, while Suhandi et al. (2025) successfully reconstructed students' mental models using the Four-Level MOTION Diagnostic Test, achieving an acceptable correction rate of 52%. Some of these findings are consistent across a range of contexts, strengthening the evidence base for technology-integrated pedagogical interventions.

The novelty of this research lies in the systematic integration of three important elements: 1) the TPACK framework as a comprehensive design principle for educational technology; 2) the Four-Level Diagnostic Test as a rigorous instrument for measuring conceptual understanding and epistemic beliefs; and 3) a digital flipbook as a multimodal learning environment specifically designed to overcome physics misconceptions. In contrast to previous studies that examined these components separately, this study provides clues to the synergistic effects of combining the three, resulting in a much greater reduction in misconceptions from 27.86% to 5.71% compared to conventional teaching approaches. The scientific contribution of this research can go beyond just the implementation of technology with this study providing empirical evidence for a theory-based model that can be replicated, allowing physics educators to systematically diagnose and correct student misconceptions. This study can advance the field of physics education by showing that strategic alignment between technological capabilities, pedagogical strategies, and content-specific learning design can result in an increase in measurable conceptual understanding so as to overcome the challenges that continue to arise in science education as documented in various international contexts (Chi & Roscoe, 2002; Vosniadou, 2013). Although the results of this study are positive, there are some limitations that must be considered. The limited scope and small sample size can limit the ability to extrapolate the results to a broader population. In addition, the short duration of the intervention can delay assessment of the long-term effects of flipbooks on concept retention and knowledge change, so this study specifically assesses cognitive outcomes in students. However, the dimensions, for example, affective, such as attitudes on physics and self-efficacy in solving problems, can be further researched. Given the limitations that exist, several research directions in the future can be carried out: 1) Carry out similar

research on a larger scale and a more diverse sample from various regions and school levels to be able to assess the external validity of the findings; 2) Conducting a longitudinal study design to observe the resilience of learning effects and the possibility of transferring concepts to other physics topics; 3) Conduct research on students' cognitive processes when using flipbooks through qualitative approaches such as hard thinking protocols or in-depth interviews to be able to understand the mechanisms that provide the impetus for conceptual change; 4) The development of professional programs aimed at enabling teachers to master the TPACK framework so that it will facilitate the implementation and adaptation of similar media in other subjects.

The practical implications of this study are its coverage of various stakeholders in the education ecosystem. For physics teachers themselves, TPACK-based digital books provide a ready supply of learning resources that can be directly integrated into the curriculum, reducing preparation time and improving student learning outcomes. The effectiveness of this medium in reducing misconceptions from 27.86% to 5.71% provides strong evidence for school administrators to invest in digital learning infrastructure and professional development programs focused on TPACK competencies. For curriculum developers and education policymakers themselves, this research provides a scalable model for technology integration that can be adapted to various topics in physics and other STEM disciplines. In addition, this research also supports teacher education programs by providing empirical evidence for TPACK-based pedagogical training and the preparation of prospective teachers to design effective learning experiences with the support of technology. The long-term impact of implementing evidence-based digital learning media is to improve student achievement in physics, strengthen scientific literacy, and better prepare students for advanced STEM education and careers, ultimately increasing national competitiveness in science and technology.

CONCLUSION

This research developed a digital flipbook based on TPACK for Newton's Second Law, demonstrating both practicality and effectiveness. Expert validation and student feedback indicate the high quality of this learning medium. The results of the experiment are supported by strong statistical analysis which indicates that this media is significantly more effective in terms of improving concept understanding and reducing misunderstandings in students' understanding when compared to traditional learning methods, so this study emphasizes the importance of connected learning planning so that technology has a role as a core component in pedagogical strategies that deliver specific content so that digital flipbooks based on TPACK can provide innovative solutions based on research on challenges by teaching physics concepts in the abstract and prone to misunderstandings at the high school level.

DECLARATION OF GENERATIVE AI

The authors declare that no generative AI or AI-assisted technologies were used in the writing process of this manuscript.

CONFLICTING INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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