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TPACK-Based E-Textbooks for Science Literacy: A Systematic Review in Primary School Education

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Abstract

The purpose of this study is to investigate the need for TPACK-based digital book development in an effort to improve science literacy in primary schools. The study used a systematic review method of 67 domestic and international academic articles published between 2019 and 2025. This research was carried out through the provision of seven main indicators, namely the characteristics of students at the elementary school level, the characteristics of teachers at the elementary school level, the need for digital media and digital books for science learning at the elementary school level, TPACK strategies in learning design, incorporating TPACK into digital books, science literacy as the main goal of science learning, and the use of digital books in education. The results of the analysis showed that students needed interactive, multimodal, and context-specific learning media, while teachers needed detailed TPACK-based training assistance. Furthermore, digital books designed based on TPACK are able to increase students' knowledge of concepts, learning engagement, and learning abilities. These results confirm the fact that TPACK-based digital book design is an innovative solution applied to learning science in primary schools. This study is likely to have an impact on the basis for adaptations, contexts, and effective products on digital science books to enable national learning services.

Keywords: Digital Books, TPACK, Science Literacy, Elementary School

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INTRODUCTION

The integration of Natural Sciences (IPA) and Social Sciences (IPS) in one integrated subject reflects the response to the increasingly complex educational needs of the 21st century. The world of education is required to no longer rigidly separate the natural and social sciences, but to integrate them in order to equip students with a holistic understanding of the phenomena around them. Research shows that this kind of integration allows students to understand the relationship between natural phenomena and social dynamics in a more meaningful and applicable way (Jayanti et al., 2023); (Ritonga et al., 2022).

The need for the integration of science and social studies is driven by global challenges such as environmental crises, social inequality, and technological developments, which cannot be understood through just one scientific perspective. Interdisciplinary education helps students develop critical thinking, problem-solving, and empathy skills for real issues in daily life (Penner, 2019; Lund et al., 2020). This integration also strengthens the relevance of learning through the contextual that encourages exploration and hands-on experience as part of a student's knowledge construction (Shifflet & Hunt, 2019).

Local values integrated in IPAS materials are also one of the important aspects of the Independent Curriculum. Learning based on local wisdom aims to deepen students' understanding of the cultural diversity that exists around them, as well as foster respect and appreciation for Indonesia's cultural diversity. With this approach, students not only gain scientific and social knowledge, but also diversity values that are important for their social life (Cahyani, 2024).

Overall, the introduction of IPAS in the current curriculum in Indonesia aims to strengthen science and social literacy among Indonesian students, as well as prepare them to face global challenges with broader and applicable skills. The reality in the field shows that the science literacy of Indonesian students is still not optimal (Jufrida et al., 2019), (Kembara et al., 2020). Based on the results of PISA studies in 2009, 2012, and 2018, the scores of Indonesian students in science literacy skills are still far below the international standard scores set by OECD institutions (Hartono et al., 2022), (Esti et al., 2023). The low science learning outcomes are said to be related to the science learning process that has not provided opportunities for students to develop critical thinking (Hussein, Ow, Cheong, & Thong, 2019; Sutiani et al., 2021). This requires innovation in science learning in elementary schools, both in approaches, strategies, and learning materials used. One of the factors that cause low science literacy is the lack of student participation in learning and the limited resources of teaching materials available to support the formation of contextual scientific thinking skills (Zubaidah, S., Angraini, E., & Susanto, 2023; Hadisaputra et al., 2019).

The textbooks that have been used in schools tend to be conventional and are not fully able to meet the needs of students in facing the challenges of the 21st century. Many textbooks have not integrated information technology, contextual pedagogical approaches, and adequate content understanding at the same time. Therefore, innovation in the form of digital books is needed that is able to integrate three important elements in 21st century learning, namely technology, pedagogy, and content which in the world of education is known as *Technological Pedagogical Content Knowledge* (TPACK) (Herring et al., 2020).

Technological Pedagogical Content Knowledge (TPACK) is a framework that integrates three main domains of knowledge: technology, pedagogy, and content. (Warr & Mishra, 2022) identified seven main components in TPACK, namely *Content Knowledge* (CK) knowledge about the subject matter to be taught, *Pedagogical Knowledge* (PK)

knowledge about teaching methods and processes, *Technological Knowledge* (TK) knowledge about technology that can be used in teaching, *Pedagogical Content Knowledge* (PCK) knowledge of how to teach specific content, *Technological Content Knowledge* (TCK) knowledge of how technology can be used to deliver content, *Technological Pedagogical Knowledge* (TPK) knowledge of how technology can support teaching strategies, and *Technological Pedagogical Content Knowledge* (TPACK) is an integrative knowledge that combines all three domains for effective teaching.

TPACK is an important framework in designing technology-based learning because it allows teachers and learning resource developers to compile teaching materials that are not only relevant in terms of content, but also interesting and easily accessible to students (Hosseini, 2021). The application of TPACK in the development of digital books is seen as a potential alternative solution to improve the quality of IPAS learning and encourage the growth of science literacy among students (Zubaidah, S., Angraini, E., & Susanto, 2023).

Although TPACK-based digital books have been shown to increase student engagement, facilitate active learning, and help teachers deliver material more effectively (Zubaidah et al., 2023; Tseng, 2022; Abu-Hardan et al., 2019), several studies show that the implementation of TPACK digital books still faces serious challenges. One of the main weaknesses is the low mastery of technology by teachers, especially in the context of elementary schools, which causes digital books to often not be used optimally in the learning process (Fazilla et al., 2022). In addition, the existing digital book design is often too generic and does not consider the contextual needs and integrative characteristics of IPAS that combine scientific and social aspects in a balanced manner (Zainuddin et al., 2021; Nilsson & Lund, 2022).

Another weakness lies in the digital divide, where teachers in non-urban areas experience limitations in access to devices, training, and technical support, which magnifies the inequality in the implementation of learning technologies between urban and rural schools (Li, 2024). Therefore, research on the need for the development of TPACK-based IPAS digital books is very important. This research is needed to ensure that the development of digital teaching materials is truly in accordance with teacher competencies, student characteristics, and specific local learning contexts Especially in an effort to strengthen the science literacy of elementary school students which until now is still relatively low (Uçar, 2024; Clark & Mayer, 2023; Girwidz & Kohnle, 2022).

This research is important to carry out because the results will be the basis for designing and developing TPACK-based IPAS digital book products that suit user needs. With a clear needs map, the TPACK-based digital book development process can be carried out systematically and on target, so that the resulting product is not only theoretically feasible, but also practical and applicable in the context of daily learning.

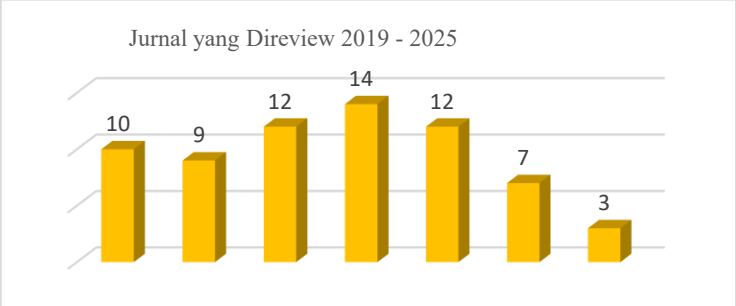
This research specifically aims to analyze the need for IPAS digital books that are integrated with the TPACK framework in the context of learning in elementary schools. This needs analysis includes the identification of the characteristics of students and teachers, the current learning conditions of IPAS, and the expectations and preferences of users for digital books. Preliminary data show that most teachers and students have difficulty accessing interactive and contextual learning resources (Bidarra et al., 2015; Ali & Hasanah, 2024). This indicates that there is a gap between the need and the availability of effective and efficient learning resources in elementary schools. This study fills the gap in previous research results that show that despite efforts to integrate technology in learning, there are still significant challenges in effective implementation (Zubaidah et al., 2023; Fakhriyah et al., 2023). Therefore, this research is important to carry out because the results will be the basis for designing and developing TPACK-based IPAS digital book

products that suit user needs. With a clear needs map, the TPACK-based digital book development process can be carried out systematically and on target, so that the resulting product is not only theoretically feasible, but also practical and applicable in the context of daily learning.

RESEARCH METHOD

Research Design In this study, the *Systematic Literature Review* (SLR) method was used with a content analysis approach, involving scientific articles related to digital books, TPACK, science literacy, and learning in elementary schools. Systematic literature review is a methodical approach to identifying, evaluating, and interpreting existing research in a particular field (Mulyani et al., 2021).

The sample of this study consists of 67 carefully selected and relevant articles within the framework of TPACK's integrated digital books in improving the science literacy of elementary school participants. These articles were published in the time range from 2019 to 2025 and can be found in the publish or Perish database (Scopus and Crossref). To ensure the quality and academicity, the articles that are part of this research sample are indexed in journals recorded in the Sinta and Scopus index. The selection of samples based on the journal index aims to ensure that the articles taken are representative of research that has gone through a rigorous peer review process and has been proven to have an impact in the scientific community.



Gambar 1. Jurnal yang Direview Tahun 2019-2025

The Systematic Literature Review (SLR) Procedure Data Collection in this study follows the PRISMA (*Preferred Reporting Items for Systematic Review and Meta-Analyses*) approach. Data is obtained through the search method and retrieved electronically through the Publish or Perish application with the databases used are Scopus and Crossref. The keywords used include the terms digital books, TPACK, science literacy, learning in elementary schools. Using this search keyword, a total of 1200 articles (from publish or Perish) were obtained. Furthermore, the articles obtained are screened with inclusion and exclusion criteria as listed in table 1.

Table 1 Inclusion and Exclusion Criteria

Yes	Category	Kriteria Inklusi	Exclusion Criteria
1	Publication Type	Articles published in journals, proceedings	Book chapters, books, reviews, notes, short surveys, corrections
2	Journal Indexation	Sinta and Scopus indexed journals	Journals are not indexed both
3	Year of Publication	2019-2025	Less than 2019

4	Variable Independence	TPACK integrated digital books	Digital books in addition to TPACK integration
5	Research subjects	Primary school	High school, high school

After filtering several irrelevant articles, there are 67 articles left to be used as data for this research. A literature selection flow chart is shown in Figure 2.

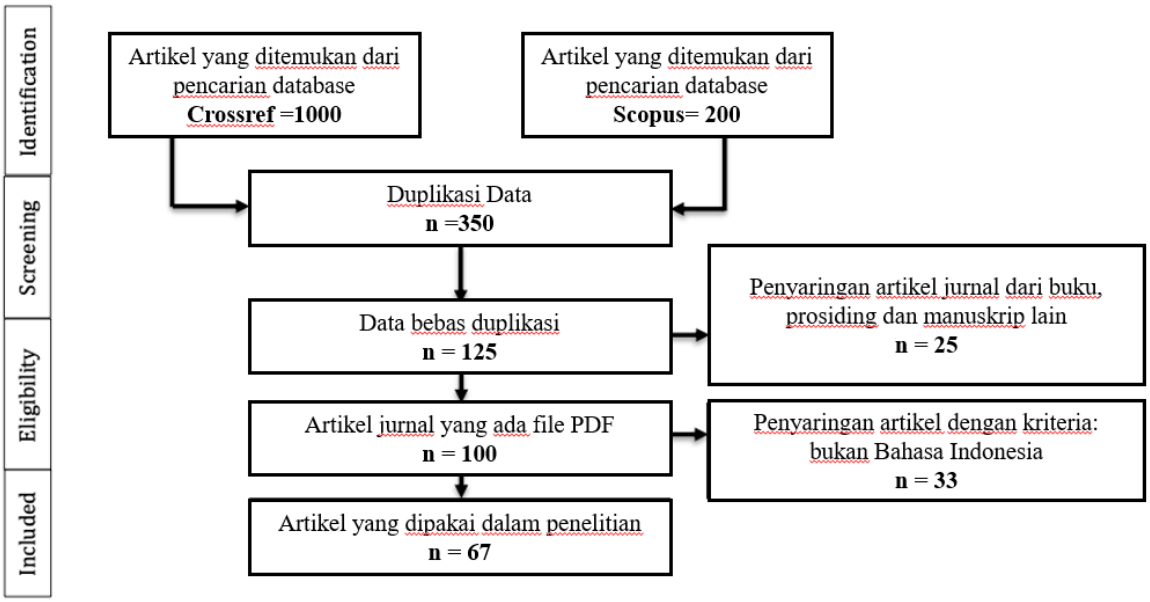


Figure 2 PRISMA Flowchart

The image above shows a flowchart of PRISMA (*Preferred Reporting Items for Systematic Reviews and Meta-Analyses*), which represents the systematic process of selecting articles for a systematic literature review entitled "TPACK-Based E-Textbooks for Science Literacy: A Systematic Review in Primary School Education."

At the identification stage, the researcher searched the literature through two main databases, namely Crossref, which produced 1,000 articles, and Scopus, which produced 200 articles. Thus, the total number of initial documents that were successfully collected was 1,200 articles.

Furthermore, a screening process is carried out to eliminate duplicate articles. It was found that as many as 350 articles were duplicates between the two data sources, so that there were 125 articles that were not duplicates and could be analyzed further. These articles were then re-screened through two additional screening stages. First, it is excluded from documents that are not included in the category of scientific journals, such as books, proceedings, and other manuscripts, which A total of 25 articles. Second Thirty-three articles not in Indonesian were also excluded because they did not meet the study's inclusion criteria.

This process resulted in 100 scientific journal articles available for full access in PDF format. After a final feasibility analysis based on the topic's suitability to the study's focus, namely the integration of digital science textbooks with the TPACK framework in the context of elementary school science literacy, 67 articles were deemed to meet all criteria and were used as the primary source material for this study. This selection process was conducted systematically to ensure that only relevant, credible, and accountable articles were used as the basis for compiling the literature review results.

RESULTS AND DISCUSSION

The analysis of 67 scientific articles reviewed using a Systematic Literature Review (SLR) approach indicates that the development of digital science textbooks integrating TPACK (TPACK-based digital textbooks) is urgently needed and relevant to the conditions in Indonesian elementary education. From a student perspective, elementary school students are found to be most responsive to visual, interactive, and contextual learning. Students learn science and social science concepts more quickly when presented through illustrations, animations, simulations, and explorations based on direct experience (Falloon, 2019) and (Klofutar et al., 2022). The ideal digital textbook for students is one that combines visual narratives, simple interactive experiments, and narrative explanations of concepts (Klofutar et al., 2022).

Conversely, for teachers, numerous studies indicate that they still face challenges in adopting technology into science teaching. Teacher familiarity with the TPACK framework is not yet widespread, and in practice, teachers still prefer using printed textbooks and lecture methods. Thus, teachers need digital learning materials that not only provide well-structured science content but also act as guides for the use of pedagogical principles supported by modern technology. Overall, a TPACK-based digital science textbook will bring together three essential components: relevant and current science content (Content Knowledge), active and context-specific pedagogical approaches (Pedagogical Knowledge), and interactive technology facilitation (Technological Knowledge). This textbook should be created with TPACK integration principles in mind to act as a bridge between students' learning needs and optimize the teacher's role as a facilitator. Interactive visual design, high interactivity, and usability are key aspects to consider when creating it. Therefore, a TPACK-based digital textbook will not only function as a learning medium but also as a transformative tool for science learning that remarkably catalyzes the development of students' scientific literacy.

A systematic study of 67 articles shows that the development of digital teaching materials based on TPACK (Technological Pedagogical Content Knowledge) plays a central role in supporting science literacy, especially in the context of basic education. Studies focused on the integration of TPACK in digital teaching media, such as those conducted by Cacik et al. (2022), Masrifah et al. (2021), and Putri (2022), show that the effective use of the TPACK framework can strengthen the design and implementation of e-books in science learning. These studies demonstrate that teachers' understanding of technology, pedagogic, and content simultaneously is essential in creating teaching materials that are appropriate for the needs of the 21st century.

In line with that, science literacy as the main goal of science learning in primary schools has also been highlighted in a number of studies, such as those presented by Aristeidou & Herodotou (2020), Howell & Brossard (2021), and Saroughi & Cheema (2023). They emphasized that science literacy is not only about understanding scientific concepts, but also includes the ability to think critically, make evidence-based decisions, and participate in scientific discourse. These studies confirm the importance of developing digital books that are not only informative but also encourage active scientific exploration and reflection in students.

The effectiveness of e-books as a learning medium has also been strengthened by a number of experimental and quasi-experimental studies, such as those conducted by Hadaya & Hanif (2019), Diarta et al. (2021), and Setyo et al. (2023). The results of these studies consistently show that e-books are able to increase student motivation, engagement, and learning outcomes in various learning contexts. With an interactive and multimodal design, e-books provide a richer, more flexible, and adaptive learning

experience to the needs of students, including those at the elementary school level. This makes TPACK-based e-books a potential medium in bridging complex and contextual IPAS learning challenges.

On the other hand, the development and validation of digital teaching materials shows that the process of designing TPACK-based e-books cannot be separated from the involvement of teachers as the main user. Studies such as those conducted by Lachner et al. (2021), Nilsson (2024), and Zahroh (2025) show that teachers' TPACK competencies are positively correlated with the quality of digital-based learning they implement. In fact, several studies emphasize the importance of training, reflection, and systematic support to ensure teachers' readiness to use and develop e-books independently.

Other significant contributions come from studies highlighting digital education trends, theories, and policies, such as those conducted by Thyssen et al. (2023) and Tlili et al. (2024). These studies enrich the understanding of the place of e-books in the global digital learning ecosystem, as well as show that TPACK's approach continues to evolve through various derivative models, such as DPACK, which emphasizes the importance of digitality in learning. Nonetheless, most of the research has not specifically directed its focus on basic education or science literacy explicitly.

The excellence of these studies lies in their diversity in examining topics from various experimental approaches, R&D, surveys, to conceptual studies that collectively form a strong basis for the development of TPACK-based e-books. However, there are also a number of limitations that must be considered, such as the context of research that is still largely carried out outside of primary education, small sample scales, and the lack of longitudinal research that tests the effectiveness of e-books in the long term. Based on the description above, it can be explained as follows:

1. Characteristics of Elementary School Students

Students at the elementary school level have unique characteristics that are very important to understand in the context of designing and implementing TPACK-based science learning. As a generation that grew up in the digital era, they showed a high interest in visual and interactive media. Media such as multimode e-books, flipbooks, multimedia, and game-based applications are able to attract students' attention and increase their motivation and involvement in the learning process (Masrifah et al., 2021; Hussein, Ow, Cheong, Thong, et al., 2019; Hung, 2021)

Research by (Hadaya & Hanif, 2019) confirms that students are more motivated when using interactive digital media such as e-books and flipbooks than conventional print media. They have a strong preference for visual elements and interaction, which makes the learning process more enjoyable and meaningful. However, even though they are familiar with technology, elementary school students still need guidance in making optimal use of digital media, especially in science learning such as IPAS (Fakhriyah, 2022).

Their level of technology proficiency is not uniform, so TPACK's approach must be inclusive and adaptive, so that all students can get the maximum benefit from technology-based learning. (Diarta et al., 2021) shows that students need interesting and interactive learning media to maintain the spirit of learning, especially at the elementary level. This is corroborated by (Hassinger-Das et al., 2019) and (Hasbiyati et al., 2022) who found that students are more focused and enthusiastic when learning is packaged in communicative and visual forms. Elementary school students also show high curiosity and interest in visualization and have become accustomed to using technology devices from an early age. Therefore, digital media needs to be adapted to their age stage of development, in order to be able to encourage active participation and involvement in learning.

In addition, the findings from (Putri, 2022) emphasize that elementary school students have a strong preference for exploratory, contextual, and fun media. Digital media that adapts to the context of their daily lives is able to create more meaningful and applicable learning. Learning will be more effective if the material is delivered through media that supports multiple representation, such as simulation, animation, and augmented reality (Y. H. Wang, 2020); (Salsabila & Yuliani, 2024). This is especially helpful in explaining abstract concepts in IPAS, such as plant growth, climate change, or the structure of matter.

These characteristics of learners also reinforce the importance of a visual, active, digital, and experience-based learning approach (Chiu et al., 2023). The integration of TPACK in the development of digital teaching materials must consider these characteristics to create inclusive, relevant, and effective science and technology learning in building science and technology literacy from an early age (Tseng et al., 2020).

However, even though they are familiar with technology, elementary school students still need guidance in making optimal use of digital media. Their skills in using technology vary widely, depending on family background, social environment, and access to digital devices (Abu-Hardan et al., 2019; Li, 2020). Therefore, the TPACK-based learning approach must be designed to be inclusive, adaptive, and contextual, so that all learners can access and understand the material well.

Another characteristic that stands out is the high level of curiosity and emotional involvement of students in learning, especially if the topic is associated with social and environmental issues relevant to their daily lives (Aruta, 2023); (Zahroh, 2025). Students show great enthusiasm for project-based, exploratory, and collaborative learning activities that foster creativity and 21st century skills (F. F. K. Sari & Atmojo, 2021; Afidah & Mahardika, 2023; Ahliana et al., 2025).

No less important, in the context of using e-books, students show varied responses to digital interactions. Some log data from e-books show that learners who have difficulties in comprehension can be identified early, so an adaptive and responsive system is needed to support individual learning needs (Akçapınar et al., 2019). Research by (Hadaya & Hanif, 2019) confirms that students are more motivated when using interactive digital media such as e-books and flipbooks than conventional print media. They have a strong preference for visual elements and interaction, which makes the learning process more enjoyable and meaningful. However, even though they are familiar with technology, elementary school students still need guidance in making optimal use of digital media, especially in science learning such as IPAS (Fakhriyah, 2022).

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create inclusive, relevant, and effective science and technology learning in building science and technology literacy from an early age.

2. Characteristics of Elementary School Teachers

Primary school teachers play a crucial role in the successful integration of the TPACK framework in learning, particularly in the context of science and science. The characteristics of elementary teachers that emerge from various studies show that although they are at the forefront of learning, many of them still face challenges in bringing together three main aspects: pedagogic, content, and technology (Abu-Hardan et al., 2019; Fakhriyah et al., 2023). These barriers often arise due to limited knowledge, technological skills, and experience integrating technology in meaningful learning.

Research shows that most elementary school teachers need structured and ongoing training to strengthen their integrative abilities within the framework of TPACK (Ghayyur & Mirza, 2021; Handayani et al., 2020). Not only mastery of digital devices, but also a deep understanding of learning design that suits student characteristics is indispensable (Mohamad, 2021). In this context, training that integrates hands-on practice is essential so that teachers not only know TPACK theory, but also be able to apply it in daily learning (Kadıoğlu-Akbulut et al., 2023; Lachner et al., 2021).

One of the main challenges is the limited understanding of teachers on how to design digital-based learning that suits the needs of students. Teachers often have difficulty in developing accurate, relevant, and up-to-date digital content, so structured TPACK training is needed so that they are able to align learning content with pedagogical approaches and effective use of technology (Afidah & Mahardika, 2023). In addition, teachers also need to understand the social and religious context in learning, where the integration of technology is not only technical but must also consider the values and norms that apply. In this case, a thorough understanding of the TPACK framework is important so that teachers are better prepared to face the digital era holistically (Hidayati et al., 2023).

In the digital era, elementary school teachers need to be equipped not only with technology literacy but also with data literacy to support formative assessments and more appropriate instructional decision-making. Akçapınar et al. (2019) emphasized that teachers' ability to interpret students' interactions with digital media such as e-books is key in understanding learning dynamics and designing responsive teaching strategies. This need demonstrates the importance of a comprehensive teacher training approach, focusing not only on mastery of technological tools, but also on an analytical understanding of the learning data generated by the use of digital media.

Meanwhile, prospective teachers or pre-service teachers tend to have a more positive attitude towards the integration of technology in learning. Belda-Medina (2022) and Cacik et al. (2022) revealed that this group showed high enthusiasm for augmented reality-based approaches and the use of TPACK-based e-modules, which have great potential in encouraging the development of science and technology literacy in an integrated manner. However, despite the spirit to innovate, the study by Yanti et al. (2024) found a diversity of TPACK competencies among teachers, indicating that continuous training and professional mentoring are still urgent needs.

Furthermore, Setyo et al. (2023) and Putri (2022) underline that even teachers who have high initiative to develop technology-based learning often face structural obstacles such as limited infrastructure, lack of resources, and lack of institutional support. Therefore, teacher capacity building in the context of TPACK should not only be seen as individual development, but also as a systemic responsibility that requires policy intervention and sustained institutional support.

In the digital 4.0 era, elementary school teachers are required to be adaptive to very dynamic technological developments. However, the reality is that many teachers are still in the early adaptation stage to the use of technology in learning. They need ongoing support and training to improve their mastery of TPACK, especially in designing meaningful and digital-based learning experiences (Istiningsih, 2022). Teachers are not only required to be technically proficient, but also need to develop reflective skills the ability to adapt pedagogical approaches to the science content being taught, as well as transform pedagogic knowledge and content (PCK) into an integrative form within the framework of TPACK (Nilsson, 2024).

Teachers' readiness to face 21st-century learning is largely determined by the balance between mastery of technology and pedagogical strength. In this context, TPACK serves as the main framework for measuring teachers' readiness and quality in designing effective and relevant learning in the digital era (Suharyat et al., 2022; Therefore, it is important for educational institutions and policymakers to continue to encourage practice-based professional training, digital literacy, and collaboration between teachers to build an adaptive and innovative education ecosystem.

Another problem that is quite striking is the low digital literacy of elementary school teachers. There are still many teachers who do not have basic skills in operating learning technology, especially in designing TPACK-based teaching media. For this reason, continuous training is needed that is not only oriented towards technical skills, but also supports the simultaneous development of pedagogic and digital literacy (Salsabila & Yuliani, 2024).

In general, the characteristics of elementary school teachers in the context of TPACK integration are characterized by a great need for professional support, practical training, and reflective capacity building. The ability of teachers to understand and apply the TPACK framework greatly determines the success of digital education transformation, especially in science and science learning. Therefore, teacher development is not only an individual responsibility but also requires systemic commitment from educational institutions and policymakers to create a sustainable and technology-adaptive learning ecosystem.

3. The Need for Digital Media and Digital Books in Science Learning in Elementary School

As technology develops and the demands of 21st-century learning, the need for digital media, especially digital books, is increasing in the context of learning Natural and Social Sciences (IPAS) in elementary schools. Digital media not only serves as a complement but also as a primary means in building science literacy and developing students' critical, creative, and collaborative thinking skills.

The use of digital media such as e-books, interactive applications, and other online resources has been proven to be able to increase students' accessibility and understanding of IPAS materials. Although some studies do not specifically address IPAS, as stated by (Abu-Hardan et al., 2019), the role of digital media in TPACK-based reading learning can be drawn as relevant for the needs of science literacy at the elementary school level. This emphasizes that the existence of digital media that is contextual and integrated with pedagogy is needed.

Various studies show that the use of digital media such as e-books, e-modules, digital comics, and interactive multimedia in social studies learning makes a real contribution to improving the quality of student learning processes and outcomes. Diarta et al. (2021), Cacik et al. (2022), and S. Y. Sari et al. (2022) emphasized that the use of these media is able to improve students' conceptual understanding, strengthen science literacy, and foster 21st-century skills such as critical and collaborative thinking. More than just conveying

information, effectively designed digital media also acts as a bridge between learning materials and students' real experiences. Hasbiyati et al. (2022) and Hussein, Ow, Cheong, Thong, et al. (2019) show that contextual media can help students relate learning to everyday life and personal experiences, thereby increasing learning engagement and relevance.

Furthermore, Bliss (2019) and Aruta (2023) reinforce these findings by showing that digital media has the potential to broaden students' knowledge of scientific and social phenomena through the presentation of material that is actual, contextual, and adaptive to the development of the times. Media developed with the right pedagogical principles and technology not only increases learning motivation, but also encourages exploration and deepening of material independently and collaboratively. Therefore, the design of digital-based IPAS learning media needs to consider the integration of content, technology, and student needs in order to create an active, meaningful, and transformative learning experience.

Based on various studies, there are important characteristics that digital media, especially digital books, must have in order to be effectively used in IPAS learning, namely interactive and multimodal**:** Digital books equipped with visual, audio, animation, and interaction elements are considered more attractive and able to increase student learning retention (Siregar et al., 2021); (Sung et al., 2022); (S. Y. Sari et al., 2022); contextual and relevant**:** Learning media must be close to students' daily lives so that abstract concepts can be easily understood. For example, digital media for the topic of environmental pollution that is linked to local conditions (Hasbiyati et al., 2022); (Hussein, Ow, Cheong, Thong, et al., 2019), (Jannah et al., 2022); easily accessible and user-friendly where e-books should be able to be used flexibly both at home and at school, with a simple and child-friendly interface (Alhammad & Ku, 2019); (Alice Chen et al., 2023); and support differentiated learning: Digital books should be designed to suit the diverse needs and learning styles of students, including low-grade students who have concentration limitations (Tambunan et al., 2021); (Tuah et al., 2019).

Furthermore, digital books that are designed contextually, are easily accessible, and have attractive visualizations have been proven to be able to increase student active engagement, both in classroom learning and independent learning at home (Hadaya & Hanif, 2019); (Febrianti et al., 2023), (Handayani et al., 2020)

Digital books are an important medium in building a fun and meaningful IPAS learning experience. Research by (Afidah & Mahardika, 2023) and (Ahliana et al., 2025) shows that digital books designed by integrating elements of art, culture, and science are able to strengthen local contexts in learning and provide a more personalized learning experience for learners.

In addition, the use of digital comics as a lighter and more fun form of media representation is also effective in conveying IPAS and language materials simultaneously, as reported by (Febrianti et al., 2023). This kind of media is perfect for elementary school students who have a limited attention span and need a more visual and narrative approach to learning.

Digital books have been proven to support the exploration, investigation, and project-based learning approach that is the hallmark of the IPAS curriculum. Research by Khasanah et al. (2022) shows that digital books provide space for students to learn independently, experiment virtually, and develop curiosity. Some innovative forms such as digital comics, flipbooks, and e-magazines have been shown to enrich the learning experience and increase student motivation (Muttaqiin, 2019); (Masrifah et al., 2021); (Meutiawati et al., 2024).

Furthermore, TPACK-based and multimodal e-books also have a contribution to the development of students' critical thinking and problem-solving skills. (Radović et al., 2020) and (Zaim et al., 2025) underline that digital media are able to present IPAS content in a more flexible and reflective way, which is oriented towards 21st century skills.

Looking at the trends and findings of various studies, it can be concluded that the development of digital media for IPAS learning needs to be directed towards the development of e-books based on the needs of students and teachers, with a project-based, exploration, and cross-disciplinary integration approach (Afidah & Mahardika, 2023; Ahliana et al., 2025); the use of interactive media such as Geogebra and educational games that can dynamically visualize the concept of IPAS (Salsabila & Yuliani, 2024; Y. H. Wang, 2020) collaboration between educators, media designers, and content experts to produce digital books that are not only aesthetically appealing, but also accurate and content-rich (Diarta et al., 2021; Hamidah et al., 2022; Hadaya & Hanif, 2019).

The need for e-modules and digital books is increasingly relevant in the context of IPAS learning, especially at the elementary school level which emphasizes exploratory and project-based approaches. Digital media not only presents content in a static manner, but is also designed to spark students' curiosity and encourage independent and collaborative exploration, as affirmed by Y. H. Wang (2020) and Yang & Ogata (2023). Interactive digital books allow students not only to receive information, but also to play an active role in the process of searching for and interpreting knowledge. In line with that, Qotrunnada and Prahani (2022) and Putri (2022) show that visual and contextual-based digital books are very effective in fostering a more fun and meaningful understanding of science concepts, especially when applied to the elementary school level that demands an intuitive, imaginative, and appropriate pedagogical approach in accordance with the characteristics of child development. Thus, the integration of e-modules and digital books in science learning not only strengthens conceptual understanding, but also revives the exploratory spirit that is at the core of science literacy.

Looking at trends and research results, there are several important implications for the development of digital media in elementary schools, namely: the development of digital books based on local and cultural contexts, to build a connection between IPAS material and the real lives of students (Afidah & Mahardika, 2023; Ahliana et al., 2025); improving visual quality and interactivity in e-books and other digital media, so that students can understand IPAS concepts in a more in-depth and fun way (Hadaya & Hanif, 2019; Siregar et al., 2021); the integration of art, storytelling, and dynamic visualization in comics or digital flipbooks, as an effort to bring scientific concepts closer to students in a more visual and narrative way (Febrianti et al., 2023), flexibility of access and engagement through application-based or web-based media that allows learning to take place inside and outside the classroom (Alice Chen et al., 2023; Alhammad & Ku, 2019); and TPACK-based design and IPAS curriculum needs so that digital books can support the achievement of science literacy, numeracy, and character and cultural literacy competencies (Radović et al., 2020; Setyo et al., 2023).

4. TPACK's Approach to Learning Design

The Technological Pedagogical Content Knowledge (TPACK) approach is a conceptual framework that is very relevant in designing 21st century learning. This framework emphasizes the importance of integrating three main components in the learning process: content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (Technological Knowledge / TK). The integration of these three provides a foundation for teachers to create learning experiences that are effective, contextual, and relevant to the needs of today's students.

According to (Abu-Hardan et al., 2019), the TPACK approach encourages teachers to not only understand the content of the subject matter, but also how to deliver it effectively through appropriate pedagogical strategies and relevant technological support. This understanding is very important because teachers are required to be able to integrate three main aspects, namely content, pedagogy, and technology in the learning process. In the context of modern education, this ability is crucial because students need to be equipped with 21st-century skills, such as critical thinking, collaboration, and digital literacy. Therefore, the implementation of TPACK is an important foundation for the professional development of teachers in this digital era.

The TPACK approach is increasingly recognized as an essential framework in the development of digital books for primary education, due to its ability to harmoniously integrate content, pedagogy, and technology. Research by Afidah and Mahardika (2023) and Ahliana et al. (2025) shows that the application of TPACK is very effective in designing digital books in various fields, such as physics and cultural arts, with results that are more informative, pedagogical, and contextually relevant in digital classrooms. Although it does not explicitly mention TPACK, Alice Chen et al. (2023) affirm the importance of learning design that blends e-books with content-aligned teaching strategies, which essentially reflects the core of TPACK's approach: that the effectiveness of digital media lies not only in its technology, but in its learning design.

In the context of teachers' professional competence, Belda-Medina (2022) emphasized that the strategic implementation of TPACK is able to strengthen teachers' digital skills and increase the effectiveness of learning in the classroom. This is reinforced by Cacik et al. (2022), who found that TPACK-based e-modules are very feasible to use in training science literacy, especially for teachers who are still in the professional development stage. Drugova (2021) even proposed a merger between TPACK and the SAMR (Substitution, Augmentation, Modification, Redefinition) model to encourage more transformative learning innovations. The findings are supported by Hidayat et al. (2023) and Istiningsih (2022), who highlight that the TPACK approach assists teachers in developing learning strategies that not only rely on technology, but also in accordance with basic educational content and values.

Furthermore, Kadıoğlu-Akbulut et al. (2023) and Lachner (2021) show that technology integration through the TPACK approach is able to improve the quality of learning, especially in the delivery of complex science materials at the elementary level. In a similar direction, Masrifah et al. (2021) and Meutiawati et al. (2024) emphasized the importance of developing TPACK-based e-books as a medium that encourages active, meaningful, and contextual learning. In its practical dimension, TPACK is not only a conceptual framework, but serves as a bridge between teaching theory and digital practice in the classroom. This is as affirmed by Nilsson (2024) and Putri (2022), who explain that the TPACK approach allows teachers to align learning strategies and science content with the characteristics and needs of elementary school students. Therefore, the integration of TPACK in the development of digital books not only strengthens science literacy, but also equips teachers with relevant pedagogical instruments in the era of digital transformation of education.

Research by E. F. Sari et al. (2024) shows that collaborative project-based learning designed with the TPACK approach not only improves students' digital literacy skills**,** but also encourages teacher involvement in teaching innovation. (Setyo et al., 2023), (Setyo et al., 2024) reinforces this by stating that TPACK supports the development of interactive and multimodal flipbooks that are able to increase the attractiveness of learning and encourage students' high-level thinking skills.

In terms of the development of teaching media**,** (Suharyat et al., 2022) and (Siregar et al., 2021) emphasized that TPACK is very useful in combining pedagogical elements, content, and technology in the context of local culture and science, thus producing media that is closer to the reality of students. In fact, this approach has evolved into DPACK (*Digitality-related Pedagogical and Content Knowledge*) as proposed by (Siregar et al., 2021) and (Thyssen, 2023), as a form of response to the challenges of STEM learning in the digital era.

Finally, according to (A. Y. Wang, 2022), teachers who have high TPACK integration are able to design learning that is adaptive, innovative, and in accordance with the needs of the 21st century**.** This is also agreed by (Zahroh, 2025) and (Yanti et al., 2024) in the context of IPAS learning, where *the TPACK-based* Project-Based Learning (PBL) approach has been proven to be able to increase student engagement and learning outcomes holistically.

5. TPACK Integration in Digital Books

The integration of TPACK in digital books is a strategic approach that aims to optimize the learning process through a combination of content knowledge*, pedagogical* knowledge*, and technology*. Several studies support the importance of this integration in the development of digital books that not only convey information, but are also able to present material in an interactive, contextual, and meaningful way.

(Abu-Hardan et al., 2019) underlined that although digital books are not explicitly discussed, TPACK's approach is highly relevant in the development of learning media, including digital books. The ideal digital book should be designed not only to present content but also to accommodate pedagogical approaches and technological features such as hyperlinks, multimedia, and app-based self-paced exercises.

The integration of the TPACK framework in the development of digital books has been proven to have a positive impact on science literacy and student learning outcomes. Afidah and Mahardika (2023) and Ahliana et al. (2025) emphasized that this approach is effectively applied to various subjects because it is able to connect content, technology, and pedagogy synergistically with each other. The delivery of TPACK-based material encourages the presentation of information that is more contextual, relevant, and in accordance with the characteristics and needs of students. Thus, TPACK-based digital books not only improve students' conceptual understanding, but also strengthen the scientific thinking skills that are at the core of science literacy.

The integration of the TPACK framework in the development of digital books continues to demonstrate its relevance and effectiveness in the context of modern education, particularly to strengthen science literacy and improve the quality of learning. Although it does not explicitly mention the term TPACK, Alice Chen et al. (2023) affirm the importance of integration between content, pedagogy, and technology in the design of educational e-books, which reflects the basic principles of the TPACK model. In line with that, Belda-Medina (2022) and Cacik et al. (2022) highlight that the application of TPACK in digital books not only supports the learning process, but also strengthens teacher competence, especially in the context of training and development of prospective technology-based educators. Empirical support for the effectiveness of TPACK in improving student understanding is also shown by Febrianti et al. (2023) and Hasbiyati et al. (2022), who found that media such as digital comics and TPACK-based e-books are able to explain science issues such as environmental pollution in a multimodal and contextual manner.

Furthermore, Hung (2021) and Istiningsih (2022) emphasized that TPACK-based digital books are able to integrate modern pedagogical approaches with the use of

technology, creating a more meaningful learning experience for students. This is also supported by Khasanah et al. (2022) and Masrifah et al. (2021), who explain that the development of TPACK-based digital teaching materials facilitates teachers in compiling content that is relevant to student needs and learning situations. Putri (2022) added that the ability of teachers to adjust the content of materials and technology according to the classroom context is a key factor in increasing student engagement and learning outcomes through TPACK-based e-books. In a collaborative framework, Salsabila and Yuliani (2024) show that the combination of TPACK with the Collaborative Learning model not only trains students' critical thinking, but also improves interaction and the quality of the learning process. Learning innovations are also demonstrated by Setyo et al. (2024) through the development of interactive flipbooks based on TPACK and philosophical values, which provide a holistic learning experience, as well as by Siregar et al. (2021) who found that TPACK e-books are able to stimulate students' creativity.

More broadly, the studies of Thyssen (2023), Tlili et al. (2024), and Yang & Ogata (2023) underscore the importance of integrating TPACK in IPAS digital books as a contextual, collaborative, and experiential-based learning tool. Finally, Zaim et al. (2025) and Zubaidah, Angraini, and Susanto (2023) reinforce these findings by showing that TPACK-based digital books support active and deep learning, especially when integrated with a problem-based learning approach. These findings confirm that TPACK's approach to digital book design is an essential pedagogical strategy in 21st century education, as it is able to bridge content, technology, and pedagogy in a harmonious manner, and support the improvement of science literacy and active involvement of students.

6. Science Literacy as the Main Goal of Science Learning

Science literacy is the ability to understand scientific concepts, think critically, and apply this knowledge in daily life. In the context of Natural and Social Sciences (IPAS) learning, science literacy is the main goal that must be achieved, especially in the current digital era. A number of studies support the importance of science literacy as a learning outcome that emphasizes not only the memorization of concepts, but also on application, problem-solving, and decision-making

(Afidah & Mahardika, 2023) shows that TPACK-based digital books are able to increase students' understanding of physics concepts such as business and energy. The integration of accurate and up-to-date content with pedagogical and technological approaches encourages a deeper understanding of scientific concepts. Although it does not explicitly discuss science literacy, research (Akçapınar et al., 2019) and (Alhammad & Ku, 2019) indicate that an interactive e-book system makes a positive contribution to improving students' literacy by providing content that is easy to understand and track its effectiveness

(Bliss, 2019), (Aristeidou & Herodotou, 2020), and (Aruta, 2023) highlight that science literacy can be improved through student involvement in online scientific communities, citizen science activities, and integrating global issues in learning. This approach enables students to understand and contextualize real-life science concepts.

Research (Cacik et al., 2022) strengthens that science literacy is a key component in TPACK-based e-modules that are able to improve students' critical thinking and ability to understand scientific phenomena. This approach is also relevant for teacher education, as shown by (Fakhriyah, 2022), (Fakhriyah et al., 2023), where prospective teachers trained with the TPACK approach show increased understanding and ability to apply science in real life.

Research (Hadaya & Hanif, 2019) supports these findings by showing that the use of digital media such as e-books can improve the understanding of scientific concepts and

their applications in daily life. (Höttecke & Allchin, 2020) and (Howell & Brossard, 2021) added that science literacy is essential for developing critical thinking skills and sorting out correct information, especially in the era of social media and misinformation.

The ethnoscience and posthumanism approaches make an important contribution to strengthening contextual and critical science literacy in primary education. Jannah et al. (2022) show that ethnoscience is able to connect science materials with local wisdom values, making them more relevant to students' lives. Meanwhile, Jeong et al. (2021) emphasized that the posthumanism approach opens up a reflective space for students to understand the relationship between science, technology, the environment, and socio-cultural issues more holistically. Thus, the integration of these two approaches can enrich science learning in elementary schools by fostering scientific awareness that is not only theoretical, but also contextual and humanistic.

(Reinhold et al., 2020) show that digital representation in learning is able to help students with low academic ability to understand science concepts better. This is reinforced by the findings (Li, 2020) and (Meutiawati et al., 2024) which highlight the importance of TPACK-based digital modules and e-magazines in building students' awareness and understanding of the use of technology in the context of science.

Science literacy is not only shaped by digital learning media, but also greatly influenced by the role of teachers and social interaction in the learning process in the classroom. Saroughi (2023) emphasized that teacher involvement and the creation of a sense of belonging through constructive social interaction are important factors that strengthen students' science literacy. Furthermore, strong science literacy allows students to identify and evaluate misinformation in daily life, as Sharon and Baram-Tsabari (2020) demonstrate. These findings are in line with the results of research by Tan (2022) and Thyssen (2023), which stated that the TPACK-based IPAS learning approach is able to form the character of students who are critical, collaborative, and have a contextual understanding of the surrounding scientific phenomena. In a broader context, Valladares (2021) and Wen et al. (2020) view science literacy as a tool of social transformation that enables learners to make decisions based on data and logic, as well as to encourage emancipation in social life. Finally, Zubaidah, Angraini, and Susanto (2023) emphasized that the integration of the TPACK approach can significantly improve science literacy, especially in conveying complex materials such as genetics at the elementary school level. Therefore, the TPACK approach is not only relevant, but also essential in achieving the objectives of science literacy-oriented learning that are critical, contextual, and transformative.

7. The Use of Digital Books in Education

In today's digital era, the use of digital books (e-books) in education has become an increasingly important and relevant approach. Various studies show that digital books are not only an alternative to conventional printed books, but also as a medium that is able to revolutionize the way students learn through integrated educational technology.

One of the key approaches that stands out in digital book design is the TPACK (*Technological Pedagogical Content Knowledge*) principle. TPACK-based digital books are designed to provide a contextual, personalized, and collaborative learning experience. Research by (Abu-Hardan et al., 2019) shows that this approach encourages active student engagement in learning, effectively integrating aspects of technology, pedagogy, and content.

In general, digital books have been proven to improve student learning outcomes due to their ease of access, material visualization ability, and high interactivity (Afidah & Mahardika, 2023), (Ahliana et al., 2025). In addition to being more interesting than printed

books, e-books also received positive responses from students in various parts of the world. Global trends since 2011 show a significant increase in the use of e-books, both in general education and in the context of foreign language teaching (Alhammad & Ku, 2019), (Alice Chen et al., 2023), (Akçapınar et al., 2019).

Furthermore, digital books also function as a means of learning that combines information, science, and digital literacy at the same time. When integrated with technologies such as Augmented reality (AR), digital books are able to create flexible and participatory learning experiences (Bliss, 2019), (Belda-Medina, 2022). However, the effectiveness of these digital learning spaces is highly dependent on user understanding and proper learning strategies (Bygstad et al., 2022); (Casselden & Pears, 2020), (Casselden & Pears, 2020).

The integration of digital books with the TPACK-SAMR model has also been proven to be able to enrich the learning experience at both the student and student levels. This model is an important reference in the sustainable adoption of educational technology (Drugova, 2021); (Febrianti et al., 2023). In addition, the use of digital books has been proven to support online and offline learning, with improvements in the aspects of learning outcomes, motivation, and flexibility (Hadaya & Hanif, 2019).

Multimedia and interactive features in digital books are highly effective in increasing student engagement, enriching learning experiences, and accommodating cross-cultural learning and various age groups (Hassinger-Das et al., 2019); (Hasbiyati et al., 2022). Digital tools such as educational games also strengthen understanding in subjects such as language and science (Hung, 2021); (Hussein, Ow, Cheong, Thong, et al., 2019).

Several studies have shown a significant increase in science literacy and concept understanding through digital books equipped with interactive features (Khasanah et al., 2022). When developed through an expert validation process and direct testing to students, digital books are able to increase personal learning satisfaction and engagement (Muslim et al., 2021), (Masrifah et al., 2021).

The effectiveness of digital books is also seen in improving problem solving skills and student assessment performance at the primary and secondary levels (Pickering & Swinnerton, 2019). For the fields of science and mathematics, applications such as Geogebra are helpful in the visualization and exploration of abstract concepts (Radović et al., 2020). In the context of 21st century learning, modern visual-based e-books are very effective in increasing students' interest and understanding of complex concepts (S. Y. Sari et al., 2022), (F. F. K. Sari & Atmojo, 2021).

Digital books make a significant contribution to improving the quality of learning in the digital era. One of its strengths is its ability to present complex material, including classic texts such as the Analects of Confucius, through a contextual approach supported by multimedia elements (Sung et al., 2022). In addition, systematic studies show that e-books not only expand access to education, but also support the flexibility of learning time, personalization of materials, and the increase of students' independence (Tlili et al., 2024; Tuah et al., 2019). Thus, the use of digital books is a strategic solution in answering the challenges of 21st century learning.

By utilizing simulations, AR, and project-based approaches, e-books have been shown to improve academic achievement and student engagement, especially when supported by data analytics for personalization (Y. H. Wang, 2020), (Wen et al., 2020), (Yang & Ogata, 2023). Recent studies confirm that TPACK-based digital books have great potential in building deep conceptual understanding, delivering material flexibly, and adapting to individual learning needs (Zubaidah, S., Angraini, E., & Susanto, 2023), (Zaim et al., 2025).

CONCLUSION

Literature findings show that elementary school students tend to be more interested in learning media that are interactive and fun, such as e-books, flipbooks, animations, and educational games. The medium has proven to be effective in simplifying abstract science concepts through attractive visual presentations. Students' enthusiasm for the digitalization of education is also quite high, although it is not entirely able to integrate technology, learning content, and pedagogical approaches synergismically. On the other hand, elementary school teachers still need support in the form of educational technology training in order to design innovative learning that suits the needs of students. Digital books designed with the right pedagogical approach not only serve as a source of information, but also as a means of developing students' critical and creative thinking.

The integration of the TPACK framework in the development of digital books has been proven to make a significant contribution to improving science literacy and student learning outcomes at the primary education level. Afidah and Mahardika (2023) and Ahliana et al. (2025) emphasized that the use of the TPACK approach allows for the delivery of learning materials that are more contextual, interesting, and in accordance with the characteristics of the cognitive development of elementary school students. In this context, digital books not only function as an information medium, but also as a means of facilitating scientific thinking that fosters curiosity, the ability to classify information, and social responsibility for scientific issues that are close to daily life. Therefore, the results of this study imply the need for the development of TPACK-based digital books more broadly and in the structure of the elementary school curriculum, in order to support holistic, transformative, and science-oriented learning in the 21st century.

One approach that has proven to be effective is the TPACK (*Technological Pedagogical Content Knowledge*) framework, which is able to integrate content, instruction, and technology in a harmonious manner in learning design. The application of TPACK in science digital books allows students to gain a more comprehensive understanding, not only in terms of theory but also in the context of daily life practice. Science literacy as a learning goal is also strengthened through electronic books that are flexible, adaptive to learning styles, and able to increase student engagement and conceptual understanding. However, this study has limitations in the scope of the literature which is mostly sourced from the context of basic education in Indonesia, as well as the lack of longitudinal data on the long-term impact of the implementation of TPACK-based digital books. However, the significance of this study lies in its contribution to mapping the urgency of transforming digital learning resources that are relevant to the needs of 21st century learning, especially in strengthening science literacy at the elementary school level.

This research has an important significance in supporting efforts to improve the science literacy of elementary school students. In general, this research contributes to the development of innovative and relevant teaching materials that can strengthen the understanding of science concepts through a learning approach that is integrated with technology. In particular, the results of this research are expected to be a reference for teaching material developers, educators, and policy makers in designing science-based learning strategies that are technology-based and oriented towards strengthening science literacy. In addition, this research is also expected to enrich the treasures of scientific literature in the field of developing digital learning resources and implementing social studies learning at the elementary school level.

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