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Designing Child-Friendly Digital Comics Integrating Local Wisdom and PBL-SSI for Environmental Disaster Learning Materials in Primary Schools

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Abstract. The principle of child-friendly learning emphasizes the importance of providing safe, meaningful, participatory learning experiences that are appropriate to the developmental characteristics of students. However, the learning of science and science in grade IV of primary schools on environmental disaster material encountered obstacles in connecting science concepts with real problems experienced by students. The researchers also found non-optimally utilized digital media that integrated local wisdom. This study analyzed the learning needs of environmental disaster material reviewed from the aspect of media and integration of child-friendly local wisdom; design a child-friendly digital comic that integrates local wisdom and PBL-SSI in disaster material; and identify the characteristics of digital comics that support science and science learning. This Research and Development (R&D) method used the ADDIE model limited to the Analysis and Design stages. The researchers collected through observation, interviews, and document analysis, then analyzed using thematic analysis. The results of the study indicate the need for contextual, interactive, and close-to-student experience learning media. Based on these needs, the researchers designed the digital comic "Pahlawan Lingkungan dari Kesambi", integrating local wisdom, child-friendly principles, PBL-SSI, QR Code, and Heyzine flipbook. The resulting comic has eight key characteristics that support environmental awareness and critical thinking. This research contributes to the development of a child-friendly digital comic design framework based on local wisdom and PBL-SSI for environmental disaster learning in primary schools.

Keywords: child-friendly; digital comics; problem-based learning (PBL); socio-scientific issues (SSI); local wisdom; environmental disaster; primary schools

INTRODUCTION

Child-friendly learning has become a crucial element in present learning environment, with the advancement of technology widely used by children. Children must be introduced to the challenges of present world and to support their learning and daily activities. Objects children encounter must contain child-friendly elements. Child-friendly learning places students at the center of the learning process through a safe, inclusive, participatory learning environment that supports children's social-emotional development. The principles of child-friendly learning extend beyond physical safety to active student involvement, psychological well-being, respect for diversity, and opportunities to develop their full potential.

The principles of child-friendly learning emphasize that every student has the right to a safe, inclusive, and participatory learning experience that respects children's developmental needs. UNICEF proposes the Child-Friendly School Framework, suggesting a child-friendly learning environment by ensuring physical and psychological safety, encouraging active student engagement, respecting diversity, and providing equal opportunities for all students to develop optimally. Mahinay et al., (2025) explains the characters of child-friendly principle learning implementation includes high student participation, support for health and well-being, the creation of safe learning spaces, and teacher and community support in the learning process. Furthermore, a child-centered learning approach enables students to construct knowledge through meaningful experiences, active exploration, and positive social interactions. Atashpanjeh et al., (2026) shows that story-based narratives and a child-centered approach can improve emotional involvement, learning motivation, and conceptual understanding in primary school-aged students.

Mahinay et al., (2025) explains that a child-friendly learning environment must support participation, well-being, safety, academic achievement, teacher motivation, and community support as part of the Child-Friendly School (CFS) framework. The implementation of child-friendly principles is important in learning activities because students are at a concrete developmental stage that requires enjoyable and meaningful learning experiences. At this stage, students need real daily-contextual objects to understand a concept of the material being studied. Therefore,

the development of child-friendly learning media is a supportive strategy to improve learning quality based on student needs.

One of the challenges primary education encounters is the presentation of environmental disaster learning materials due to its tendency of conveying concepts and factual information without deeply connecting them to students' real-life experiences. In terms of factual information, Indonesia, as a coutnry with a high level of disaster vulnerability, requires disaster education immediately from an early age as part of disaster risk mitigation efforts. In Kudus Regency, for example, a flood-prone area, several villages are affected almost every year during the rainy season. This significantly impacts students' learning activities at school. Suarmika et al., (2022) argues the importance of disaster education in increasing students' awareness, preparedness, and mitigation skills against various disaster threats. Disaster education is also part of the implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030, which emphasizes the importance of understanding disaster risk through education. However, the presentation of disaster material in primary school learning encounters various obstacles, particularly related to the availability of approriate media and learning to student characteristics.

In the Independent Curriculum or *Kurikulum Merdeka*, science and science learning is designed to facilitate students understand the relationship between natural phenomena, social life, and the surrounding environment through contextual learning experiences. Contextual learning enables students to connect scientific knowledge with daily-life problems, providing more meaningful learning. The preliminary interviews, with several principals and primary school teachers, revealed the dominance of conventional textbooks and worksheets in primary schools, which were less effective in encouraging active student engagement. Innovative teaching materials for environmental disasters have not been provided. Furthermore, teachers have not yet considered the use of either friendly-language and friendly-learning tools. Pratiwi et al., (2026) revealed that the use of learning media in primary schools was still largely one-way, leaving students passive recipients of information and little opportunity for independent exploration. This situation highlights the need to innovate interactive, adaptive, and suited learning media to the characteristics of present digital generation.

The preliminary observations in several schools in Kudus Regency, especially in areas prone to flooding, indiccated the urgency of engaging learning media to facilitate students understand and analyze and provide solutions to flooding incidents in their neighborhoods. One innovative medium developed to address issues in disaster-related science learning is the use of digital comics. Digital comics are a learning medium with significant potential to support contextual learning in primary schools. This medium combines text, images, color, and a storyline to facilitate students grasp concepts more easily and engagingly. Darmadi & Aljamaliah (2024) shows that digital comics can improve student literacy because they present material in an attractive and easy-to-understand visual form. Furthermore, Pratiwi et al., (2025) have shown that digital comics effectively increase student learning motivation, reading comprehension, and character development through the integration of local cultural values. Digital comics serve not only as a visual medium but also as a learning tool that can connect students' cognitive, affective, and social aspects.

In addition to the engaging visualization aspect of digital comics, the integration of local wisdom is also a crucial factor in creating meaningful and contextual learning relevant to students' lives. Local wisdom encompasses values, knowledge, and cultural practices that have developed within a community and can be used as a learning context that is relevant to students' lives. Pratiwi (2021) explains that integrating local culture into digital comics can strengthen cultural identity while increasing the relevance of learning because students more easily understand material related to their social environment. Suarmika et al., (2022) regarding disaster learning, explain the importance of local knowledge based on disaster mitigation as the community experience inheritance in dealing with disaster threats. Therefore, integrating local wisdom into disaster learning media can help students understand the relationship between humans, culture, and the environment more comprehensively.

The development of digital comics requires a pedagogical approach that will ultimately develop critical thinking skills and environmental awareness in primary school students. One widely recommended approach is the integration of Problem-Based Learning (PBL) and Socio-Scientific Issues (SSI). PBL places real-world problems as the starting point of learning, encouraging students to investigate and find solutions independently. SSI encourages students

to analyze social issues related to science through argumentation and evidence-based decision-making. The integration of PBL and SSI can create more contextual learning by connecting scientific concepts with problems that occur in society (Lubis et al., 2022; Ramos et al., 2021). This approach is highly relevant for environmental disaster learning materials because issues of flooding, pollution, and environmental damage are issues closed to students' lives and require in-depth understanding.

Previous research on digital comics, local wisdom, PBL, and SSI has flourished in recent years, but studies integrating all of these components are still very limited. Previous research generally focused on developing digital comics to improve literacy and learning motivation, integrating local wisdom as a learning context, or applying PBL and SSI to develop critical thinking skills separately. Pratiwi (2021) revealed that research on digital comics in primary schools generally focuses on improving reading literacy and integrating local culture. Meanwhile, Fatimah et al. (2025) found that PBL-SSI research has been mostly applied to science and biology learning to enhance critical thinking, but has not been widely developed in child-friendly digital media. Research on disaster education also tends to emphasize mitigation and preparedness without integrating digital comics, child-friendly principles, and local wisdom.

The aspect of child-friendly learning is still rarely used as the main basis in developing environmental disaster learning media in primary schools, even though this principle is important for creating a safe, participatory, and appropriate learning experience to children's development (Mahinay et al., 2025). This research gap points out the unavailability of digital comic designs that simultaneously integrate child-friendly principles, local wisdom, PBL, and SSI in the context of environmental disaster learning. Therefore, the current research's novelty lies in the development of a child-friendly digital comic design framework that integrates local wisdom and PBL-SSI to support contextual science learning, increase environmental awareness, and facilitate critical thinking skills of primary school students. This novelty expands previous studies by positioning digital comics not only as a visual medium, but as an instructional design framework, connecting pedagogical aspects, local culture, and disaster learning in one complete learning design in primary schools.

Based on these gaps, this study analyzed learning needs and design a child-friendly digital comic that integrates local wisdom and PBL-SSI for environmental disaster learning in primary schools. The research focuses on three main questions:

RQ1: How are the learning needs for environmental disaster material reviewed from the aspect of media and integration of child-friendly local wisdom?

RQ2: How to design child-friendly digital comics that integrate local wisdom and PBL-SSI in disaster material in primary schools?

RQ3: What are the characteristics of child-friendly digital comic designs that support contextual science learning on disaster material in primary schools?

This Research and Development (R&D) approach research used the ADDIE model limited to the Analysis and Design stages. The product developed in this study is a child-friendly digital comic design integrated with local wisdom and PBL-SSI in science learning.

METHODS

This Research and Development (R&D) research used the ADDIE (Analysis, Design, Development, Implementation, Evaluation) model developed by Creswell, (2011). However, currently the researchers limited only to two initial stages, namely Analysis and Design. The underlying reasons of limiting the current resarch model are: as the research main objective to identify learning needs and as a conceptual design producer for a child-friendly digital comic integrating local wisdom and Problem-Based Learning–Socio-Scientific Issues (PBL-SSI) for environmental disaster learning in primary schools. The limitation of the analysis and design stages considers the Educational Design Research approach, which emphasizes the importance of exploring user needs and developing a design framework before the product is further developed and tested (McKenney & Reeves, 2018). The researchers conducted analysis stage to obtain information related to learning needs, student characteristics, media needs, and the potential integration of local wisdom in environmental disaster learning. Next, the design stage focused on developing a digital comic design framework, storyboard, character development, storyline, and the integration of PBL-SSI syntax into the developed comic.

This early-stage R&D approach is widely used in learning design research because it enables researchers to produce relevant products to user needs and learning contexts (Plomp & Nieveen, 2010). In addition, the design approach also supports the development of educational innovations based on theory and field needs, resulting in products with an excellent conceptual foundation (McKenney & Reeves, 2018). The research data sources consisted of primary and secondary data. The researchers collected the primary data through observations and interviews with teachers, students, and the principal. Meanwhile, secondary data were obtained from curriculum documents, science learning outcomes, teaching modules, teaching materials used in schools, and relevant scientific literature on child-friendly learning, digital comics, local wisdom, problem-based learning (PBL), SSI, and environmental disaster education.

The research participants consisted of primary school teachers, fourth-graders, and school principals in Kudus Regency, selected using a purposive sampling technique. The researchers selected this technique due to the consideration about the students' previous direct experience related to science learning and the implementation of environmental disaster material in primary schools. Teachers were selected as key informants to identify learning needs, media use, and challenges in environmental disaster learning. Students were selected to obtain information on their learning characteristics, interest in digital media, experience using comics, and their perceptions of environmental learning. School principals were involved to obtain information on school policies, support for learning innovations, and the potential for integrating local wisdom into learning.

The applied research instruments included observation sheets and semi-structured interview guidelines. These instruments allowed researchers to obtain comprehensive data and increase the credibility of the findings through triangulation of sources and methods (Creswell, 2014). The observation sheet was useful to identify the conditions of science learning, teacher and student activities, the use of learning media, and the integration of environmental materials into the learning process. The researchers developed interview guideline based on the results of theoretical studies and learning needs indicators, which included aspects of learning, media, local wisdom, and characteristics of child-friendly learning. The interviews were semi-structured, allowing researchers to obtain in-depth data while also providing participants with the flexibility to express their opinions (Miles et al., 2014). In addition, document analysis was useful to assess the suitability of environmental disaster material with the learning outcomes of science and natural sciences, the potential for integrating local wisdom, and the need for developing learning media. In the design stage, an instrument in the form of a product design sheet was used to compile the specifications of digital comics, storyboards, character designs, story structures, and integration of PBL-SSI syntax.

The data was analyzed using thematic analysis developed by (Ahmed et al., 2025). The researchers used thematic analysis due to its capability to systematically identify, organize, and interpret patterns of meaning that emerge from qualitative data. Thematic analysis in this study consisted of six stages, namely: 1) Familiarization with the data, namely reviewing all observation data, interviews, and documents repeatedly; 2) Generating initial codes, namely assigning codes to information relevant to learning needs and comic design; 3) Searching for themes, namely grouping codes into initial themes; 4) Reviewing themes, namely reviewing the suitability of themes with research data; 5) Defining and naming themes, namely defining and naming the main themes; and 6) Producing the report, namely compiling an interpretation of the analysis results in the form of a narrative description that supports the digital comic design process.

RESULTS AND DISCUSSION

Learning Needs Analysis for Media Aspects

The results of the needs analysis indicate that one of the problems in environmental disaster learning in primary schools in Kudus Regency was the limited availability of learning media capable of connecting scientific concepts with the environmental realities encountered by students. Disaster material was introduced in fourth-grade science lessons, but the presentation was still dominated by textbooks and verbal explanations from teachers. This situation made the students tend to understand flooding as a theoretical concept, rather than as a phenomenon close to students' lives. This sittuation also made the learning less able to build links between knowledge, attitudes, and actions in dealing with environmental problems. Fourth-grade primary school students are at the concrete operational stage, requiring visual representations and

contextual experiences to understand abstract concepts. Mayer & Fiorella, (2022) explains that combined multimedia-based learning with text and images can improve conceptual understanding because it helps students build connections between verbal information and visual representations. Therefore, learning media that can present environmental disaster phenomena in a more concrete, engaging, and easily understood way are needed for primary school students.

The need for innovative learning media to support 21st-century competencies, including critical thinking, problem-solving, environmental literacy, and decision-making. Media not only serves as a means of conveying information but also as a tool that can facilitate students' thinking processes in analyzing the causes, impacts, and solutions to environmental problems. Pratiwi et al. (2025) shows that story-based digital media can increase student engagement because it provides a more interactive and meaningful learning experience. In addition, Pasalkar et al., (2025) explains that digital comics have the potential to develop students' conceptual understanding and emotional engagement through a combination of narrative, illustration, and characters that are close to their lives.

Based on the needs analysis, digital comics are one of the relevant media alternatives for environmental disaster learning in primary schools. Based on the results of interviews with teachers, the researcher said that

"*We don't have special media that discuss flooding in Kudus. In fact, children often experience flooding in their surroundings so they need examples that are closer to their lives*."

In addition, the results of interviews with students stated

"*I prefer to learn if there are pictures. If I only read books, I sometimes get bored quickly. If there are comics, it is easier to understand because I can see the story*."

Through digital comics, environmental problems are presented through a systematic storyline so that students can follow the identification process, problem-solving, causal analysis, and step-by-step solution development for environmental conditions in Kudus Regency (Taqqiyah et al., 2021). The characters, dialogue, and visual illustrations in comics can help students understand complex concepts in a simpler and more enjoyable way. İlhan et al. (2026) also found the use of digital comics in science learning can increase students' learning motivation, critical thinking skills, and knowledge retention compared to conventional learning. In this study, the need for media led to the development of digital comics that are not only visually appealing, but also integrate Problem-Based Learning (PBL) and Socio-Scientific Issues (SSI) approaches so that they can encourage students to understand flooding as an environmental issue that requires analysis and real action. In line with research Fita et al., (2021) explained that integrating SSI into PBL provides a more meaningful learning experience because students are encouraged to evaluate scientific data while considering the social consequences of decisions. Therefore, the required media is a digital comic that can connect cognitive, affective, and contextual aspects in environmental disaster learning that integrates PBL-SSI using child-friendly principles.

Learning Needs Analysis of Kudus Local Wisdom Aspects

Kudus Regency is a region in Central Java with geographic characteristics that are vulnerable to flooding, especially in areas along rivers that originate in the Muria Mountains. The almost annual flooding phenomenon makes the surrounding environment a highly potential learning resource for primary school students. The results of the needs analysis indicated that environmental disaster learning in schools still did not optimally utilize local experiences and community knowledge as part of the learning process. Based on teacher interviews,

"*The flood material in textbooks is general in nature. There are not many examples that take river conditions or the environment in Kudus.*"

Suarmika et al., (2022) explain that disaster education with local knowledge integration is more effective because it helps students understand the relationship among culture, the environment, and disaster mitigation based on real-life community experiences.

The local wisdom of the Kudus community contains various values relevant to supporting disaster education and environmental conservation. These values include mutual cooperation in cleaning the environment, concern for river cleanliness, reforestation, and the tradition of maintaining balance between human activities and nature. Interviews with teachers

revealed,

"*People in this village still have a culture of community service in cleaning the environment and waterways. Such activities are very good if introduced to students as part of the learning process*."

The activities implemented by the community represent a realization of community-based disaster mitigation that has developed over generations. Wahyudi et al., (2025) found that integrating local wisdom into science learning could increase the relevance of the material because students could more easily understand concepts related to their own experiences and culture. The strong value of mutual cooperation could instill awareness that flood risk reduction is not only the responsibility of the government, but also the responsibility of all members of society.

The integration of local wisdom also plays a crucial role in creating contextual and meaningful learning. When students learn about flooding through examples they observe and experience in their surroundings, the learning process becomes more authentic and relevant. During an interview, a teacher said,

"*If we use examples that are close to students' lives, they usually understand more quickly. For example, the mutual cooperation activity of cleaning the river that is often carried out by residents here*."

In this study, the flooding incident in Kesambi Village was used as the basis for developing a digital comic story due to its representation of relevant environmental conditions to students' lives. Supryanto et al. (2025) found that integrating local culture into comics can deepen students' understanding of culture while improving critical thinking skills. The study explains that combining local cultural elements, comics, and enjoyable learning creates a more meaningful learning experience. Therefore, environmental disaster education in Kudus Regency needs to be integrated with local wisdom as a learning resource, learning context, and a means of developing environmentally conscious character. This integration is crucial so that students not only understand the causes and impacts of flooding but also recognize cultural values that can be used to reduce the risk of future disasters.

Learning Needs Analysis Reviewed from Child-Friendly Principles

The results of the needs analysis indicate that environmental disaster learning in primary schools needs to consider the principles of child-friendly learning. Disaster material often relates to events with potency of causing fear, anxiety, or worry in students if not presented with an appropriate approach to their developmental stage. Interviews with teachers revealed,

"*If the flood picture is too frightening, children usually focus on their fear, not on the lesson being taught*."

Amin & Bahri (2024) also found that story appeal, character suitability, relevance of the material to students' lives, and ease of use of language were important factors in the success of digital comics. Learning should be designed with engaging images and use daily-life language to provide a psychologically safe learning experience that can enhance students' understanding of disaster risks. A child-friendly learning environment must ensure safety, participation, inclusivity, and respect for students' developmental needs. These child-friendly principles are important to implement so that students can understand environmental risks without experiencing excessive emotional stress.

Child-friendly principles prioritize active student involvement in the learning process. Students must receive the opportunity to ask questions, discuss, express their opinions, and explore solutions to the problems they encounter. Mahinay et al. (2025) explain that child-friendly learning is characterized by high student participation, support for emotional well-being, and the creation of a pleasant learning environment. In environmental disaster learning, active student involvement can be realized through the use of story-based media that allows students to empathize with characters, understand environmental problems, and think about possible solutions. This helps students develop critical thinking and decision-making skills. Therefore, the developed learning media must provide space for students to actively participate in the learning process.

The need for child-friendly learning, based on student interviews, explains,

"*I like stories with characters like children like me. If the pictures are colorful and funny, I'm more enthusiastic about reading*."

The child-friendly principles in this study are realized through the development of digital comics that use simple language, non-threatening visuals, peer characters that students can easily identify with, and solution-oriented storylines. Sujinah et al., (2023) explain that digital comics combined with text, images, color, and technology could increase students' motivation, curiosity, and understanding of learning materials. Atashpanjeh et al. (2026) also found story-based media designed to meet children's developmental characteristics can enhance emotional engagement, learning motivation, and conceptual understanding. A learning approach using visual images aligns with the concept of child-centered learning, considering students as the primary subjects in the learning process. In environmental disaster learning, child-friendly digital comics enable students to understand flooding incidents without displaying traumatic or frightening visuals. Thus, learning needs, based on a child-friendly perspective, led to the development of safe, enjoyable, and participatory media that fostered environmental awareness through positive and meaningful learning experiences.

Child-friendly digital comic design integrating local wisdom and PBL-SSI in disaster material of primary schools

Based on the results of the needs analysis, the next stage in this research was to design a child-friendly digital comic integrating local wisdom and the Problem-Based Learning–Socio-Scientific Issues (PBL-SSI) approach for environmental disaster learning in primary schools. The design stage was carried out to produce a conceptual framework and an appropriate comic storyboard to the characteristics of primary school students, the needs of science learning, and the local environmental context of Kudus Regency especially the flooding vulnrability. The comic design was developed based on the principles of child-friendly learning, contextual learning, local wisdom, and disaster education oriented towards developing students' environmental awareness and critical thinking skills. The design results were realized in a digital comic entitled *"Pahlawan Lingkungan dari Kesambi"* which raises the flood phenomenon in Kesambi Village as the main learning context.

These four components complement each other in creating meaningful and contextual learning experiences. Child-friendly principles ensure that content, visuals, and storylines are appropriate for the cognitive and emotional development of primary school students. Local wisdom serves as a student-life learning context to facilitate students understanding the relationship between humans and the environment. Meanwhile, PBL and SSI were useful as pedagogical foundations that encouraged students to identify problems, analyze causes, evaluate various alternative solutions, and make environmentally responsible decisions. Child-friendly digital comics provide a safe, inclusive, participatory learning environment that supports student development. Smit et al., (2025) explains that the integration of SSI in science learning can improve argumentation skills, decision-making, and understanding of complex environmental issues.

The digital comic design was developed in the form of a narrative story consisting of ten main pages, one character introduction page, and one closing page. The storyline was structured systematically following the stages of problem-based learning and socio-scientific issues. The main characters consisted of Raka, Sinta, Bu Rini, and Pak Lurah, each of whom plays a role in helping students understand environmental issues and find solutions to flood disasters.

The main characteristic of this comic design was the application of child-friendly principles throughout the design elements. The comic's visuals use bright colors, engaging illustrations, and positive character expressions, creating a pleasant learning environment. Although the theme is a flood disaster, the illustrations do not depict frightening or potentially traumatic scenes for students. The story focuses on understanding the problem and finding solutions together. The use of peer figures such as Raka and Sinta could encourage students to self-identify with the characters in the story. The language is simple, communicative, and appropriate for the developmental level of primary school students. Mahinay et al. (2025) also explain that child-friendly learning media must provide a sense of security, increase participation, and support the emotional well-being of students.

The integration of Kudus' local wisdom serves as an authentic learning context. The comic was set in Kesambi Village, resembling an area prone to flood in Kudus Regency. The selection of local

wisdom elements enabled students to connect the learning material with real-life experiences. The local wisdom values integrated into the comic include working together to clean the environment, maintaining river cleanliness, planting trees, and caring for environmental sustainability. These values are demonstrated through interactions among students, teachers, community members, and the village government. Suarmika et al., (2022) explain the integration of local knowledge in disaster education can increase the relevance of learning because students learn from experiences and practices that develop in the surrounding community.

One of the key characteristics of this comic's design is the integration of PBL syntax and the SSI approach into the storyline. The flooding problem serves as the starting point for learning, encouraging students to understand its causes and impacts before finding appropriate solutions. Table 1 presents the process of integrating PBL and SSI into the digital comic.

Table 1. Integration of PBL-SSI in the Digital Comic "*Pahlawan Lingkungan dari Kesambi"*

PBL-SSI Syntax	Implementation in Comics
Problem orientation	Floods occurred in Kesambi Village
Identification of problems	Trash and illegal logging
SSI Exploration	The relationship between human activities and flooding
Investigation	River and environmental observations
Solution Development	Discussion and proposed actions
Action	Cleaning rivers and planting trees
Reflection	Summarizing lessons and commitment to protecting the environment

The table explains the integration of PBL-SSI through the learning syntax implemented in the 4th grade primary school science lesson on disaster material, chapter 8 "Becoming an Environmental Hero" includes: 1) problem orientation, namely the occurrence of flooding in Kesambi village, 2) problem identification, students explain the existence of garbage and ilegal logging, 3) SSI exploration, students can connect human activities with flooding, 4) Investigation, students observe around the river and the environment, 5) solution development, discussion and action proposals from students, 6) action, students clean the river and plant trees, and 7) reflection, students conclude the lesson and provide a commitment to protecting the environment. This design aligns with research Lubis et al., (2022) the research states that the integration of PBL and SSI allows students to connect scientific knowledge with social problems in a more meaningful way. In addition, Smit et al., (2025), explained that effective SSI learning increases learning interest and self-efficacy, as well as providing opportunities for students to make decisions based on scientific and moral considerations.

Digital comics are designed not only as a visual reading medium but also as an interactive learning medium to increase student engagement in environmental disaster learning. The comic designs are developed through the integration of digital technologies, including the Canva application for visual design, QR Codes to connect students with educational games, and the Heyzine platform to transform comics into interactive flipbooks accessible through various digital devices. The integration of these three technologies create a more engaging, participatory learning experience that aligns with the characteristics of the digital generation in primary schools. Mayer & Fiorella, (2022) explains multimedia learning that combines text, images, interactivity, and learning activities can improve conceptual understanding and student engagement more effectively than conventional media. Therefore, this digital comic design serves not only as an information medium but also as a means of exploration and active learning for students. The digital comic design process includes eight stages, as seen in Figure 1 below.

Figure 1. Design Stages of the Digital Comic *"Pahlawan Lingkungan dari Kesambi"*

The image explains the digital comic design process includes some steps. The first one was determining the Core Competence and Core Competence (CP) for the Fourth Grade Primary School Science lesson on the topic "Becoming an Environmental Hero," which relates to natural resource conservation, environmental change, and disaster mitigation. Based on the results of the curriculum analysis, the formulated learning objectives included students' abilities to recognize environmental problems, analyze the causes of flooding, understand the impact of disasters on society, evaluate alternative solutions, and demonstrate environmentally conscious behavior. Determining these learning objectives align with the principle of backward design, which places learning outcomes as the basis for developing media and learning activities (Wiggins & McTighe, 2021).

The second stage was developing a PBL-SSI pedagogical framework as a comic storyline. This study used the integration of Problem-Based Learning (PBL) and Socio-Scientific Issues (SSI) because of the capability of encouraging students to understand the relationship between scientific concepts and social problems that occur in their environment. Lubis et al. (2022) explain that PBL-SSI-based learning is effective in developing critical thinking, argumentation, and decision-making skills regarding complex environmental issues. Through this integration, comics function not only as a reading medium but also as a means of guiding students through scientific thinking and problem-solving processes.

The third stage involved identifying and integrating local wisdom relevant to environmental disaster material in Kudus Regency. The integrated local wisdom elements, namely mutual cooperation, river awareness, reforestation, and community service, were social practices within the community and highly relevant to flood disaster material. Suarmika et al. (2022) explain the integration of local knowledge into disaster education can increase the relevance of learning because students learn from the experiences of communities they know. In this study, Kesambi Village was chosen as the main setting for the story because of its relevant environemental condition representation to the students' lives. Local wisdom was presented not only as a setting but also as part of the solutions offered to address the flooding problem.

The fourth stage was implementing child-friendly principles. This principle is crucial because disaster themes can potentially cause anxiety if presented inappropriately to primary school students. UNICEF (2021) explains that child-friendly learning media must ensure psychological safety, active participation, and comfortable learning for students.

The fifth stage was compiling a comic storyboard, such as composing dialogue text and a storyline based on the predetermined PBL-SSI syntax. Cohn, (2021) explains storyboards could ensure the systematic arrangement of the relationship among narrative, visuals, and learning objectives to produce a coherent storyline that is easy for readers to understand.

The sixth stage involved designing the comic visuals using the Chatgpt and Canva applications. These applications were chosen because they offer various graphic design features that support the creation of educational illustrations with an attractive and child-friendly appearance. At this stage, the characters for Raka, Sinta, Mrs. Rini, and the Village Head were created. Comic panels with dialogue text and illustrations were compiled.

The seventh stage involved developing an educational game to increase student interactivity, accessible via QR Code. The QR Code was created and inserted on the last page of the comic. When the code was scanned using a smartphone, students were directed to a pre-prepared game activity. Güleç & Çoklar, (2022) explain integrating QR Codes into learning can increase student engagement because it allows for direct interaction between print or digital media and technology-based learning activities. The final stage involved converting the comic to Flipbook format using the Heyzine platform. The comic file, exported from Canva in PDF format, was uploaded to Heyzine to produce an interactive digital book with a page-flipping effect.

Characteristics of digital comic design that supports contextual science learning on disaster material in primary schools

The results of the needs analysis and design process indicate that the digital comic *"Pahlawan Lingkungan dari Kesambi"*has several characteristics to support contextual, meaningful, and student-centered science and science learning. These characteristics relate to visual aspects, pedagogical, social, cultural, technological, and psychological dimensions, integrated into a single learning medium. Effective media not only conveys information but also facilitates students construct understanding through learning experiences that are close to their lives (Johnson et al., 2025). This digital comic design was

developed to mediate scientific concepts about environmental disasters with the social and cultural realities experienced by students in Kudus Regency. Here are the characteristics of the developed digital comic design.

Contextual characteristics based on environment

The main characteristic of the Kesambi Environmental Heroes digital comic is its use of a real-life environmental context to primary school students. The entire storyline was created around the frequent flooding phenomenon in Kudus Regency, particularly in areas along the Muria river basin. This local context was chosen because science learning emphasizes the connection between scientific concepts and phenomena experienced by students. Based on constructivist learning theory, knowledge will be more meaningful while being constructed on students' existing experiences (Fosnot, 2020). Therefore, using the example of flooding in Kesambi Village can connect the concept of environmental change with the realities that students encounter directly. This characteristic makes comics not just a medium of information, but also a means of building contextual understanding.

The contextual approach in this comic aligns with the concept of place-based education, which utilizes the local environment as the primary learning resource. Ardoin et al. (2020) explain learning based on real-world situations can increase student engagement because they found an emotional connection to the issues being studied. In this comic, students not only read about flooding as a common phenomenon but also see how flooding affects community activities, schools, and the surrounding environment.

Characteristics of PBL-SSI Integration

The second characteristic is the integration of Problem-Based Learning (PBL) and Socio-Scientific Issues (SSI) syntax into the comic's storyline. Based on the PBL-SSI syntax, the comic's storyline begins with the emergence of a flooding problem in Kesambi Village. This approach aligns with the PBL principle, which places real-world problems as the starting point for learning. Ardiansyah et al., (2024) explain PBL enables students to develop higher-order thinking skills because they must identify problems, seek information, and formulate solutions based on available evidence. The integration of PBL in the comic is evident in the investigative process carried out by the main characters. After identifying the flood problem, Raka and Sinta are invited to observe environmental conditions, discuss with the teacher, and investigate the causes of the flooding. This process reflects the stages of investigation that are at the core of problem-based learning. Amin et al., (2020) stated that PBL not only improved conceptual mastery but also developed students' critical thinking and problem-solving skills. Rofifah et al., (2026) explain that problem-based learning combined with visual media can increase students' cognitive engagement because they are encouraged to construct knowledge independently.

The integration of the Socio-Scientific Issues (SSI) approach, namely the existence of flooding as a social and scientific issue. The comic explains that flooding is not only explained as a result of heavy rainfall, but is also linked to human behavior such as littering, reduced water catchment areas, and low public awareness of the environment. The SSI approach facilitates students understand that environmental issues are complex issues involving scientific, social, economic, and ethical dimensions. Smit et al., (2025) explain SSI-based learning enables students to develop scientific reasoning skills while considering the social implications of a problem.

The integration of SSI in the comic was realized through dialogue between characters explaining the causes and solutions to flooding. For example, the student character sees flooding as a problem that disrupts school activities, while the community leader views flooding as a threat to daily life. This diversity of perspectives provides an opportunity for students to understand that environmental issues may not always have one right answer. Pessoa et al. (2025) explain that SSI learning is effective in developing argumentation skills because students are encouraged to consider multiple perspectives before making decisions. The characteristics of SSI also strengthen the character education dimension in science learning. Through analysis of socio-environmental issues, students are encouraged to consider the impact of their actions on society and the surrounding environment. Susilawati et al., (2021) explain the SSI approach plays an important role in shaping responsible citizens because it facilitates students develop moral awareness and evidence-based decision-making skills.

Characteristics Based on Local Wisdom

Characteristics based on local wisdom serve as a contextual basis for learning. This comic integrates local values of the Kudus community, such as mutual cooperation, maintaining river cleanliness, and reforestation. These activities represent community knowledge that has been proven to play a role in maintaining environmental balance (Suarmika et al., 2022). Disaster education that integrates local knowledge can increase the relevance of learning and strengthen students' environmental awareness. The elements of local wisdom in this comic are part of the problem-solving process. The characters in the story carry out community service to clean rivers, plant trees, and encourage the community to protect the environment. This approach demonstrates that solutions to environmental problems can originate from social practices that develop within a community. In the era of globalization, learning that emphasizes local values plays a crucial role in strengthening character and a sense of belonging to regional culture. Sustainable education needs to integrate local knowledge as part of efforts to build resilient communities to environmental change.

Child-Friendly Characteristics

The distinguishing characteristic of the digital comic *"Pahlawan Lingkungan dari Kesambi"*is its application of child-friendly learning principles. These principles were developed based on the needs of primary school students who are at the cognitive, social, and emotional developmental stage and still require a safe, enjoyable learning environment that supports active participation. Child-friendly principles are crucial because disaster-related material has the potential to cause anxiety if presented inappropriately to the developmental characteristics of students. The comic's design avoids visualizations that depict damage, disaster victims, or situations that could trigger excessive fear in students. The story focuses on understanding the problem, building awareness, and finding shared solutions to environmental issues.

The application of child-friendly principles was also evident in the use of simple, communicative and appropriate language for the developmental level of primary school students. Dialogue between characters is structured using short sentences and vocabulary familiar with everyday life. Main characters like Raka and Sinta are designed to depict primary school students who are highly curious and care about the environment. The presence of peer figures allows for a process of self-identification, where students see themselves in the characters depicted, thus increasing emotional connection to the story. Furthermore, a child-friendly characteristic is the story's orientation, which focuses on hope and solutions. Although the story begins with the emergence of a flood problem, the comic's plot is directed at the process of finding a solution through cooperation, mutual assistance, and environmental action. Mahinay et al. (2025) explain that child-friendly learning media must not only be psychologically safe but also encourage optimism, self-confidence, and the ability to encounter challenges. In this comic, students are shown that environmental problems can be addressed through collective action and responsible behavior.

Supportive Visual-Narrative Characteristics to Science Literacy

The visual and narrative characteristics are designed to support a more effective understanding of science concepts. In this digital comic, information is conveyed through a combination of illustrations, dialogue, character expressions, and a complementary storyline. This approach is based on the Cognitive Theory of Multimedia Learning, which states that students learn more effectively when information is presented through visual and verbal channels simultaneously (Mayer & Fiorella, 2022). The integration of text and images can realize stronger student mental attachment to the environmental concepts being studied.

The visual-narrative characteristics of comics also serve to concretize abstract concepts contained in environmental disaster material. For example, the relationship between pilling-up wastes in rivers and flooding is visualized through a series of panels showing gradual changes in environmental conditions. The visualization and narrative in comics facilitates students understand cause-and-effect relationships more clearly than solely text explanation. Man Seong et al. (2025) explain a strong narrative can increase learning motivation because it encourages students to find out what happens in the future and understand the conflicts encounterd by the characters. In the digital comic "*Pahlawan Lingkungan dari Kesambi*" the flood conflict is the main driving force behind the story, which then develops into a learning process about the environment.

Interactive Characteristics Based on Digital Technology

The technology-based interactive characteristic is one of the main innovations in research integrating digital technology through QR codes, educational games, and the Heyzine flipbook platform. Unlike conventional printed comics, with one-way characteristics, these digital comics allow students to interact directly with various learning activities connected through digital technology. This integration was designed to meet the needs of digital generation students who were accustomed to interacting with technological devices in their daily lives. (Wang et al., 2022) explain the use of interactive technology in learning can increase student engagement by providing a more dynamic and personalized learning experience. QR codes are implemented in comics when accessing quizzes related to the story's content. When students scan the code using a smartphone or tablet, they are directed to activities designed to strengthen conceptual understanding and develop critical thinking skills (Hwang et al., 2023), QR Code-based learning could increase student motivation and engagement because it creates a direct connection between learning materials and interactive activities.

Digital comics are presented using flipbooks with the Heyzine platform to provide a more engaging reading experience than traditional PDF formats. The flipbook's page-flipping effect supports students' reading of comics in a more flexible and enjoyable way. Risnawati & Purwaningsih, (2025) explain interactive digital media can enhance the learning experience by giving students greater control over their learning process. In this study, the combination of digital comics, QR codes, and flipbooks creates an integrated digital learning environment that supports independent learning. These characteristics demonstrate how technology is applicable to expand the function of comics from mere reading media to a comprehensive digital learning ecosystem.

CONCLUSION

This study analyzed the learning needs of environmental disasters in primary schools, design child-friendly digital comics that integrate local wisdom and PBL-SSI, and identify the characteristics of digital comic designs to support science learning in primary schools. The results of the study indicated that teachers and students needed interesting, contextual, and relevant learning media to students' real experiences, especially in understanding the flood problems in Kudus Regency. Then the researchers designed the digital comic, *"Pahlawan Lingkungan dari Kesambi"* comic. The resulting comic design has eight main characteristics, namely contextual based on real environments, integrated PBL, integrated SSI, based on local wisdom, child-friendly, visual-narrative, interactive based on digital technology (QR Barcode and Flipbook), and oriented towards the development of environmental awareness and critical thinking. The contribution of this study lies in the development of a digital comic design framework that integrates pedagogical aspects, local culture, and digital technology in one learning medium on environmental disaster material in primary schools. Further research could develoop, validate, implement, and evaluate the practicality and effectiveness of digital comics in increasing environmental awareness and critical thinking skills.

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