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Developing a RAW-Based Science E-Comic to Enhance Junior High School Students' Learning Outcomes and Higher-Order Thinking Skills in Environmental Science

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Abstract
This study aimed to develop a RAW-based *E-Comic Sains Green Ranger* for teaching environmental pollution and global warming and to examine its preliminary effectiveness in improving seventh-grade students' science learning outcomes and higher-order thinking skills (HOTS). Using a research and development approach structured by the ADDIE stages (analysis, design, development, implementation, and evaluation), the e-comic combined contextual environmental narratives with Reading, Analyzing, and Writing activities. A limited trial involved 64 Grade VII students at SMPN 2 Ponorogo, Indonesia, divided equally between an experimental class (n = 32) and a control class (n = 32). Data were obtained from pretests and posttests of science learning outcomes and HOTS observation sheets and analyzed descriptively using normalized gain (N-gain). The experimental class achieved a higher mean posttest score (88.44) than the control class (81.72). Its learning-outcome N-gain was 0.78 (high), compared with 0.64 (moderate) in the control class; corresponding HOTS N-gain values were 0.76 and 0.51, respectively. These descriptive findings suggest that integrating an environmental e-comic with structured reading, analysis, and writing activities may support conceptual learning and higher-order thinking. However, the limited two-class trial and absence of reported inferential testing constrain claims of comparative effectiveness. Further studies with larger samples and rigorous statistical evaluation are needed to establish the intervention's impact and transferability.

Keywords: Digital Comics; Environmental Education; Higher-Order Thinking Skills; RAW Learning Model; Science Education.

INTRODUCTION

Science education at the lower-secondary level plays a strategic role in developing students' scientific literacy, conceptual understanding, environmental awareness, and higher-order thinking skills because students at this stage are expected to connect scientific concepts with real-life phenomena, evaluate evidence, and propose reasoned solutions to socio-environmental problems (Ardoin et al., 2020; OECD, 2023; Rousell & Cutter-Mackenzie-Knowles, 2020). However, international and national studies continue to indicate that science learning often remains dominated by teacher explanation, textbook-based instruction, and routine assessment practices that are insufficient to stimulate inquiry, analysis, and reflective reasoning (Haleem et al., 2022; Li et al., 2024; Yu et al., 2021). This condition becomes more critical when students learn environmental topics such as environmental pollution and global warming, which require not only factual comprehension but also the ability to identify causal relationships, interpret environmental impacts, and formulate responsible actions based on scientific reasoning (Ardoin et al., 2020; Monroe et al., 2019; Rousell & Cutter-Mackenzie-Knowles, 2020). Therefore, science learning needs instructional innovations that can transform abstract environmental concepts into contextual, visual, and problem-oriented learning experiences.

Environmental pollution and global warming are highly relevant topics for junior high school students because these issues are closely connected to waste management, air pollution,

climate change, ecosystem degradation, temperature increase, and human responsibility toward environmental sustainability (Ardoin et al., 2020; Monroe et al., 2019; Rousell & Cutter-Mackenzie-Knowles, 2020). Nevertheless, students frequently experience difficulty in linking observable environmental problems with scientific concepts such as greenhouse gas accumulation, human-induced environmental change, energy use, ecological balance, and mitigation strategies (Makransky & Petersen, 2021; Radianti et al., 2020). Environmental education research emphasizes that effective learning should not be limited to transmitting information, but should also develop knowledge, attitudes, values, skills, and action competence through locally meaningful and problem-based contexts (Collado et al., 2020; Farinella, 2018). In this regard, learning media that present environmental problems through visual stories, characters, conflicts, and reflective tasks can help students understand science as a way of interpreting and solving real-world problems.

Digital and visual learning media have become increasingly important in contemporary education because they can support students' attention, representation of complex concepts, learning motivation, and active engagement (Mansyur & Aminah, 2024; Staneviciene & Žekienė, 2025; Wong & Hughes, 2023). Studies on immersive learning, augmented reality, and digital visual environments show that technology-supported media can improve learning gains, motivation, and conceptual understanding when the media are integrated with appropriate instructional strategies rather than used merely as decorative tools (Garzón et al., 2019; Makransky & Petersen, 2021). Similarly, digital learning environments that include narrative, visual, interactive, or game-like elements have been reported to strengthen engagement, motivation, problem-solving, and critical thinking when learning activities are intentionally designed to guide students' cognitive processes (Cheung & Ng, 2021; Yu et al., 2021). These findings imply that media effectiveness depends not only on technological attractiveness, but also on the pedagogical structure that directs students to observe, question, analyze, and communicate ideas.

Comics and e-comics represent a promising form of visual narrative media in science learning because they combine illustrations, dialogue, storyline, characters, and contextual problems into a learning sequence that can make scientific concepts more concrete and memorable (Nuraini & Saputro, 2019; Susanto et al., 2021, 2022). In science education, comic-based media can bridge everyday experience and scientific explanation by presenting phenomena through narrative conflicts that students can follow, interpret, and discuss (Hidayah et al., 2024; Septiana & Nur Fadhilah, 2024). The use of comic-based and visual media is also consistent with research showing that students learn more meaningfully when abstract concepts are represented through visual, contextual, and multimodal forms that reduce cognitive distance between content and experience (Garzón et al., 2019; Parong & Mayer, 2018). For environmental science topics, an e-comic can provide a particularly meaningful learning context because pollution, climate change, and conservation issues can be presented through characters, environmental conflicts, and solution-oriented storylines.

The development of E-Comic Sains Green Ranger is grounded in the assumption that science learning becomes more meaningful when students are not only exposed to content, but also invited to read, interpret, analyze, and express scientific ideas. Previous studies on comic media, e-comic Reyog, and culturally contextualized comics have demonstrated that visual narratives can support student engagement, character formation, and learning achievement when the content is aligned with students' social and cultural environment (Fianto et al., 2023; Susanto et al., 2021, 2022). Recent empirical studies in Indonesian elementary and science education contexts also report that three-dimensional media, augmented reality, digital comics, and gamified visual learning media can improve student learning outcomes and participation when used to make abstract concepts more concrete (Cahyani et al., 2024; Hidayah et al., 2024). However, many of these studies focus primarily on the effectiveness of media use, while fewer studies explicitly describe the systematic development of the product, the learning syntax embedded in the media, and the relationship between visual narrative activities and higher-

order thinking skills.

Higher-order thinking skills are essential in science learning because environmental problems require students to analyze causes, evaluate impacts, compare alternatives, and construct solutions rather than merely recall definitions. Game-based and digital learning studies indicate that learning outcomes can improve when students experience active learning processes involving problem-solving, feedback, engagement, and meaningful interaction with learning tasks (Bai et al., 2020; Sailer & Homner, 2020; Zainuddin et al., 2020). Educational game research further demonstrates that motivation and engagement often mediate students' learning experiences, suggesting that enjoyable media should be connected to structured cognitive tasks to produce deeper learning outcomes (Cheung & Ng, 2021; Li et al., 2024). Thus, an e-comic designed for science learning should not only attract students' attention but also organize learning activities that require students to reason, justify, and communicate their understanding.

The RAW model, conceptualized in this study as Reading, Analyzing, and Writing, provides a structured pedagogical sequence to transform comic reading into active scientific learning. The Reading stage allows students to construct initial understanding through visual narratives and environmental storylines; the Analyzing stage guides students to identify problems, causal relationships, scientific concepts, and possible environmental consequences; and the Writing stage encourages students to formulate conclusions, arguments, and solution-oriented reflections. This sequence is consistent with student-centered digital learning research, which emphasizes that learners need opportunities to interact with content, construct meaning, engage in problem-solving, and communicate ideas in order to achieve deeper understanding (Coleman & Money, 2020). It is also aligned with research on visual and immersive media showing that learning is more effective when media affordances are combined with instructional methods that support reflection, agency, and self-regulated learning.

The integration of the RAW model into E-Comic Sains Green Ranger is therefore expected to address two common weaknesses in science learning media. First, visual media are sometimes used only as supplementary materials without clear instructional syntax, which may limit their contribution to conceptual understanding and higher-order thinking. Second, digital or comic-based learning media often emphasize attractiveness and motivation, but do not always provide explicit analytical and written activities that train students to construct scientific explanations (Coleman & Money, 2020; Garzón et al., 2019). By embedding Reading, Analyzing, and Writing activities into the e-comic, the product developed in this study is intended to function not merely as visual reading material, but as a structured learning medium that facilitates conceptual understanding, environmental awareness, and higher-order thinking skills.

Although previous studies have examined comic media, e-comics, augmented reality, gamification, and digital science learning, several research gaps remain. Studies on science comics and e-comics have generally emphasized learning motivation, character values, or achievement, but they have not sufficiently connected comic-based narratives with a specific learning syntax designed to foster higher-order thinking. Studies on digital games and gamification have demonstrated positive effects on motivation, engagement, and learning outcomes, but they are not always situated in environmental science topics or developed as comic-based learning products for junior high school students (Bai et al., 2020; Li et al., 2024; Sailer & Homner, 2020; Yu et al., 2021). Meanwhile, studies on environmental education and climate change education emphasize contextual and action-oriented learning, but there remains a need for learning media that translate environmental issues into visual, narrative, and student-centered classroom activities (Ardoin et al., 2020; Monroe et al., 2019; Rousell & Cutter-Mackenzie-Knowles, 2020). Therefore, this study offers novelty by developing E-Comic Sains Green Ranger as a science e-comic that integrates environmental pollution and global warming content with the RAW learning sequence to support both learning outcomes and higher-order thinking skills.

Based on these gaps, this study aims to develop E-Comic Sains Green Ranger based on the RAW model for environmental pollution and global warming topics in junior high school science

learning. Specifically, this study seeks to describe the characteristics of the developed e-comic, explain how the RAW syntax is embedded in the product, and examine the initial effectiveness of the product in improving students' learning outcomes and higher-order thinking skills. The study is expected to contribute to science education by providing a contextual e-comic development model that combines visual narrative, environmental issues, and structured analytical learning activities.

METHODS

This study employed a research and development approach to produce and evaluate the E-Comic Sains Green Ranger as a contextual science learning medium for the topics of environmental pollution and global warming. The use of a development-oriented design was considered appropriate because the study did not only aim to test instructional effectiveness, but also to generate a learning product that was systematically designed, implemented, and evaluated in an authentic classroom context (Creswell & Creswell, 2018; Pellas et al., 2019; Yaşar et al., 2024). The development procedure followed the ADDIE framework, which consists of analysis, design, development, implementation, and evaluation, because this framework allows instructional products to be constructed through a logical sequence from needs identification to formative evaluation. In this study, ADDIE was used as a flexible development model rather than as a rigid linear procedure, since learning media development requires continuous alignment among learner characteristics, content demands, media design, classroom implementation, and evaluation results (Fraenkel et al., 2019; Lakens, 2013; Navarrete et al., 2024).

The analysis stage was conducted to identify the instructional problems, learner needs, content characteristics, and learning context related to junior high school science learning. This stage focused on the need for a visual, contextual, and problem-oriented medium that could help students understand environmental pollution and global warming as scientific and socio-environmental issues rather than as isolated textbook concepts (Fraenkel et al., 2019; Wasserstein et al., 2019; Yaşar et al., 2024). The analysis also considered the importance of higher-order thinking skills in environmental science learning because students need to analyze causal relationships, evaluate human actions, and propose responsible solutions to environmental problems. Based on these considerations, the e-comic was designed to combine science content, environmental narratives, character-based visual storytelling, and guided learning activities that could stimulate students' conceptual understanding and analytical reasoning (Gopalan et al., 2020; Hake, 1998; Wasserstein et al., 2019).

The design stage involved the preparation of the product structure, learning flow, visual concept, storyline, student activities, and the integration of the RAW learning sequence into the e-comic. In this study, RAW refers to Reading, Analyzing, and Writing, which was used to transform comic reading into an active learning process that requires students to understand information, examine environmental problems, and communicate scientific solutions in written form. The Reading stage was designed to support initial comprehension through visual narratives and dialogues, the Analyzing stage was designed to guide students in identifying problems, causes, impacts, and scientific concepts, and the Writing stage was designed to encourage students to construct conclusions, arguments, and solution-oriented reflections (Creswell & Creswell, 2017; Judijanto et al., 2024). The design of the e-comic was also aligned with principles of digital and visual learning media, which emphasize that media should not only attract attention but also facilitate meaningful interaction with learning content.

The development stage produced the E-Comic Sains Green Ranger: Pencemaran Lingkungan as a digital visual narrative medium for science learning. The product contains characters, environmental conflicts, visual representations of pollution, and learning prompts that guide students to connect the story with scientific concepts on environmental pollution and global warming. The use of comic-based visual narration was intended to reduce the abstractness of environmental science concepts and to increase students' engagement with the learning material. The product was developed as a pedagogical medium rather than merely as a reading

material because each section of the e-comic was connected with the RAW syntax to support reading comprehension, analytical thinking, and written scientific communication. At this stage, the product was prepared for limited classroom implementation, while broader expert validation, readability testing, and large-scale usability evaluation were positioned as directions for subsequent refinement of the product.

The implementation stage was conducted through a limited field trial in grade VII science learning at SMPN 2 Ponorogo during the 2025/2026 academic year. Two intact classes were involved in the implementation, with 32 students assigned to the experimental class and 32 students assigned to the control class. The use of intact classes was considered suitable for school-based instructional research because random assignment of individual students is often difficult in natural classroom settings (Fraenkel et al., 2019; Gopalan et al., 2020). The experimental class learned the topics of environmental pollution and global warming using the E-Comic Sains Green Ranger based on the RAW model, whereas the control class received conventional science instruction using teacher explanation and regular learning materials. This comparison was used to examine the initial effectiveness of the developed product in supporting learning outcomes and higher-order thinking skills under authentic classroom conditions.

The instruments used in this study consisted of a learning outcome test and a HOTS observation sheet. The learning outcome test was administered as a pretest and posttest to measure students' conceptual understanding before and after the learning intervention. The use of pretest and posttest data was intended to capture learning progress more accurately because the design allows researchers to compare students' initial ability and final achievement after instructional treatment. The HOTS observation sheet was used to document students' analytical and evaluative behaviors during the learning process, particularly their ability to identify environmental problems, explain causal relationships, evaluate impacts, and formulate solutions. These indicators were aligned with the notion that higher-order thinking involves analysis, evaluation, problem solving, reasoning, and the production of justified responses rather than the simple recall of information. The use of both test and observation data was intended to provide a more comprehensive picture of product effectiveness because learning media should be evaluated not only through cognitive achievement but also through students' participation in thinking-oriented learning activities.

The evaluation stage analyzed the initial effectiveness of the developed product by comparing students' learning outcomes and HOTS improvement in the experimental and control classes. Descriptive statistics were used to summarize students' mean pretest scores, mean posttest scores, mean HOTS observation scores, score increases, and normalized gain values. Normalized gain analysis was used to determine the magnitude of improvement relative to the maximum possible score because it is commonly applied in pretest–posttest educational studies to describe learning progress after an intervention (Fraenkel et al., 2019; Hake, 1998). The N-gain score was interpreted using three categories: high when the value was greater than 0.70, moderate when the value ranged from 0.30 to 0.70, and low when the value was less than 0.30. In addition, an independent sample t-test was proposed to examine whether the posttest and HOTS differences between the experimental and control classes were statistically significant, while effect size analysis was recommended to support the interpretation of practical significance beyond statistical significance (Lakens, 2013; Wasserstein et al., 2019). This analytical strategy was used to ensure that the evaluation of the e-comic product was not limited to descriptive comparison but also supported by inferential and practical evidence of learning improvement.

Ethical considerations were addressed by ensuring that the learning activities were implemented within regular classroom instruction and did not disadvantage students in either class. Students in both classes received instruction on the same science topics, while the difference lay in the learning medium and instructional sequence used during the intervention. The data were analyzed at the group level to protect student identity and to maintain the confidentiality of individual learning results. These procedures were consistent with the ethical

principle that school-based educational research should minimize risk, protect participants, and ensure that instructional interventions remain educationally beneficial for learners.

RESULT AND DISCUSSION

Product Development of the E-Comic Sains Green Ranger

The main product generated in this study was the E-Comic Sains Green Ranger: Pencemaran Lingkungan, a digital science comic designed to support junior high school students in learning environmental pollution and global warming. The product was developed as a visual-narrative learning medium that integrates environmental issues, fictional characters, contextual conflicts, and guided learning activities based on the RAW model. The comic was not designed merely as supplementary reading material, but as a structured pedagogical tool that guides students to read science-related narratives, analyze environmental problems, and write scientific arguments or solutions. The visual identity of the product is presented in Figure 1.



Figure 1. Cover of the E-Comic Sains Green Ranger: Pencemaran Lingkungan

Figure 1 shows the visual cover of the developed e-comic. The cover presents the title Pencemaran Lingkungan, the identity of E-Comic Sains Green Ranger, and several characters associated with environmental awareness. The visual elements, such as plants, natural background, and student-like figures, were designed to create an initial contextual impression before students entered the learning activities. This visual design is important because the first interaction between students and the learning medium can influence their attention, curiosity, and readiness to engage with the content. In the RAW sequence, the cover functions as an initial stimulus for the Reading stage, while the storyline and environmental conflicts inside the comic become the basis for the Analyzing and Writing stages.



Figure 2. Description of characters in comics

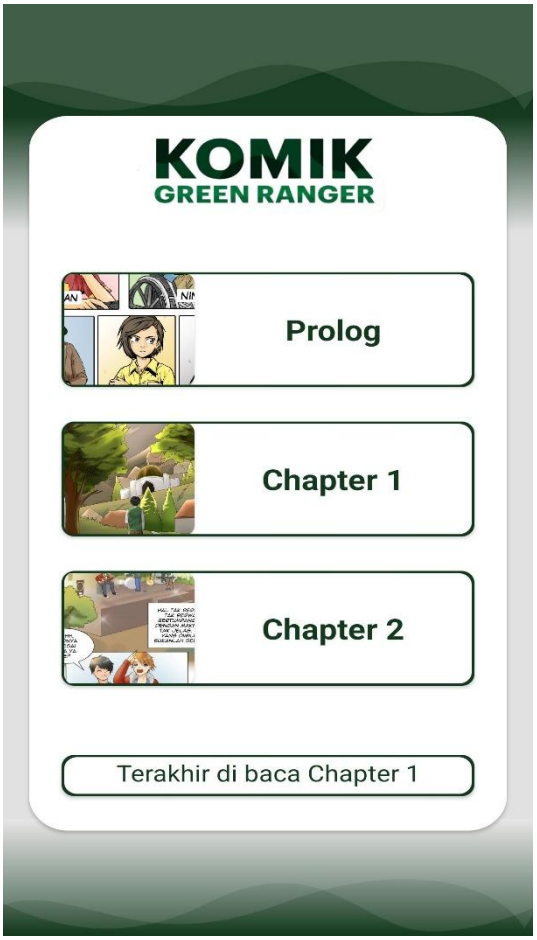


Figure 3. Chapter list view

Figure 2 presents the character introduction interface in the digital comic. This screen introduces the main characters Gibran, Nino, Robin, Erin, Erik, and the president through illustrated visual profiles and name labels. The interface also provides a brief introductory narrative and a "Next" navigation button, enabling users to proceed to the subsequent content. This feature is intended to help students recognize the characters, understand their roles in the storyline, and build initial engagement before entering the main learning chapters. Figure 3 illustrates the chapter selection interface of the Green Ranger comic. The screen provides structured access to the Prologue, Chapter 1, and Chapter 2, with each section accompanied by a visual preview from the corresponding comic content. A "last read" indicator is also displayed to inform users of their most recently accessed chapter. This interface supports clear navigation, facilitates independent learning, and enables students to continue reading from their previous progress.

Integration of the RAW Model into the E-Comic

The developed e-comic was structured based on the RAW model, which consists of Reading, Analyzing, and Writing. Each stage was embedded into the learning activities to ensure that students did not only read the comic passively, but also processed the content through analysis and written reflection. The integration of the RAW syntax into the e-comic is summarized in Table 1.

Table 1. Integration of the RAW Model into the E-Comic Sains Green Ranger

RAW stage	Learning activity in the e-comic	Pedagogical function
Reading	Students read the environmental storyline and observe the visual illustrations in the e-comic.	Builds initial understanding of environmental pollution and global warming through visual and narrative

		representation.
Analyzing	Students identify environmental problems, causes, impacts, and science concepts presented in the story.	Trains students to analyze cause-and-effect relationships and evaluate human actions toward the environment.
Writing	Students write conclusions, arguments, and proposed solutions based on their analysis.	Strengthens scientific communication, reflection, and problem-solving related to environmental issues.

Table 1 shows that the RAW model provides a clear learning pathway within the e-comic. The Reading stage introduces students to the environmental context through visual narratives. The Analyzing stage transforms the comic storyline into problem-based science learning by asking students to identify causes and impacts of pollution and global warming. The Writing stage encourages students to express their scientific understanding through written arguments and solutions. Thus, the e-comic product combines visual engagement with structured cognitive activities.

Students' Learning Outcomes in the Limited Field Trial

The limited field trial involved two grade VII classes at SMPN 2 Ponorogo. Each class consisted of 32 students. The experimental class learned using the E-Comic Sains Green Ranger based on the RAW model, whereas the control class received conventional science instruction. The learning outcome test was administered before and after the intervention to examine students' conceptual improvement in the topic of global warming. The descriptive and inferential results are presented in Table 2.

Table 2. Students' Learning Outcome Scores in the Experimental and Control Classes

Group	N	Pretest M ± SD	Posttest M ± SD	Mean increase	N-gain M ± SD	N-gain category
Experimental class	32	47.03 ± 9.91	88.44 ± 8.08	41.41	0.78 ± 0.15	High
Control class	32	47.50 ± 10.70	81.72 ± 7.68	34.22	0.64 ± 0.16	Moderate

As shown in Table 2, the experimental and control classes had comparable initial learning achievement. The experimental class obtained a pretest mean score of 47.03, while the control class obtained a pretest mean score of 47.50. The independent sample t-test indicated no significant difference in the pretest scores between the two groups, $t(62) = -0.18$, $p = .856$, suggesting that both classes started from a relatively similar level of prior knowledge before the intervention.

After the intervention, the experimental class achieved a higher posttest score than the control class. The mean posttest score of the experimental class was 88.44, whereas the control class reached 81.72. The independent sample t-test showed a significant difference in posttest scores between the two groups, $t(62) = 3.41$, $p = .001$. The effect size was also large, with Cohen's $d = 0.85$. This result indicates that students who learned through the RAW-based e-comic achieved better conceptual understanding than those who learned through conventional instruction.

The N-gain result further supports the effectiveness of the developed product. The experimental class obtained an average N-gain score of 0.78, which falls into the high category, while the control class obtained an average N-gain score of 0.64, which falls into the moderate category. The difference in N-gain scores was statistically significant, $t(62) = 3.56$, $p < .001$, with a large effect size, Cohen's $d = 0.89$. This finding shows that the RAW-based e-comic provided stronger learning improvement than conventional instruction, particularly in helping students

connect visual environmental narratives with scientific concepts related to global warming.

Students' Higher-Order Thinking Skills in the Limited Field Trial

In addition to learning outcomes, this study also examined students' higher-order thinking skills (HOTS) through observation. The HOTS observation focused on students' ability to identify environmental problems, analyze causal relationships, evaluate environmental impacts, and formulate possible solutions during the learning process. The HOTS observation results are presented in Table 3.

Table 3. Students' HOTS Observation Scores in the Experimental and Control Classes

Group	N	HOTS observation 1 M ± SD	HOTS observation 2 M ± SD	Mean increase	N-gain M ± SD	N-gain category
Experimental class	32	20.09 ± 1.63	35.22 ± 1.54	15.13	0.76 ± 0.08	High
Control class	32	20.13 ± 1.52	30.09 ± 1.47	9.97	0.51 ± 0.04	Moderate

Table 3 shows that the initial HOTS scores of the two groups were almost identical. The experimental class obtained an initial HOTS mean score of 20.09, while the control class obtained 20.13. The independent sample t-test confirmed that there was no significant difference between the two groups at the first observation, $t(62) = -0.08$, $p = .937$. This indicates that both groups had similar initial HOTS levels before the learning intervention was fully implemented.

At the second observation, the experimental class showed a higher HOTS score than the control class. The mean HOTS score of the experimental class increased to 35.22, while the control class increased to 30.09. The difference between the two groups was statistically significant, $t(62) = 13.63$, $p < .001$. The effect size was very large, with Cohen's $d = 3.41$. This result indicates that the RAW-based e-comic strongly supported the development of students' analytical and evaluative thinking during science learning.

The N-gain analysis also showed that the experimental class experienced stronger HOTS improvement than the control class. The experimental class obtained an average N-gain score of 0.76, categorized as high, while the control class obtained an average N-gain score of 0.51, categorized as moderate. The difference in HOTS N-gain scores was statistically significant, $t(62) = 16.99$, $p < .001$, with a very large effect size, Cohen's $d = 4.25$. This finding suggests that the combination of visual storytelling, environmental problem contexts, and RAW-based activities created more opportunities for students to practice higher-order thinking than conventional instruction.

Summary of Product Effectiveness

Overall, the results indicate that the E-Comic Sains Green Ranger based on the RAW model has promising effectiveness as a science learning medium. The product helped students improve their learning outcomes and HOTS in the topic of environmental pollution and global warming. The experimental class outperformed the control class in both posttest achievement and HOTS observation. The N-gain scores also showed that the experimental class reached the high category in both learning outcomes and HOTS, whereas the control class remained in the moderate category. The summary of the product effectiveness is presented in Table 4.

Table 4. Summary of the Limited Field Trial Results

Measured variable	Experimental class	Control class	Interpretation
Posttest mean score	88.44	81.72	The experimental class achieved higher conceptual understanding.
Learning outcome N-gain	0.78	0.64	The experimental class reached high improvement, while the control class reached moderate improvement.
HOTS observation	35.22	30.09	The experimental class demonstrated stronger

2 mean score			higher-order thinking performance.
HOTS N-gain	0.76	0.51	HOTS improvement was higher in the experimental class.

Table 4 confirms that the developed e-comic was not only visually relevant but also pedagogically functional. The product supported conceptual learning through its environmental storyline and visual representation, while the RAW model strengthened the learning process through reading, analysis, and writing activities. These results provide empirical evidence that the E-Comic Sains Green Ranger can be used as an alternative contextual science learning medium to improve learning outcomes and higher-order thinking skills among junior high school students.

Discussion

The results of this study indicate that the RAW-based E-Comic Sains Green Ranger contributed positively to students' learning outcomes and higher-order thinking skills in junior high school science learning. The experimental class achieved higher posttest performance and stronger N-gain improvement than the control class, suggesting that the developed e-comic was not merely visually attractive but also pedagogically functional. This result is consistent with Yu et al. (2021), who reported that educational games and visually engaging learning environments can improve learning outcomes, motivation, engagement, and satisfaction when students are actively involved in the learning process. A similar pattern was also reported by Li et al. (2024), who found that digital educational games influence learning motivation through learning engagement, indicating that media-supported instruction becomes more effective when students interact meaningfully with the learning content. In the present study, the e-comic provided such interaction through visual narratives, environmental conflicts, and RAW-based activities that required students to read, analyze, and write scientific responses.

The improvement in students' learning outcomes also aligns with previous meta-analytic evidence on gamification and game-based learning. Sailer and Homner (2020) found that gamified learning tends to produce positive effects when game elements are aligned with learning objectives, while Bai et al. (2020) emphasized that gamification can improve learning outcomes when it supports cognitive engagement rather than simply adding rewards or entertainment. Although the present study did not use a fully gamified digital game system, the E-Comic Sains Green Ranger adopted game-like narrative features, heroic characters, environmental missions, and problem-solving situations that encouraged students to participate more actively. This suggests that the motivational logic of game-based learning can also be adapted into e-comic media when the learning activities are structured and conceptually directed.

Compared with studies that focus on digital educational games, this research highlights the distinctive role of visual narrative in science learning. Cheung and Ng (2021) argued that educational games can enhance student learning because they create active participation, interaction, and meaningful challenge. The present study extends this idea by showing that structured e-comic learning can also support active participation through the sequence of Reading, Analyzing, and Writing. Unlike digital games that often emphasize gameplay mechanics, the RAW-based e-comic emphasizes narrative comprehension, problem interpretation, causal analysis, and written explanation. Therefore, the learning process in this study was not dependent on competition, scores, or badges, but on students' ability to transform visual information into scientific reasoning.

The results are also in line with studies on visual and immersive learning media. Garzón et al. (2019) showed that augmented reality in educational settings can improve learning because it helps students visualize concepts that are difficult to understand through verbal explanation alone. Makransky and Petersen (2021) similarly explained that immersive visual media can support learning when cognitive and affective processes are properly facilitated. In this study, the e-comic helped students understand environmental pollution and global warming

by presenting abstract ecological issues through characters, scenes, and story-based conflicts. However, the present research differs from AR or VR studies because the product does not require advanced immersive technology. Instead, it uses a more accessible e-comic format, making it potentially easier to implement in schools with limited technological infrastructure.

The positive development of HOTS in the experimental class supports the argument that science learning media should be connected to analytical tasks. Zainuddin et al. (2020) stated that gamified and technology-supported learning can enhance instruction when students are required to solve problems and reflect on their learning experience. Yu et al. (2021) also found that educational games are associated with student engagement and learning satisfaction, but their impact becomes more meaningful when the learning design promotes active cognitive involvement. In this study, the Analyzing stage of the RAW model required students to identify environmental problems, examine causes and consequences, and evaluate possible solutions. The Writing stage then strengthened this reasoning process by asking students to construct conclusions and arguments. This explains why the HOTS improvement in the experimental class was higher than that in the control class.

The findings also correspond with environmental education literature. Ardoin et al. (2020) emphasized that effective environmental education should develop knowledge, attitudes, skills, and action-oriented awareness. Monroe et al. (2019) argued that climate change education becomes more effective when students engage with personally relevant and solution-focused learning experiences. Young learners need opportunities to understand climate change through participatory and meaningful approaches. The present study supports this view because the e-comic presented environmental pollution and global warming through a contextual storyline closely related to students' everyday experiences. Students were not only encouraged to memorize definitions but also guided to interpret environmental problems and propose relevant solutions.

The novelty of this study lies in the integration of three components that are often examined separately in previous studies: science e-comic media, environmental learning content, and the RAW learning model. Previous studies have generally discussed comics as media for motivation or conceptual understanding, digital games as tools for engagement, or environmental education as a contextual learning approach. This research combines these elements into a single development product, namely the E-Comic Sains Green Ranger, which embeds Reading, Analyzing, and Writing activities into environmental science learning. This combination provides a more specific pedagogical contribution because the e-comic is not only designed to attract attention but also to train students' higher-order thinking through guided scientific reasoning.

The theoretical implication of this study is that visual narrative media can serve as a bridge between environmental science concepts and students' cognitive processes when supported by a structured learning model. The findings suggest that e-comic-based learning is more powerful when students are directed to process information through analysis and written communication. This contributes to science education theory by showing that comic media can move beyond motivational support and become a scaffold for higher-order thinking. It also supports the view that learning media should be evaluated not only from their visual quality but also from their capacity to organize meaningful cognitive activities.

The practical implication is that science teachers can use e-comics as an accessible alternative medium for teaching environmental pollution and global warming. Because the product does not require complex technology, it can be implemented in schools with varying levels of digital infrastructure. Teachers may use the RAW syntax to guide students in reading the comic, discussing environmental issues, analyzing cause-and-effect relationships, and writing proposed solutions. This approach can help teachers transform science lessons into more contextual, reflective, and student-centered learning experiences. For curriculum developers, the product offers a model for designing environmental science materials that integrate visual storytelling, scientific content, and HOTS-oriented tasks.

Despite its contribution, this study has several limitations. First, the implementation was

conducted in one school with two intact classes, so the results cannot be generalized to broader student populations without further testing. Second, the study used a limited field trial; therefore, the effectiveness of the product still needs to be examined through larger samples, longer intervention periods, and more diverse school contexts. Third, the data focused mainly on learning outcomes and HOTS observation, while other important variables such as environmental attitudes, scientific literacy, student creativity, reading engagement, and long-term retention were not deeply investigated. Fourth, the product development stage still requires more comprehensive expert validation involving media experts, science content experts, language experts, and user readability testing. Future research should therefore conduct broader product validation, compare the RAW-based e-comic with other digital learning media, and examine its effectiveness across different science topics and grade levels.

CONCLUSION

This study developed the E-Comic Sains Green Ranger based on the RAW model as a contextual science learning medium for environmental pollution and global warming topics in junior high school. The product was designed through the ADDIE development stages by integrating visual narratives, environmental problem contexts, and the Reading, Analyzing, and Writing learning sequence to support students' conceptual understanding and higher-order thinking skills. The limited field trial showed that students who learned through the RAW-based e-comic achieved higher learning outcomes and HOTS improvement than those who received conventional instruction, as indicated by the higher posttest mean score, higher learning outcome N-gain, and higher HOTS N-gain in the experimental class. These findings suggest that the developed e-comic is not only visually engaging but also pedagogically meaningful because it encourages students to read scientific narratives, analyze environmental problems, and communicate solution-oriented ideas. The study contributes to science education by offering an accessible model of e-comic-based learning that connects environmental issues with structured analytical activities. Nevertheless, this study was limited to a small-scale implementation in one school and focused only on learning outcomes and HOTS; therefore, future research should involve broader samples, longer implementation periods, expert validation, readability testing, and additional variables such as environmental attitudes, scientific literacy, creativity, and long-term retention.

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