JISE 14 (2) (2025): 183-193

Journal of Innovative Science Education

https://journal.unnes.ac.id/journals/jise/

Development of E-Comic Based on Culturally Responsive Teaching on the Topic of Matter and Its Changes to Improve Students' Science Literacy

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Article Info

Article History :
April 2025
Accepted
July 2025
Published
August 2025

Keywords:
Science Literacy; E-Comic; Culturally Responsive Teaching; Science Education; Digital Learning Media

Abstract

This study examined the effectiveness of e-comics based on culturally responsive teaching (CRT) in improving students' science literacy. A quasi-experimental design was employed with seventh-grade students at SMP Negeri 3 Lasem in the 2024/2025 academic year as the population. The sample was selected using cluster random sampling, with Class VII C assigned as the control group and Class VII D as the experimental group. Data were collected using a scientific literacy test and analyzed through quantitative and descriptive methods. The findings revealed that e-comics based on CRT significantly improved students' scientific literacy. The experimental group achieved an average N-gain score of 0.64 (moderate category), which was higher than the control group's average of 0.40. A Mann–Whitney test confirmed a significant difference between the two groups ($p < 0.05$). These results indicate that e-comics grounded in CRT are effective in enhancing junior high school students' scientific literacy.

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p-ISSN 2252-6412
e-ISSN 2502-4523

INTRODUCTION

The 21st century demands high-quality performance in all aspects of human endeavor. This era is characterized by rapid advancements in information technology and the increasing automation of human labor. Knowledge has become a central resource for meeting the needs of modern life (Yusmar & Fadilah, 2023). In the field of education, technological progress has encouraged the widespread adoption of digital learning media, as they offer accessibility, affordability, and flexibility. For instance, a single device such as a smartphone or tablet can store numerous learning resources that previously required multiple physical books (Adiguzel et al., 2020). Moreover, digital media provide diverse formats—such as videos, high-resolution images, animations, and other emerging technologies—that enhance learning experiences. Such innovations are particularly relevant for today's students, who are not only familiar with technology but also increasingly adept at engaging with its continuous development. The accessibility and versatility of digital learning media highlight their potential to foster more innovative teaching and learning practices.

The development of digital learning media has been widely undertaken, including research by Handayani (2021) on the development of digital learning media, such as e-comic STEM-based learning, to improve scientific literacy skills. Based on Marlina et al., (2020), learning media has an impact on students' scientific literacy skills, as evidenced by the experimental class experiencing more significant improvement compared to the control class with regular learning. In response to the evolving learning preferences of Generation Z students, e-comics have been developed as innovative learning media that align with their visual learning style and preference for direct experiences over traditional textbook reading. This not only increases student engagement and attention during learning but also facilitates better information retention, making the learning process more effective. E-comics not only enhance student engagement and attention during lessons but also support better information retention, thereby making the learning process more effective. To further address the needs of Generation Z learners, digital learning media can be enriched with complementary features such as audio explanations, short videos, animations, and infographics. These elements provide a more comprehensive and interactive learning experience, consistent with students' preference for visual and multimedia-rich content (Arifin et al., 2021). By combining various forms of multimedia, educators can create dynamic and engaging learning environments that cater to the diverse learning styles of modern students, ultimately increasing the effectiveness of digital learning media in education.

Marlina et al., (2020) investigated the influence of media development on the scientific literacy skills of fourth-grade students using a quasi-experimental design. Their findings indicated that e-comics improved students' scientific literacy in the experimental class, showing a 38.8% increase, which was categorized as moderate. Similarly, Handayani, (2021) developed STEM-based e-comic learning media to enhance students' scientific literacy through a descriptive research and development (4D) approach. However, this study focused solely on developing STEM-based e-comics without examining other potential strengths of digital comics. The results demonstrated that STEM-based e-comic learning media were highly suitable for both material and media aspects, with an average score of 3.24.

Priyangga et al. (2023) also conducted research on comic development with a CRT approach to foster students' scientific literacy. The type of research used is R&D with the ADDIE development model. The results of the media expert validation study obtained a score of 29 percent (90.6%), categorized as very valid. The results of the material expert validator obtained a score of 37 percent (92.5%), categorized as very valid. The results of the learning expert validator obtained a score of 53 percent (94.64%), categorized as very valid. The results of the responses of ten fifth-grade elementary school students obtained a score of 429 percent (89.375%), categorized as very valid. Equipping students with scientific literacy is crucial for

preparing them for the increasingly complex challenges of daily life and future societal demands. In this case, science learning can be directed to train students' abilities in scientific literacy competencies. Scientific literacy competencies refer to students' abilities in reading, writing, and communicating topics scientifically, as well as understanding problem-solving procedures in everyday life. Scientific literacy is a skill that students need for informed decision-making, participation in diverse social and cultural contexts, and future career preferences. Understanding scientific concepts and processes can also help students navigate real-life scientific situations, including understanding scientific theories and terms. Research by Cetin et al. 2023 & Meenu highlights that improving scientific literacy equips students to address various challenges intelligently, creatively, and innovatively. A comprehensive education that emphasizes scientific literacy not only fosters personal growth but also contributes to national development. Scientific literacy helps individuals navigate the complexities of the modern world and make meaningful contributions to society. Individuals' ability to participate in science-related issues and scientific thinking enables them to become reflective citizens (Rohmaya, 2022).

Given the importance of scientific literacy, students must possess this competency to face the challenges of the 21st century. Based on the results of the Programme for International Student Assessment (PISA) survey, Indonesian students' scientific literacy skills are still below the average of member countries. Organisation for Economic Co-operation and Development (OECD). In 2018, the average scientific literacy score of Indonesian students was only 396, far below the OECD average of 489 (Kemendikbud, 2020; Rizkianti et al., 2024). The results of the 2022 PISA (Philosophy of Science and Technology) showed an increase in the scientific literacy score to 398, with an overall ranking increase (Kemendikbudristek, 2023). However, Indonesia's position remains relatively low compared to other participating countries. This data highlights the need for improvements in the education system, particularly in improving scientific literacy (Johar et al., 2023). Field research also shows that student literacy in the educational process has not developed students' competencies and interest in knowledge. The learning process carried out by teachers has not prioritized the goal of improving students' thinking skills as expected in the 21st century. It has not been able to enhance students' conceptual understanding of the material, making learning seem less meaningful.

Low student scientific literacy stems from a lack of interest in science subjects. Interest in learning plays a crucial role in students' scientific literacy, as it is directly related to intrinsic motivation, engagement in learning, and an understanding of scientific concepts (Dewi Gustika et al., 2023). Students with a strong interest in learning tend to be more motivated, active, and enthusiastic in participating in lessons, thus achieving better learning outcomes. Conversely, low student interest in learning can reduce participation in the learning process, which in turn affects their understanding and mastery of scientific concepts. To foster greater interest, teachers need to design learning environments that are engaging, interactive, and closely connected to students' daily lives. One contributing factor to the lack of interest in science learning is the reliance on predominantly text-based resources, while today's generation is more accustomed to visual information such as illustrations, comics, and animations. Therefore, improving scientific literacy requires the development of electronic learning resources that incorporate appealing visual elements and align with students' learning preferences.

To address these issues, innovations in learning methods and media are needed that can engage students and be relevant to their cultural context. One approach that can be used is Culturally Responsive Teaching (CRT), which offers a solution by integrating students' cultures into the learning process. The CRT approach not only fosters an inclusive learning environment (Hermawan et al., 2025), but also enhances students' cultural identities, boosts their motivation, and increases their engagement in learning (Abdalla & Moussa, 2024; Lan, 2024). This approach emphasizes the importance of cultural competence among educators, the

incorporation of culturally relevant content into the curriculum, and the cultivation of positive teacher-student relationships, all of which contribute to a more effective and engaging learning experience for students from diverse cultural backgrounds (Abdalla & Moussa, 2024). In this context, the development of learning media in the form of e-comic CRT-based displays is a promising solution.

E-comic CRT-based learning can be an effective medium for improving students' scientific literacy. E-comics are digital comics that can be accessed through electronic devices, including computers, tablets, and smartphones. This media offers the advantage of presenting learning materials in a visual and interactive format, thereby capturing students' attention and facilitating their understanding of scientific concepts. Comics are a media that is essentially visual and textual in nature, where several elements can be used simultaneously to build an understanding of the entire source (Golding & Verrier, 2020; Susanti et al., 2025). Comics are a visual medium that engages all five human senses, as readers are invited to activate various sensations through visual clues (Maratus et al., 2025; Ogier & Ghosh, 2017). Comics are a representation of everyday life, often reflecting social realities and the evolving world around us (Maratus et al., 2025; Mcvicker, 2018). Therefore, comics are a very effective medium in education because they can be used at all levels and help improve the effectiveness of learning.

The development of CRT-based e-comic learning can facilitate contextual learning. Through culturally responsive teaching (CRT), teachers are able to connect subject matter to students' experiences and cultural backgrounds, making the material more relevant to their daily lives. Consequently, learning that integrates the CRT approach has the potential to enhance students' scientific literacy. The e-comic was designed with a storyline that incorporates students' cultural contexts while embedding scientific phenomena. Building on previous research, the present study aims to further develop CRT-based e-comic learning media, specifically focusing on the topic of substances and their changes in Integrated Science for Grade VII SMP/MTs. The purpose of this study is to evaluate students' scientific literacy skills following the implementation of the developed CRT-based e-comic.

METHODS

This research was conducted based on a quasi-experimental design with a nonequivalent control group. A pretest was conducted to determine students' scientific literacy skills. The experimental and control classes received different treatments, namely by providing CRT-based e-comics to the experimental class. Meanwhile, the control class used their usual learning media. After the learning process, a posttest was administered to both classes. The study population consisted of all seventh-grade students of SMP Negeri 3 Lasem in the 2024/2025 academic year. The sample was selected using a cluster random sampling technique, with class VII C assigned as the control class and class VII D as the experimental class.

This study used a written test instrument to measure students' scientific literacy and learning interests. The scientific literacy instrument consisted of multiple-choice, complex multiple-choice, matching, true-false, and descriptive questions. The test consisted of 10 questions obtained from 30 validated questions.

Table 1. Data Collection Techniques and Instruments

No	Data	Technique	Instrument	Subject	Time
1.	Qualifications	Questionnaire	Material and media validation questionnaire	Subject matter expert Members of the media	Development
2.	Effectiveness	Hands	Science literacy questions	Student	Implementation

In this study, data validity was tested in two ways: content validation and construct validation. The instrument tested for validity was a question on scientific literacy. The content validation test process involved an assessment process by four experts in their respective fields (expert judgement). The assessment results were then calculated using Aiken's V formula, which helps identify expert agreement on item relevance. Furthermore, content validity testing was conducted by experts, and then the scientific literacy instrument was piloted on ninth-grade students at SMP Negeri 3 Lasem. The results of the instrument trial were then analyzed using the SPSS 27.0 program, employing the correlation formula and product-moment correlation to measure the validity of the test items. The reliability of the instrument was calculated using the Cronbach's Alpha analysis in SPSS version 27.0. An instrument is considered reliable if the Cronbach's Alpha coefficient is greater than 0.600 and yields a positive value.

Data analysis in this study used quantitative descriptive methods. The effectiveness of the e-comic was assessed through N-gain scores and difference tests. The N-gain was calculated using the formula:

$$\langle g \rangle = \frac{\langle S_{post} \rangle - \langle S_{pre} \rangle}{100\% - \langle S_{pre} \rangle}$$

Information

$\langle g \rangle$: average normalized gain

$\langle S_{post} \rangle$: score after treatment

$\langle S_{pre} \rangle$: score before treatment

The N-gain value obtained is then converted into N-gain criteria, and the size of the $\langle g \rangle$ factor is categorized as in Table 2.

Table 2. N-gain criteria

N-gain value	Criteria
$0.70 \leq \langle g \rangle \leq 1.00$	high
$0.30 \leq \langle g \rangle < 0.70$	moderate
$\langle g \rangle < 0.30$	low

CRT-based e-comics are considered effective if the N-gain falls into the moderate or high categories. To support the N-gain results, a difference test was conducted to analyze whether there was a significant difference in the improvement of science literacy between the experimental and control groups. Prior to the difference test, normality and homogeneity tests were performed as prerequisites.

RESULTS AND DISCUSSION

Results

Effectiveness-comic The effectiveness of CRT-based learning in improving scientific literacy is measured by the N-gain value and supported by the results of the Mann-Whitney test. The average score and N-gain value can be seen in Table 3.

Table 3. Mean Score and N-gain of Science Literacy

Class	Average Score		N-gain	
	Pre	Post	Score	Criteria
Eksperimen	53.24	83.43	0.64	Moderate
Control	55.63	73.75	0.40	Moderate

The data in Table 2 indicate that the use of CRT-based e-comics in the experimental class was more effective in improving students' science literacy than the conventional materials used in the control class. Although both classes showed moderate N-gain improvements, the experimental class had a higher average post-test score and N-gain value.

Effectiveness-comic the effectiveness of CRT-based learning in improving scientific literacy is measured by the N-gain value and supported by the results of the Mann-Whitney test. The average score and N-gain value can be seen in Table 4.

Table 4. Results of the Normality Test of Science Literacy Data

	Class	Shapiro-Wilk			Description
		Statistic	Df	Sig.	
Pretest	Experiment	0.929	27	0.065	Normally distributed
	Control	0.957	28	0.293	Normally distributed
Posttest	Experiment	0.748	27	0.001	Not normally distributed
	Control	0.928	28	0.055	Normally distributed
N-gain	Experiment	0.819	27	0.001	Not normally distributed
	Control	0.990	28	0.994	Normally distributed

Furthermore, a Mann–Whitney U test was conducted on the N-gain values of the experimental and control classes to determine whether there was a significant difference in the improvement of scientific literacy between the two groups. The test was applied to the pretest, posttest, and N-gain data, as presented in Table 5.

Table 5. Results of the Mann-Whitney U Test of Scientific Literacy

	Z	Asymp Sig. (2-tailed)	Description
Pretest	- 0.736	0.493	No significant differences
Posttest	-4.771	< 0.001	Significant differences
N-gain	-4.750	< 0.001	Significant differences

Based on the data presented in Table 2, the significance value of the results of the difference test using the Mann-Whitney U test on N-gain, the significance value obtained was less than 0.05 (<0.001), which indicates a significant difference in scientific literacy between the experimental and control groups after the treatment was given. The increase in students' scientific literacy can also be assessed through each indicator, the results of which are presented in Figure 1.

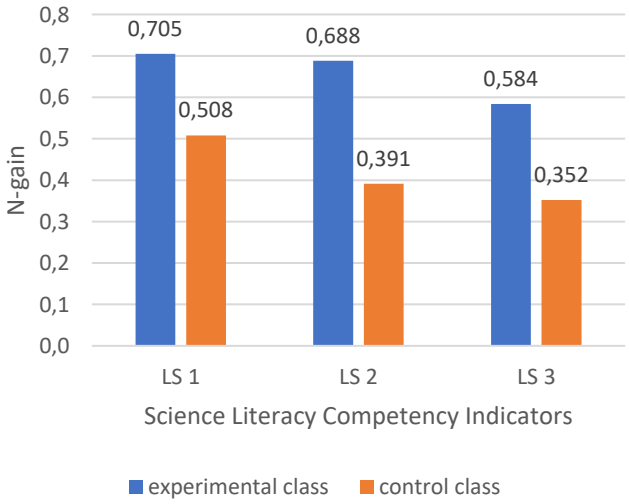

Figure 1. Improvement by Each Science Literacy Competency Indicator

Legend:
LS1 : Explaining phenomena scientifically
LS2 : Evaluating and designing scientific investigations
LS3 : Interpreting scientific information and evidence

Figure 1 illustrates that the experimental class achieved a higher increase across all indicators of scientific literacy competency compared to the control class. For the LS1 indicator, the experimental class recorded an increase of 0.705 (high category), while the control class achieved only 0.508 (medium category). For the LS2 indicator, the experimental class showed an increase of 0.688 (medium category), higher than the control class, which recorded 0.390 (medium category). Similarly, for the LS3 indicator, the experimental class obtained an increase of 0.584, whereas the control class recorded 0.352; both fall within the medium category. These results indicate that the developed CRT-based e-comics were more effective in improving students' scientific literacy than the conventional teaching materials used in the control class.

Overall, the assessment results indicate that the experimental class, which used CRT-based e-comics, was more effective in improving students' scientific literacy compared to the control class that relied on conventional media. The conventional media used in the control class primarily emphasized systematic scientific procedures. This approach is efficacious in improving understanding of basic scientific concepts, but tends to be less flexible in accommodating individual differences. This allows students to receive standardized learning experiences, which, while beneficial, are not always in-depth or relevant to each student. In contrast, e-comic CRT-based offers a more personal and contextual approach. This approach is specifically designed to integrate elements of local culture and students' everyday experiences into scientific narratives (Al Kamil et al., 2023; Mutiara et al., 2024). This approach helps students see how scientific concepts are relevant to their lives, thereby increasing their interest and engagement in the learning process.

Discussion

The improvement of students' scientific literacy through CRT-based e-comics can be examined from several aspects, including the ability to explain scientific phenomena, evaluate and design scientific research, and interpret data and scientific evidence. The ability to explain scientific phenomena is fostered when comics encourage students to connect abstract concepts with real-life experiences, thereby enhancing their understanding and retention of the material. By presenting scientific ideas in contexts that are familiar and relevant to students' everyday lives, e-comics help learners build a more contextual and comprehensive framework of thinking. For example, in one storyline, students observe the batik-making process and relate it to physical changes, identifying the forms of matter and particles involved in the process. This not only strengthens their understanding of the topic 'Matter and Its Changes' but also stimulates curiosity and interest in science. Through such narratives, students gain insight into scientific concepts as well as their practical applications in daily life.

The ability to evaluate and design scientific research is also enhanced through activities that challenge students to think critically and analytically. Students are asked to analyze the data and information presented in the text. e-comic, and designing simple experiments to test hypotheses. This aspect of the comic is depicted as students' experiment to prove that the wax used to create the pattern undergoes a physical change. The ability to interpret data and scientific evidence is crucial in this information age. This helps students develop these skills by presenting data and information in engaging and easy-to-understand visual formats. This way, students are trained to identify patterns, trends, and causal relationships in data and draw conclusions based on strong scientific evidence.

The ability to interpret scientific data and evidence is crucial, as scientific literacy extends beyond memorizing facts to include analyzing information and drawing logical conclusions. This aspect is integrated through the presentation of experimental data in interactive graphs and diagrams. Students are encouraged to identify patterns and trends in the data and relate them to relevant scientific concepts. Furthermore,e-comic also provides various additional sources of information, such as experimental videos, that students can access to deepen their understanding of the topics discussed. With this approach,

students are not merely passive consumers but also active learners capable of evaluating and synthesizing information from various sources. Computational thinking (CT) refers to the cognitive processes involved in formulating problems and designing their solutions so that they can be effectively addressed by humans or machines (Akhyaruddin, 2022; Hidayat et al., 2020; Soeprianto et al., 2021). This is achieved by presenting contextual problems that are relevant to everyday life. In the comic, this is presented in a story about students observing the batik-making process and then interpreting this process in relation to the material on Substances and Their Changes.

In this context, research seeks to bridge the gap between theory and practice by producing an innovative product that is not only visually appealing but also contextually relevant for students. The use of comics in learning can have a maximum effect on students' visual recognition (Yuliariatiningsih, 2016). Comics serve as a learning medium that provides students with opportunities to learn independently, develop critical thinking skills, and enhance their retention of the material. Previous research has demonstrated that comics significantly support students' understanding of subject matter, enhance learning motivation, and enable teachers to deliver content in a more engaging and effective manner (Moniati et al., 2022).

The storyline. The e-comic CRT-based story begins with students discussing a lesson they will take outside of class by visiting a batik workshop, but one of them hasn't prepared the materials for the lesson. This conflict begins with the story. By highlighting the Lasem batik culture, the story continues by connecting the learning material and the batik-making activity. Through this approach, Culturally Responsive Teaching, this e-comic aims to bridge the gap between the learning material and the students' cultural backgrounds and experiences. Thus, students not only memorize scientific concepts but also apply them in real-life contexts. This encourages students to play an active role in the learning process.

Thus, e-comic CRT-based learning contributes to the development of comprehensive scientific literacy, encompassing conceptual understanding, critical thinking skills, and the ability to apply knowledge in real-world contexts. The application of information technology in various fields requires computational thinking skills, which have become popular in recent years and are a fundamental skill that every individual must possess in this digital era (Hidayat et al., 2020). Furthermore, e-comic CRT-based learning also has the potential to increase students' interest in science by making learning more relevant, engaging, and enjoyable. The use of innovative learning media, such as digital comics, can address student boredom during the learning process (Nurjanah et al., 2023). E-comics are a digital-based interactive learning media, offering flexible and easily accessible solutions, enabling students to learn anytime and anywhere (Suri et al., 2021).

E-comics, an innovative learning medium, offer great potential in improving students' scientific literacy. E-comics can present complex scientific concepts in an engaging and easy-to-understand visual format (Yuliariatiningsih, 2016). Through engaging storylines and authentic characters, students can more easily connect with the material and be motivated to learn further. The use of e-comics as a learning medium also aligns with technological developments and students' increasing familiarity with digital devices (Suri et al., 2021). Furthermore, comics also have significant potential in improving students' scientific literacy, which is the ability to understand and apply scientific concepts in everyday life (Moniati et al., 2022; Mutiara et al., 2024; Yuliariatiningsih, 2016).

After conducting research and obtaining significant results regarding development-comic CRT-based on the materials of substances and their changes, the study's results indicate that comic-based learning media using CRT are effective in increasing students' interest in learning and their scientific literacy. Therefore, educators are advised to utilize this innovative learning media as an alternative in the science learning process. This media is not only engaging and accessible, but also culturally relevant, thus optimally increasing student motivation and engagement. Schools and educational institutions

should support the use of this contextual and interactive digital media to support successful learning. E-comic CRT-based learning that integrates local cultural contexts makes a significant contribution in bridging abstract science concepts with students' real-life experiences. This medium can serve as a model for developing similar teaching materials for other science subjects and other subjects, with content and cultural contexts tailored to the characteristics of local learners. This opens up opportunities for innovation in developing more engaging and meaningful learning media.

In developing and implementing CRT-based e-comics, several suggestions can be made to improve future research and product development. First, CRT-based e-comics, which are currently designed for online access, lose functionality when used offline. Therefore, future development should focus on creating electronic learning media that can be accessed without an internet connection. Second, similar learning media should be developed for other science topics to broaden their application in the learning process. Third, e-comics that rely on platforms such as Webtoon are often limited to static image illustrations; thus, further development could integrate multimedia elements by combining illustrations with relevant learning videos. Fourth, the characters in the current comics are represented by only one gender; including both male and female characters in future designs may provide a more contextual and inclusive experience for readers. Finally, the depiction of chemical change processes in the comics remains incomplete. To address this, future research should aim to fully illustrate abstract concepts, ensuring that each topic is represented comprehensively within the storyline.

CONCLUSION

Based on the findings, it can be concluded that CRT-based e-comics on the topic of Matter and Its Changes effectively enhance students' scientific literacy. The experimental group achieved an average N-gain score of 0.64, categorized as moderate, which was higher than that of the control group. Furthermore, the Mann–Whitney test confirmed a statistically significant difference between the two groups ($p < 0.05$), indicating that CRT-based e-comics make a meaningful contribution to improving students' scientific literacy.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to all parties who contributed to this research, particularly the expert validators, teachers, and students of SMP Negeri 3 Lasem, for their valuable participation. Special thanks are also extended to the advisors and examiners for their continuous support and constructive guidance. It is hoped that the findings of this study will contribute to the advancement of digital learning media.

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