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Effectiveness of STS-C-based multimodal science materials on primary students' digital science literacy and global character

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Article info

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Abstract

This study analyzes the effectiveness of Science, Technology, Society, and Culture (STS-C) based multimodal science materials in enhancing digital science literacy and global character among fifth-grade students. This quasi-experimental study employed a Non-equivalent Control Group design involving 64 students. Data gathered via digital science literacy tests, global character questionnaires, and observation sheets were analyzed using ANCOVA and N-Gain scores. The experimental group showed a significant increase in digital science literacy (mean post-test: 88.65; N-Gain: 0.74, high) and global character (mean post-test: 84.30; N-Gain: 0.58, medium). The analysis showed a significant difference in outcomes compared to the control class ($p < 0.001$). **Conclusion**: STS-C-based multimodal materials are effective in enhancing students' scientific understanding and internalizing global citizenship values within local cultural contexts. This study contributes a theoretically modeled instructional framework that bridges digital technology with socio-cultural elements in primary science education.

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1. Introduction

Elementary education in the Society 5.0 era faces a dual challenge: equipping students with high-level technological skills while simultaneously strengthening their character foundation amidst massive globalization. The 21st-century educational paradigm transformation places scientific and digital literacy as absolute competencies that learners must possess to navigate the complexity of information in the future (OECD, 2023). Natural Science (IPA) learning in elementary schools is not merely a transfer of empirical facts, but a medium for developing

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critical, collaborative, and ethical thinking skills (Zubaidah, 2016). However, the 2022 Program for International Student Assessment (PISA) report shows that Indonesian students' scientific literacy remains below the OECD average, at 383, indicating that their abilities to evaluate scientific data and design investigations remain relatively low.

This gap is exacerbated by the digitalization phenomenon, which is not balanced by proficient digital science literacy. Digital science literacy is the ability to access, critically evaluate, and communicate scientific information across various digital platforms (Indah et al., 2022; Son & Ha, 2025). Although current fifth-grade students belong to the Alpha Generation, who are fluent in technology, they are often trapped in consumptive rather than productive scientific internet use. Research indicates that without proper pedagogical intervention, the use of devices in the classroom can decrease students' concentration and analytical skills (Butterworth & Thwaites, 2013). Therefore, innovations in the form of teaching materials that integrate science content with meaningful digital simulations are required.

On the other hand, rapid technological development also carries the risk of eroding local and global character values. Global character, or global citizenship education, has become an urgent priority because students need to be aware of cross-border issues, such as climate change, environmental sustainability, and socio-cultural ethics. According to UNESCO (2017), global character encompasses responsibility, tolerance, and the ability to act ethically in a diverse global society (Gaudelli, 2016). However, integrating these values into elementary school science instruction is often neglected because the curriculum remains oriented toward short-term cognitive outcomes. Without character reinforcement, the digital technology skills students master risk being used irresponsibly.

The main problem identified in science learning practices in elementary schools is the high dependency on unimodal teaching materials, such as static printed textbooks dominated by narrative text. These conventional materials fail to accommodate students' diverse learning styles and are unable to dynamically visualize abstract scientific concepts (Bezemer & Kress, 2016; Jewitt et al., 2016). The proposed innovative solution is the development of multimodal teaching materials. The multimodality approach integrates various semiotic modes: text, images, video, audio, and interactive simulations, to build a more comprehensive understanding of meaning (Unsworth, 2020; Unsworth et al., 2022). Multimodal teaching materials have proven effective in increasing student engagement and assisting cognitive processes in understanding complex scientific phenomena (Walsh & Campbell, 2018).

However, the effectiveness of multimodal teaching materials reaches its peak only when supported by a conceptual framework that connects science to students' real-world experiences. The Science, Technology, Society, and Culture (STS-C) approach emerges as a relevant framework. STS-C not only highlights the interaction between science and technology in society but also explicitly incorporates a cultural dimension as a learning context (Çinar & Çepni, 2021; Primastuti & Atun, 2018). Integrating local wisdom, such as traditional food production practices or local natural resource management, into multimodal digital content allows students to see the relevance of science in their daily lives while strengthening their cultural identity in the global arena (Aikenhead, 2006).

Despite extensive research on STS-based teaching materials, significant research gaps remain. First, most previous studies have focused only on improving cognitive learning outcomes and science process skills separately (Chiu et al., 2012; Le Donné et al., 2016). Few studies have comprehensively examined the effectiveness of integrating digital multimodality with the STS-C framework to target two variables simultaneously (digital science literacy and global character). Second, research on the effectiveness of learning media often overlooks local socio-cultural

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aspects in the design of digital content (Gay, 2018; Taylor & Sobel, 2011). Third, there is still limited empirical evidence regarding how STS-C-based teaching materials can effectively build the global character of elementary school students through a science-culture perspective.

This study aims to test the effectiveness of science multimodality teaching materials specifically based on the STS-C framework for fifth-grade elementary students. These teaching materials are uniquely designed by incorporating local socio-cultural narratives into interactive digital formats (such as augmented reality or virtual simulations) aligned with the digital generation's profile. This differs from general digital teaching materials, which tend to be universal and detached from the students' cultural context. This research seeks to demonstrate that integrating local cultural values into the science-technology-society framework can catalyze the development of a strong global character and advanced digital literacy.

The urgency of this research stems from the need to develop adaptive and inclusive science-learning models at the elementary level. Given that fifth-grade students are in a cognitive transition stage toward formal thinking, providing interventions through multimodal STS-C teaching materials is crucial to preventing scientific misconceptions and apathy toward global issues. The successful implementation of these materials is expected to serve as a reference for educational practitioners in designing instructional materials that are not only technologically advanced but also socio-culturally meaningful.

The novelty of this study lies in the theoretical modeling and simultaneous evaluation of both digital science literacy and global character through the deliberate integration of local cultural context within a digital multimodal framework. Unlike previous universal digital tools that focus solely on separate cognitive gains, this approach builds a localized yet globally oriented pedagogical anchor specifically tailored for primary school students.

Based on the explanation above, the objective of this study is to analyze the effectiveness of implementing STS-C-based science multimodality teaching materials in improving the digital science literacy and global character of fifth-grade elementary students. Specifically, this research will examine whether there are significant differences in students' literacy and character achievements before and after using these materials, and the extent to which students respond to cultural integration within the digital content. The results of this study are expected to provide theoretical contributions to the development of the elementary science curriculum and practical contributions to the provision of innovative teaching materials relevant to 21st-century demands.

2. Literature review

2.1 The concept of multimodality in science learning

The multimodality approach in primary education is grounded in social semiotic theory, which posits that meaning is constructed not only through verbal language but also through the integration of various communication modes such as visuals, audio, gestures, and spatial layout. For fifth-grade elementary school students in the concrete operational stage, the use of multimodal teaching materials is crucial for bridging their understanding of abstract scientific phenomena. The implementation of multiple representations (multimodal) allows students to simultaneously explore concepts through text, static images, simulated videos, and narrated audio.

Analytically, the effectiveness of multimodal teaching materials lies in their ability to reduce cognitive load by presenting information that complements each mode. Research by Al-Hattali et al. (2025) demonstrates that the use of experimental videos and interactive infographics significantly improves fifth-grade students' understanding of science concepts, as dynamic

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visualizations support mental processing of changes in the state of matter that are invisible to the naked eye. Similarly, Anggraini and Rahmawati (2023), Matuk et al. (2021), Rasmet et al. (2025), and Tristaningrat and Ariyana (2025) conclude that integrating science animations and digital comics enhances students' active engagement and enthusiasm in the inquiry process.

2.2 The Science, Technology, Society, and Culture (STS-C) approach

The Science, Technology, Society, and Culture (STS-C) approach extends the traditional STS model by explicitly incorporating the cultural dimension as the primary context for learning. STS-C emphasizes that science is not value-free but interacts closely with technological developments, societal needs, and local socio-cultural values. In the context of fifth-grade students in regions such as Brebes Regency, integrating local wisdom, such as the production processes for salted eggs or krosok salt, into the "States of Matter" topic makes learning more meaningful and contextual.

Çalik and Karatas (2019) assert that STS-C-based teaching materials are effective at linking scientific concepts to real-life situations, thereby encouraging students to apply that knowledge to solve problems in their immediate environment. The STS-C model functions as an "anchor" for students' new knowledge, where local wisdom (such as the tradition of making jenang) becomes an object of scientific observation that enhances curiosity and cultural pride.

Theoretically, the integration of these variables is modeled through a cognitive-affective instructional pipeline. Multimodality serves as the representation layer that optimizes dual-channel cognitive processing, reducing cognitive load when students interact with complex scientific concepts. Simultaneously, the STS-C approach acts as the contextual anchor, weaving Brebe's local cultural wisdom into the scientific content. By critically evaluating digital simulations of socio-cultural and environmental issues (e.g., local industrial waste management), students develop digital science literacy (cognitive-evaluative domain) while fostering social responsibility and cross-cultural empathy, hallmarks of global character (affective-behavioral domain).

2.3 Effectiveness toward digital science literacy

Digital science literacy is not merely the operational ability to use technological devices but the critical proficiency to access, analyze, and evaluate scientific information from digital sources. In the information age, students are frequently exposed to scientific data online without the ability to verify its accuracy. STS-C-based multimodal teaching materials provide a structured digital environment that trains students to interpret graphs, understand virtual simulations, and make decisions based on accurate data.

An empirical study by Bezemer and Kress (2016), Incelli (2022), and Jewitt (2010) shows that multimodal text-based teaching materials effectively improve science literacy by training students to understand messages through various entry points into digital information. Robust digital literacy enables students to perform virtual experiments that might be difficult to conduct in physical laboratories, thereby deepening their understanding of the scientific method.

2.4 Effectiveness in the formation of global character

Global character encompasses a set of moral values reflecting an individual's awareness as a global citizen, including empathy, social responsibility, tolerance, and concern for global sustainability. In science learning, this character is formed when students understand the impact of technology and science on the global environment, such as climate change and pollution.

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The implementation of STS-C helps students perceive the connection between local actions (such as traditional industrial waste management) and global impacts. UNESCO (2017) emphasizes that global character education must begin early to shape individuals capable of living harmoniously amidst socio-cultural diversity. The use of teaching materials that present socio-cultural issues has been proven to enhance students' tolerant attitudes and social responsibility through reflective discussions on the role of science in society.

3. Method

3.1 Research design

This study employed a quasi-experimental design, specifically utilizing the Non-equivalent Control Group Design, which is highly appropriate for naturally occurring educational environments where random assignment of individual students is administratively unfeasible. This design was selected because the research subjects are part of naturally pre-existing classroom groups (fixed classes), making it impossible to perform random assignment of subjects without disrupting the school's organizational structure (Creswell, 2015). The research was conducted at a public elementary school in Brebes Regency, Central Java, Indonesia. This school is characterized by standard digital infrastructure, possessing a dedicated computer laboratory with moderate internet connectivity and classroom projectors. The structure of this research design is illustrated as follows:

Experiment	: O_1 X O_2
Control	: O_3 - O_4

Notes: O_1&O_3: Pre-test; X: Treatment involving the implementation of STS-C-based science multimodality teaching materials; O_2&O_4: Post-test; -: Learning using standard (conventional) textbooks.

3.2 Research Subjects

The participant selection followed a purposive sampling technique, drawing two intact fifth-grade classes to serve as the experimental group (n = 32) and the control group (n = 32). The groups were chosen based on the similarity of their prior academic performance and baseline digital literacy scores. The sampling technique employed was based on the following criteria: (1) the school possesses adequate computer laboratory facilities or device access; (2) it exhibits strong local socio-cultural characteristics aligned with the STS-C content; and (3) it has scientific literacy achievement levels that remain below the national average based on education report cards. Based on these criteria, two classes from one elementary school were selected as the research sample: Class V-A as the experimental group (n=32) and Class V-B as the control group (n=32). However, the reliance on a purposive sample drawn from a single school is explicitly acknowledged as a limitation, which constrains the immediate generalization of the findings to broader primary school populations with varying socio-economic or technological backgrounds.

3.3 Research procedure

The research was conducted systematically through three main phases, as illustrated in Figure 1.

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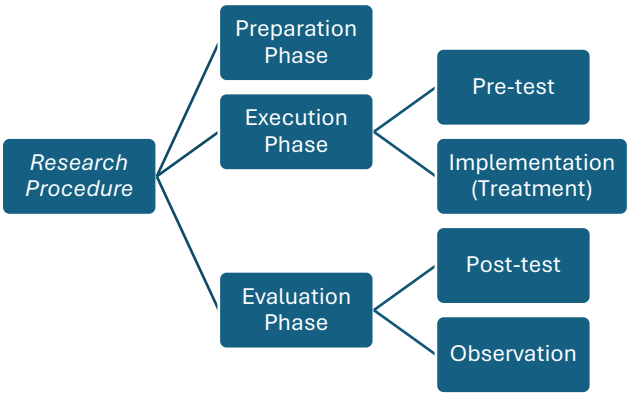

Figure 1. Research procedure

Preparation Phase: The researcher conducted instrument validation and coordinated with practitioners (teachers) regarding the schedule and learning scenarios. The multimodal teaching materials were installed on students' digital devices to ensure technical readiness.

Execution Phase: (a) pre-test: Both groups were administered an application-based digital science literacy test and a global character questionnaire; and (b) implementation (treatment): The experimental group learned using multimodality teaching materials that integrated simulation videos, socio-cultural narratives of local wisdom (such as the salted egg smoking process), and interactive quizzes. The learning process spanned six meetings. Meanwhile, the control group studied the same material but utilized the lecture method and printed textbooks.

Evaluation Phase: (a) post-test: After six meetings, both groups were re-administered the same instruments to measure achievement changes; and (b) observation: During the learning process, observers observed students' global character behavior and digital literacy using a validated observation sheet.

3.4 Intervention procedure and multimodal materials

The instructional intervention spanned six distinct sessions for both groups, with each session lasting 70 minutes (2 x 35 minutes). The control group was taught using conventional, text-heavy instructional materials accompanied by standard non-interactive presentations. Conversely, the experimental group received learning experiences powered by Science, Technology, Society, and Culture (STS-C) based multimodal science materials. The structural blueprint of these multimodal materials integrated multiple semiotic modes to reduce cognitive load and enhance representation layers, combining narrative texts, visual infographics, short documentary videos, and interactive virtual laboratory simulations. Each of the six sessions was systematically anchored around a relevant localized socio-cultural and environmental issue.

3.5 Research instrument and data collection

Data were gathered using two primary instruments: a digital science literacy test and a global character questionnaire, supplemented by a structured observation sheet.

3.6 Digital science literacy instrument

This instrument evaluated four core indicators: information searching, critical evaluation, scientific reasoning, and digital communication. It consisted of 20 multiple-choice items. Content validity was established via expert judgment using Aiken's V, yielding high coefficients ranging from 0.82 to 0.90. Item analysis was conducted to ensure appropriate difficulty levels

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(0.30 to 0.70) and high discrimination indices (> 0.30). Construct validity was empirically verified through Confirmatory Factor Analysis (CFA), which confirmed that all items loaded significantly onto their respective theoretical factors. The internal consistency reliability was confirmed with a Kuder-Richardson (KR-20) coefficient of 0.84.

Example Item (Critical Evaluation Indicator): "If you find a social media post claiming that a local river changed color due to a supernatural curse, what is the most scientifically sound digital action to take?" (Answer choices provided options ranging from checking official government environment portals to unquestioningly sharing the post).

3.7 Global character instrument and social desirability bias mitigation

Because global character represents an affective variable, relying solely on self-report questionnaires often introduces social desirability bias, leading primary students to choose answers that are socially ideal rather than reflecting their true behavior. To mitigate this bias and triangulate data, a 25-item Likert-scale questionnaire (Always, Often, Sometimes, Never) was administered, along with a rigorous 10-item Behavioral Observation Sheet completed by classroom observers during the lessons.

Table 1. Instrument specifications, validity, and reliability results

Variable	Main Indicators	Number of Items	Validity (Aiken's V)	Reliability (KR-20 / Alpha)	Status
Digital Science Literacy	1. Information Searching	5	0.88	0.84	Very High
	2. Critical Evaluation	5	0.85		Very High
	3. Scientific Reasoning	5	0.82		Very High
	4. Digital Communication	5	0.90		Very High
Global Character	1. Social Responsibility	6	0.86	0.87	Very High
	2. Cultural Tolerance	6	0.89		Very High
	3. Environmental Care	6	0.84		Very High
	4. Global Issue Awareness	7	0.85		Very High
Implementation	Teacher & Student Activity Observation	10	0.92	0.89	Very High

Note: Validity was calculated based on the assessment of 3 experts (subject-matter, linguistics, and evaluation). Reliability for the digital literacy test was measured using KR-20, while the global character questionnaire used Cronbach's Alpha.

Construct validity for the questionnaire was established via CFA, and internal reliability demonstrated a Cronbach's Alpha of 0.87. The observation sheet evaluated explicit behavioral markers, such as cross-cultural empathy, environmental stewardship (e.g., turning off digital devices to conserve energy), and collaborative responsibility. To ensure objectivity and prevent rater bias, two independent observers simultaneously evaluated the classrooms. The inter-rater reliability for the observation sheet was computed using Cohen's Kappa, yielding a highly dependable coefficient of 0.82, indicating strong inter-observer agreement.

Scoring rubric example (environmental care indicator - observation sheet): Score 4 (Excellent): Student independently and consistently turns off the computer monitor/projector when leaving the room and actively disposes of experimental waste according to its category.

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Score 1 (Poor): Student leaves electronic devices running unnecessarily and shows total disregard for classroom cleanliness despite verbal prompts. Detailed data on the validity and reliability of the instruments used in this study are presented in Table 1.

3.8 Data analysis technique

The data analysis technique in this study employed descriptive and inferential statistical approaches, processed using SPSS version 26. Descriptive analysis was used to provide a general overview of the data distribution, including the mean, median, standard deviation, and minimum and maximum values of the digital science literacy and global character scores for both subject groups. Prior to hypothesis testing, prerequisite tests were conducted, including a normality test using the Shapiro-Wilk distribution (given that the sample size per class was < 50) to ensure the data were normally distributed, and a homogeneity test using Levene's Test to ensure that the variance between the experimental and control groups was equal or not significantly different. Hypothesis testing was performed using the Independent-Samples T-Test to assess significant differences in effectiveness between the experimental and control groups based on post-test scores. Furthermore, to objectively measure the magnitude of students' improvement, a Normalized Gain (N-Gain) Score analysis was conducted, comparing the difference between pre-test and post-test scores against the ideal maximum score. The effectiveness of the STS-C-based multimodal teaching material implementation was categorized according to Hake's criteria, where a score of $g > 0.7$ indicates a high level of effectiveness. Finally, an Effect Size test using Cohen's d formula was applied to determine the strength of the treatment's influence on the dependent variables, ensuring the research results demonstrate not only statistical significance but also practical significance within the context of science learning in elementary schools.

3.9 Research ethics

This study adhered to strict academic ethical protocols. The researcher provided an informed consent explanation to the students' parents regarding the study's objectives, guaranteed the anonymity of student data, and ensured that the implementation of digital technology did not produce negative psychological impacts. Following the study's conclusion, the multimodal teaching materials were also provided to the control group as a form of educational justice.

Institutional approval was officially granted by the school's ethics committee and the local education authority. Parents provided written informed consent, explicitly stating the students' right to withdraw from the study at any time without penalty, the use of digital data encryption for child protection, and strict parental/teacher supervision during device use. Data Availability Statement: The datasets generated during the current study are available from the corresponding author upon reasonable request.

4. Results

This study aims to evaluate the effectiveness of implementing Science, Technology, Society, and Culture (STS-C)- based multimodal science teaching materials in improving digital science literacy and the global character of fifth-grade elementary school students. The research was conducted over eight weeks at SDN 4 Ketanggungan, involving two parallel classes as the experimental and control groups. The experimental group (n=32) received treatment through interactive digital teaching materials that integrate local wisdom simulation videos (e.g., salted egg production technology and traditional food preservation), while the control group (n=32) used

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conventional textbooks. The primary focus of the study was on changes in digital science literacy scores, covering aspects from information searching to critical evaluation, as well as global character, including socio-cultural responsibility and environmental concern. The data obtained were from objective test instruments and Likert-scale questionnaires that have been expertly and empirically validated.

The data were categorized into two main variables: Digital Science Literacy (DSL) and Global Character (GC). This data description presents the profile of student achievement before (pre-test) and after (post-test) the intervention was administered. The measurement results for digital science literacy showed a significant upward trend in the experimental group compared to the control group. A summary of the descriptive statistical data is presented in Table 2.

Table 2. Statistical description of digital science literacy

Group	Phase	Min Score	Max Score	Mean	Std. Deviation
Experimental	Pre-test	45	65	55.42	5.21
	Post-test	78	98	88.65	4.88
Control	Pre-test	42	68	54.88	5.65
	Post-test	65	82	72.45	6.12

Based on Table 2, the initial average scores of both groups were relatively equal (55.42 vs. 54.88), indicating a similar starting point for students' abilities. However, after treatment, the experimental group reached an average of 88.65, while the control group reached only 72.45. This striking difference in gain initially suggests that using semiotic modes (text, visuals, simulation videos) within the STS-C framework helps students process scientific information more effectively in a digital environment. The measurement of global character was conducted through self-assessment questionnaires and behavioral observation sheets. The descriptive statistical data are presented in Table 3.

Table 3. Statistical description of global character scores

Group	Phase	Mean	Std. Deviation	Max Score	Absolute Gain
Experimental	Pre-test	62.15	6.45	100	-
	Post-test	84.30	4.22	100	22.15
Control	Pre-test	61.88	6.72	100	-
	Post-test	68.55	5.15	100	6.67

Table 3 shows that the global character of students in the experimental group increased by 22.15 points. This indicates that the socio-cultural content (STS-C) in the teaching materials successfully triggered students' empathy and awareness. The control group showed a very marginal increase (6.67), indicating that without structured socio-cultural issues in the teaching materials, students' global character is difficult to develop optimally through theoretical materials alone.

Assumption tests (analysis prerequisites) were conducted to assess normality and homogeneity assumptions, ensuring the validity of statistical inferences. Normality test was performed using the Shapiro-Wilk test because the sample sizes in each group were n = 32 (< 50). The results are presented in Table 4. The normality test results show all significance values (p) are

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greater than 0.05; thus, the data are normally distributed and suitable for analysis with parametric statistics.

Table 4. Normality test results (Shapiro-Wilk)

Variable	Group	Phase	Statistic	Sig.	Interpretation
Digital Literacy	Experimental	Post-test	0.945	0.125	Normal (p>0.05)
	Control	Post-test	0.932	0.88	Normal (p>0.05)
Global Character	Experimental	Post-test	0.958	0.231	Normal (p>0.05)
	Control	Post-test	0.941	0.112	Normal (p>0.05)

A homogeneity test, Levene's test, was used to assess equality of variances across groups. The results are presented in Table 5.

Table 5. Homogeneity of variance test results

Variable	F	Sig.	Interpretation
Digital Science Literacy	1.124	0.293	Homogeneous
Global Character	0.885	0.351	Homogeneous

The significance p > 0.05 indicates that the data variances between groups are equal, meeting the requirements for the Independent Samples T-Test. Data analysis and hypothesis testing were used to evaluate effectiveness differences (independent-samples t-test). This test was conducted to compare the final scores between the experimental and control classes to prove the treatment effectiveness hypothesis.

Table 6. Independent sample t-test results (post-test)

Variable	t-value	df	Sig. (2-tailed)	Interpretation
Digital Science Literacy	11.654	62	0	Significant
Global Character	13.442	62	0	Significant

The analysis results in Table 6 show a Sig. (2-tailed) p = 0.000 < 0.05. This statistically demonstrates a very significant difference between students who learned using STS-C-based multimodal teaching materials and those who learned conventionally. This finding provides a strong empirical basis for the conclusion that the treatment had a tangible positive impact. Improvement analysis (n-gain score) to assess how effective the teaching materials were in increasing ability from the initial to the final state, an N-Gain test was conducted. The results are presented in Table 7.

Table 7. N-Gain score analysis of digital literacy and global character

Variable	Group	Average Gain	N-Gain (%)	Criteria
Digital Literacy	Experimental	0.74	74%	High (Effective)
	Control	0.39	39%	Medium
Global Character	Experimental	0.58	58%	Medium (Effective)
	Control	0.18	18%	Low

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The N-Gain analysis shows that digital science literacy in the experimental group increased by 74%, placing it in the High effectiveness category. Meanwhile, global character increased by 58%, placing it in the Medium category. This indicates that cognitive-digital aspects respond more quickly to multimodal teaching materials, while affective aspects (character) require a slightly more gradual internalization process but still show much better effectiveness than the control class.

To measure the practical strength of the treatment, Cohen's d was used. The results are presented in Table 8. Effect Size values exceeding 0.8 indicate that the implementation of these teaching materials has a very strong and significant influence within the context of educational practice in elementary schools.

Table 8. Effect size calculation results (Cohen's d)

Variable	Effect Size (Cohen's d)	Interpretation
Digital Science Literacy	2.92	Very Large
Global Character	3.35	Very Large

5. Discussion

5.1 Effectiveness of STS-C-based multimodal teaching materials in improving digital science literacy

Research findings indicate that the implementation of Science, Technology, Society, and Culture (STS-C)- based multimodal teaching materials has a significant impact on improving the digital science literacy of fifth-grade students. The experimental group's average score of 88.65 and a high N-Gain (0.74) indicate that the synergy among semiotic modes (text, visual, audio, and simulation) can facilitate the construction of complex scientific knowledge at the primary education level. This aligns with the cognitive theory of multimedia learning proposed by Clark and Mayer (2023), which states that dual-channel processing (auditory and visual) can reduce cognitive load, enabling students' working memory to absorb abstract information more effectively.

Analytically, this success is driven by interactive digital tools that enable students to conduct virtual experiments. Research by Fan and Geelan (2013) and Woodill (2011) confirms that teaching materials integrating interactive simulations can improve science literacy more effectively than static media because they provide students with immediate feedback. Correspondingly, Prain (2019) argues that 21st-century literacy is no longer unimodal; students' ability to interpret dynamic images and digital graphics in these materials represents a form of multiliteracy proficiency required in modern scientific discourse.

Furthermore, the "C" (Cultural) component in the STS-C approach proved to be a catalyst in strengthening digital science literacy. When students access digital content featuring local wisdom (such as the salted egg smoking process in Brebes), they not only learn to use digital devices but also perform critical evaluations of information relevant to their lives. This confirms the finding that science education rooted in local socio-cultural contexts facilitates students' "cultural border-crossing" from traditional knowledge to formal scientific knowledge. Amirshokoohi (2016), Çinar and Çepni (2021), Nugroho and Supriyadi (2022), and Primastuti and Atun (2018) also noted that the STS-C approach makes science more "humanized" and accessible, thereby increasing students' digital engagement in exploring natural phenomena.

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5.2 Strengthening global character through socio-cultural contexts and global issues

The improvement in global character in the experimental group, with an N-Gain of 0.58 (medium), indicates that these teaching materials are effective in transforming students' attitudes and values. Although the increase was not as rapid as that in digital science literacy, this achievement demonstrates that integrating global issues into the STS-C framework can foster global citizenship awareness. Cole (2007) emphasizes that global citizenship education must touch upon cognitive, socio-emotional, and behavioral dimensions. In these teaching materials, these dimensions are met through the presentation of ethical dilemmas regarding the impact of technology on local and global environments.

The results of this study reinforce Gaudelli's (2016) argument that global character can only grow when students are allowed to reflect on their roles within the global ecosystem. Through multimodal digital content, students see real visualizations of how pollution in one region impacts the global climate. This is supported by Zubaidah (2016) and Zubaidah et al. (2018), who emphasize that 21st-century skills must include cultural literacy and global character as navigational instruments in a borderless world. Additionally, Arini et al. (2025), Davis et al. (2015), and Listiana et al. (2016) found that learning grounded in socio-cultural issues significantly improves students' social responsibility through an emotional connection to the object of study.

The role of multimodal media is also crucial in character building. Walsh and Campbell (2018) argue that multimodal narratives involving audio and video socio-cultural testimonials can foster deeper empathy than ordinary narrative texts. In this study, students showed increased tolerance for diversity while studying various traditional technological innovations from different cultural backgrounds. These findings align with those of Eden et al. (2024) and Sutherland (2013), who argue that digital literacy focused on social issues can be a powerful tool for promoting social justice and global awareness.

5.3 Synergy of STS-C and multimodality

The success of this research theoretically bridges the gap between technological mastery and value internalization. For a long time, many innovations in digital teaching materials have been confined to purely technical concerns, neglecting humanistic ones. By implementing STS-C, these teaching materials become more than just instructional media; they become instruments for value transformation. Amirshokoohi (2016), Çinar and Çepni (2021), and Primastuti and Atun (2018) highlight that the use of technology in elementary schools is often "devoid" of cultural values. Our findings provide counter-evidence that technology, when wrapped in an STS-C narrative, actually strengthens local identity while opening global insights.

Previous research by Prain (2019) suggests that multimodal representations must be meaningfully constructed to avoid confusion. In this study, effectiveness was achieved by systematically arranging each mode (image, text, video) to support the raised STS-C issues. A study by Astria and Wardani (2024) and Rahmawati and Wardani (2025) also showed that the development of IT-supported learning tools grounded in local wisdom is highly effective in improving students' soft skills. The alignment of these results with the research of Rahmawati and Wardani (2025) on digital science literacy reinforces the argument that IT-Culture integration is the future of primary school science education.

Furthermore, Amirshokoohi et al. (2022) and Nugroho and Supriyadi (2022) found that STS-C is effective in primary education, as evidenced by active engagement with science-society issues and improvements in students' ethical decision-making abilities. This is evident in our research results, where students developed digital ethical solutions to environmental problems in their communities. Finally, studies by Bezemer and Kress (2016), Sadaf and Johnson (2017), and Son

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and Ha (2025) emphasize the importance of using language and modes familiar to the students' culture to achieve deep understanding, a principle consistently applied in these STS-C multimodal materials.

In synthesis, the effectiveness of the implementation of these teaching materials is driven by three main pillars: (1) clarity of representation through multimodality, (2) contextual relevance through the STS-C approach, and (3) digital interactivity that facilitates independent inquiry. These results show that digital science literacy and global character are not separate entities but hybrid competencies that can be developed simultaneously through holistic instructional design. This study provides a real contribution to the development of science pedagogy theory in elementary schools, confirming that technological innovation must always be rooted in cultural values and global awareness to produce a generation that is not only digitally smart but also wise as global citizens.

However, these prominent outcomes must be interpreted with caution, as several alternative explanations could account for the observed increases. The significant post-test gains might partially stem from a 'novelty effect,' in which elementary students show heightened engagement simply from the introduction of novel interactive digital devices rather than the pedagogical framework itself. Additionally, factors such as the specific instructor's teaching style (teacher effect), variations in students' baseline intrinsic motivation, and the brief duration of the intervention could influence the results. Given that global character is an affective trait susceptible to social desirability bias in self-report measures, long-term longitudinal monitoring is required before these materials can be generalized as an absolute benchmark for primary science education.

6. Conclusion and implications

This study concludes that the implementation of Science, Technology, Society, and Culture (STS-C) based multimodal science materials is effective within the specific context and sample of this study in enhancing the digital science literacy and global character of fifth-grade students. Statistical evaluations demonstrate meaningful achievements, with high-category N-Gain scores for digital literacy (0.74) and medium-category scores for global character (0.58).

The implications of this research emphasize the importance of integrating digital technology rooted in local cultural values within the primary science curriculum. In practice, the use of these materials enables educators to transform science learning from rote memorization into a contextual, exploratory experience. From a policy perspective, these findings suggest that the future development of teaching materials should not only focus on digital technical proficiency but also explicitly incorporate global socio-cultural issues to develop a student profile that is technologically competent and possesses strong character integrity on the international stage.

Nevertheless, several major limitations must be acknowledged: the study relied on a single school sample, had a relatively small sample size, employed a non-randomized quasi-experimental design, and used a restricted intervention timeline, as well as potential affective measurement bias. Theoretically, this research provides an empirical framework demonstrating that digital innovations in primary education should be structurally modeled to align with localized socio-cultural realities to foster balanced cognitive and character development.

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Credit authorship contribution statement
Novi Yuliyanti: Conceptualization, Investigation, Methodology, Project administration, Visualization, Writing – original draft. **Sarwi**: Supervision, Validation, Conceptualization. **Sri Wardani**: Data curation, Formal analysis, Writing – review & editing. **Siti Fathonah**: Resources, Validation, Writing – review & editing.

Declaration of competing interest
The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Data Availability Statement
The datasets generated during the current study are available from the corresponding author on reasonable request.

Ethical Declaration
This study complied with strict academic ethical protocols and obtained official approval from the school ethics committee and local education authorities, as well as written informed consent from the students' parents.

Declaration of AI Statement
The authors declare that generative artificial intelligence (AI) technologies or AI-powered tools were used only to check the Writing and proofread the text, and were not used for data analysis in this manuscript.

References

Aikenhead, G. S. (2006). Science education for everyday life: Evidence-based practice. Teachers College Press.

Aikenhead, G. S. (2021). Resolving conflicting subcultures within school mathematics: Towards a humanistic school mathematics. Canadian Journal of Science, Mathematics and Technology Education, 21(2), 475–492. https://doi.org/10.1007/s42330-021-00152-8

Al-Hattali, M. K. S., Abd-El-Aal, W. M. M., & Ismail, S. S. (2025). The effectiveness of teaching with interactive infographics in acquiring scientific concepts and developing visual thinking in science among fourth-grade students. Journal of Educational and Psychological Studies, 19(1), 64–87. https://doi.org/10.53543/2521-7046.1003

Amirshokoohi, A. (2016). Impact of STS issue-oriented instruction on pre-service elementary teachers' views and perceptions of science, technology, and society. International Journal of Environmental and Science Education, 11(4), 359–387. https://doi.org/10.12973/ijese.2016.324a

Amirshokoohi, A., Kazempour, M., & Soyer, M. (2022). A case study of elementary pre-service teachers experiencing an STS-based science methods course. Interdisciplinary Journal of Environmental and Science Education, 18(4), e2299. https://doi.org/10.21601/ijese/12370

Anggraini, L. W., & Rahmawati, L. E. (2023). Peningkatan literasi membaca dan menulis bagi siswa sekolah dasar melalui kegiatan Lakusi (Latihan Khusus Literasi). Jurnal Ilmiah Kampus Mengajar, 3, 60–70. https://doi.org/10.56972/jikm.v3i1.57

Arini, R., Rosmilawati, I., & Hendrayana, A. (2025). Development of culturally responsive, interactive media to improve social-emotional skills and learning motivation among primary school students. Journal Pedagogy, 12(3), 734–743. https://doi.org/10.33394/jp.v12i3.15425

Astria, F. P., & Wardani, K. S. K. (2024). Analisis kemampuan literasi sains dalam pembelajaran

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IPA di sekolah dasar. Jurnal Pendidikan dan Pembelajaran IPA Indonesia, 14(2), 46–55. https://doi.org/10.23887/jppii.v14i2.83933

Bezemer, J., & Kress, G. (2016). Multimodality, learning and communication: A social semiotic frame. Routledge. https://doi.org/10.4324/9781315687537

Butterworth, J., & Thwaites, G. (2013). Thinking skills: Critical thinking and problem solving (2nd ed.). Cambridge University Press.

Çalik, M., & Karatas, F. O. (2019). Does a "Science, technology and social change" course improve scientific habits of mind and attitudes towards socioscientific issues? Australian Journal of Teacher Education, 44(6), 35–52. https://doi.org/10.14221/ajte.2018v44n6.3

Chiu, M. M., McBride-Chang, C., & Lin, D. (2012). Ecological, psychological, and cognitive components of reading difficulties: Testing the component model of reading in fourth graders across 38 countries. Journal of Learning Disabilities, 45(5), 391–405. https://doi.org/10.1177/0022219411431241

Çinar, S., & Çepni, S. (2021). The impact of science teaching based on the science-technology-society (STS) approach on elementary school students. Educational Policy Analysis and Strategic Research, 16(4), 198–217. https://doi.org/10.29329/epasr.2021.383.11

Clark, R. C., & Mayer, R. E. (2023). E-learning and the science of instruction: Proven guidelines for consumers and designers of multimedia learning. John Wiley & Sons.

Cole, M. (2007). Culture and cognitive development in phylogenetic, historical, and ontogenetic perspectives. In Handbook of Child Psychology. https://doi.org/10.1002/9780470147658.chpsy0215

Creswell, J. W. (2015). Educational research: Planning, conducting, and evaluating quantitative and qualitative research. Pearson.

Davis, B., Sumara, D., & Luce-Kapler, R. (2015). Engaging minds: Cultures of education and practices of teaching (3rd ed.). Routledge.

Le Donné, N., Fraser, P., & Bousquet, G. (2016). Teaching strategies for instructional quality: Insights from the TALIS-PISA link data. OECD Education Working Papers, No. 148. OECD Publishing. https://doi.org/10.1787/5jln1hlsr0lr-en

Eden, C. A., Chisom, O. N., & Adeniyi, I. S. (2024). Promoting digital literacy and social equity in education: Lessons from successful initiatives. International Journal of Management & Entrepreneurship Research, 6(3), 687–696. https://doi.org/10.51594/ijmer.v6i3.880

Fan, X., & Geelan, D. (2013). Enhancing students' scientific literacy in science education using interactive simulations: A critical literature review. Journal of Computers in Mathematics and Science Teaching, 32(2), 125–171.

Gaudelli, W. (2016). Global citizenship education: Everyday transcendence. Routledge. https://doi.org/10.4324/9781315683492

Gay, G. (2018). Culturally responsive teaching: Theory, research, and practice. Teachers College Press.

Incelli, E. A. (2022). Engaging students in multimodal literacy practices in a university ESP context: Towards understanding identity and ideology in government debates. Multimodal Communication, 11(1), 49–61. https://doi.org/10.1515/mc-2021-0004

Indah, R. N., Budhiningrum, A. S., & Afifi, N. (2022). The research competence, critical thinking skills, and digital literacy of Indonesian EFL students. Journal of Language Teaching and Research, 13(2), 315–324. https://doi.org/10.17507/jltr.1302.11

Jewitt, C. (2010). The Routledge handbook of multimodal analysis. Journal of Pragmatics, 42(9), 2604–2608. https://doi.org/10.1016/j.pragma.2010.03.003

Jewitt, C., Bezemer, J., & O'Halloran, K. (2016). Introducing multimodality. Routledge.

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Listiana, L., Susilo, H., Suwono, H., & Suarsini, E. (2016). Empowering students' metacognitive skills through a new teaching strategy (group investigation integrated with think, talk, write) in the biology classroom. Journal of Baltic Science Education, 15(3), 391–400. https://doi.org/10.33225/jbse/16.15.391

Matuk, C., Hurwich, T., Spiegel, A., & Diamond, J. (2021). How do teachers use comics to promote engagement, equity, and diversity in science classrooms? Research in Science Education, 51(3), 685–732. https://doi.org/10.1007/s11165-018-9814-8

Nugroho, H. S., & Supriyadi, S. H. (2022). Mobile learning media based on science, technology, and society (STS) to improve science literacy for V-grade SD students. International Journal of Research and Review, 9(4), 180–188. https://doi.org/10.52403/ijrr.20220423

OECD. (2023). PISA 2022 Results (Volume I): The state of learning and equity in education. PISA. OECD Publishing. https://doi.org/10.1787/53f23881-en

Prain, V. (2019). Future research in learning with, through, and from scientific representations. In Theorizing the future of science education research (pp. 151–168). Springer. https://doi.org/10.1007/978-3-030-24013-4_10

Prain, V. (2022). Teachers' language-based knowledge to support students' science learning. In The role of language in content pedagogy: A framework for teachers' knowledge (pp. 137–155). Springer. https://doi.org/10.1007/978-981-19-5351-4_7

Primastuti, M., & Atun, S. (2018). Science, technology, society (STS) learning approach: An effort to improve students' learning outcomes. Journal of Physics: Conference Series, 1097(1), 012062. https://doi.org/10.1088/1742-6596/1097/1/012062

Rahmawati, K. S. N., & Wardani, R. P. (2025). Inovasi bahan ajar digital: Pengembangan e-modul Read-STEM sebagai solusi peningkatan hasil belajar peserta didik SD. Jurnal Ilmu Pendidikan Sekolah Dasar, 167–175. https://doi.org/10.19184/jipsd.v12i2.53713

Rasmet, R. R., Shaafi, N. F., Sharif, S., Nasir, S. M., Salleh, M. F. M., & Ellianawati, E. (2025). The impacts of comic-based learning on student engagement in primary education: A systematic literature review. Citra Journal of Innovative Education Practices, 1(1), 26–39. https://doi.org/10.37934/cjiep.1.1.2639

Sadaf, A., & Johnson, B. L. (2017). Teachers' beliefs about integrating digital literacy into classroom practice: An investigation based on the theory of planned behavior. Journal of Digital Learning in Teacher Education, 33(4), 129–137. https://doi.org/10.1080/21532974.2017.1347534

Son, M., & Ha, M. (2025). Development of a digital literacy measurement tool for middle and high school students in the context of scientific practice. Education and Information Technologies, 30(4), 4583–4606. https://doi.org/10.1007/s10639-024-12999-z

Sutherland, R. (2013). Education and social justice in a digital age. Policy Press.

Taylor, S. V., & Sobel, D. M. (2011). Culturally responsive pedagogy: Teaching like our students' lives matter. Emerald Group Publishing Limited. https://doi.org/10.1163/9781780520315

Tristaningrat, A. N., & Ariyana, I. K. S. (2025). The effectiveness of digital comics in improving science learning outcomes and scientific attitudes of fourth-grade elementary students. Journal of Education Technology, 9(2), 197–204. https://doi.org/10.23887/jet.v9i2.98249

Tytler, R., Prain, V., & Hubber, P. (2018). Representation construction as a core science disciplinary literacy. In Global developments in literacy research for science education (pp. 301–317). Springer. https://doi.org/10.1007/978-3-319-69197-8_18

UNESCO. (2017). A guide for ensuring inclusion and equity in education. UNESCO.

Unsworth, L. (2020). Learning from animations in science education. Springer. https://doi.org/10.1007/978-3-030-56047-8

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Unsworth, L., Tytler, R., Fenwick, L., Humphrey, S., Chandler, P., Herrington, M., & Pham, L. (2022). Multimodal literacy in school science: Transdisciplinary perspectives on theory, research and pedagogy. Taylor & Francis. https://doi.org/10.4324/9781003150718

Walsh, C., & Campbell, C. (2018). Introducing coding as a literacy on mobile devices in the early years. In Mobile technologies in children's language and literacy: Innovative pedagogy in preschool and primary education (pp. 51–66). Emerald Publishing Limited. https://doi.org/10.1108/978-1-78714-879-620181004

Woodill, G. (2011). The mobile learning edge: Tools and technologies for developing your teams. McGraw-Hill. http://books.google.com/books?id=65bKPeCNaTEC&pgis=1

Zubaidah, S. (2016). Keterampilan abad ke-21: Keterampilan yang diajarkan melalui pembelajaran. Seminar Nasional Pendidikan, 2(2), 1–17.

Zubaidah, S., Corebima, A. D., & Mahanal, S. (2018). Revealing the relationship between reading interest and critical thinking skills through Remap GI and Remap Jigsaw. International Journal of Instruction, 11(2), 41–56. https://doi.org/10.12973/iji.2018.1124a

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