



A rational decision-making learning model to enhance elementary students' environmental understanding

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Abstract. Environmental literacy is a critical competency for elementary students, yet many pedagogical approaches lack structured frameworks connecting environmental issues to real-world decision-making. This study aimed to enhance students' environmental understanding through a rational decision-making learning model supported by interactive digital multimodal teaching materials based on socioscientific issues (SSI). A pre-experimental one-group pretest–posttest design was employed with 75 fifth-grade students in Cimahi City, West Java, selected through purposive sampling. Data were collected using a validated environmental understanding test that measured knowledge of causes, impacts, and solutions to environmental problems, and were then analyzed using Wilcoxon tests. Results showed a statistically significant improvement in students' environmental understanding. The model enabled students to think systematically by connecting causes, consequences, and solutions to environmental problems, while promoting critical reasoning and

active engagement in learning. These findings suggest that integrating decision-making frameworks with multimodal SSI materials can effectively support environmental literacy in primary education. Future studies should apply this model across broader populations and examine its long-term impact on students' environmental attitudes and behavior. This study is limited to fifth-grade students in a single city; thus, its generalizability requires further investigation.

Introduction

Global environmental crises such as climate change, air and water pollution, land degradation, and declining biodiversity are serious challenges that demand a systematic and sustainable response through education (Olsson et al., 2022; Setiadi et al., 2025). Environmental education in elementary schools plays a strategic role as a foundation for ecological literacy and the formation of sustainable attitudes and behaviors in the future (Demirci et al., 2025; Lestari et al., 2023). Recent studies confirm that environmental education can improve pro-environmental knowledge, attitudes, and behaviors in school-age children through contextual and participatory activities (Devkota & Basyal, 2024). At this stage, environmental learning serves not only to build factual knowledge but also to develop reflective critical thinking skills and responsible decision-making regarding real-world environmental issues (Zsóka et al., 2013). However, learning practices oriented toward environmental understanding in elementary schools still tend to emphasize the transfer of concepts

rather than a rational analysis of the cause-and-effect relationships between human behavior, environmental impacts, and possible solutions (Jaime et al., 2023; Mousavi et al., 2024).

The solution considered appropriate for realizing learning oriented towards students' environmental understanding is a rational decision-making learning model assisted by interactive digital, multimodal teaching materials based on socio-scientific issues. With the development of educational technology, interactive digital teaching materials that incorporate multimodality play an important role in enriching the learning environment in elementary schools (Dea, 2024). Multimodal teaching materials that integrate text, visuals, audio, animation, and interactive elements can increase student engagement, deepen understanding, and encourage complex thinking processes, especially when designed according to the principles of cognitive load and affective learning theory (Liana Mumrikoh et al., 2023; Mayer, 2017; Manohari & Purwati, 2023).

Previous research on interactive digital multimodal teaching materials shows that the application of interactive learning environments can develop systemic thinking skills, cross-conceptual understanding, and evaluative skills in elementary school students (Ekowati et al., 2024; Liana Mumrikoh et al., 2023; Yatri et al., 2024). However, the integration of multimodal digital teaching materials on socio-scientific issues in elementary education remains rare, despite research indicating the need to develop such innovations tailored to the characteristics of elementary school-aged children (Cenk & Ercan Yalman, 2022).

Socioscientific issues offer an effective pedagogical framework for connecting scientific knowledge with moral and social considerations. Through socioscientific issues, students are encouraged to understand real-world phenomena within the context of public debate, evaluate evidence, and make decisions based on rational reasoning (Kinskey & Zeidler, 2021). Previous research has shown that socioscientific issue-based learning can significantly improve scientific literacy, critical argumentation, and environmental understanding (Hancock et al., 2019; López-Fernández et al., 2022; G. D. S. Rahayu et al., 2024). However, the application of socioscientific issues is still predominantly confined to secondary or higher education. Integration at the elementary school level remains minimal and requires a pedagogical approach grounded in real-world experiences relevant to the cognitive development of elementary school-aged children (Macalalag et al., 2020; Viehmann et al., 2024).

Meanwhile, the rational decision-making learning model offers a systematic framework for decision-making (Widana & Uman, 2023). The rational decision-making learning model provides students with the opportunity to seek, analyze, and evaluate information from various sources to generate alternative solutions and select the best solution as a rational, logical decision when solving a problem (G. D. S. Rahayu et al., 2026). This learning model emphasizes structured steps, including concept analysis, problem identification, alternative exploration, evidence analysis, decision selection, and designing and implementing solutions to address the problem (G. D. S. Rahayu et al., 2024). Recent research shows that implementing the rational decision-making model can improve decision-making skills and information literacy at the elementary school level (G. D. S. Rahayu et al., 2022, 2024; Shafira & Rahayu, 2025).

Despite growing research on multimodal learning and SSI, their integration within a rational decision-making framework at the elementary level remains underexplored. The research's novelty lies in: (1) the pedagogical adaptation of the rational decision-making learning model tailored to the cognitive and moral development of elementary school students; (2) the interactive digital multimodal learning materials based on socio-scientific issues to present contextual and authentic environmental situations; and (3) empirical testing of the effectiveness of a combination of learning

models, teaching materials, and socio-scientific issues on the environmental understanding of elementary school students.

The main problem of this research is students' limited ability to understand the environment, including its causes and effects, and to identify solutions to environmental problems around them, thereby affecting their participation and responsibility in environmental conservation. The primary problem in this research is students' limited ability to understand the environment, including its causes and effects, and the solutions to environmental problems around them. This impacts their participation and responsibility in environmental conservation. The research question is: Is a rational decision-making learning model supported by interactive digital multimodal materials based on socio-scientific issues effective in improving elementary school students' environmental understanding, and which indicators of environmental understanding show the greatest improvement?

Based on this statement, the purpose of this study is to evaluate the effectiveness of a rational decision-making learning model integrated with interactive digital multimodal learning materials based on socio-scientific issues in improving elementary school students' environmental understanding. Furthermore, this research is expected to provide theoretical and practical contributions to the development of modern, contextual, and evidence-based environmental pedagogy. The hypothesis of this study is that implementing a rational decision-making learning model supported by interactive digital, multimodal materials based on socio-scientific issues will significantly improve elementary school students' environmental understanding. Furthermore, it is hypothesized that the most significant improvement will occur in indicators of higher-level environmental understanding, specifically students' ability to analyze environmental problems, evaluate alternative solutions, and make responsible decisions.

Method

Design

The research design used was a one-group pretest-posttest design. This design was chosen because it aligns with the research questions and objectives, namely to determine the effect of a treatment, namely a rational decision-making learning model assisted by interactive digital multimodal teaching materials, on environmental understanding without a comparison group (Levy & J. Ellis, 2011; G. D. S. Rahayu et al., 2022). However, this design has limitations, as a one-group design cannot fully establish causality because it lacks a control or comparison group. Consequently, any observed changes may be influenced by external factors such as maturation, history, or testing effects, rather than the intervention alone (Creswell & Poth, 2023). A brief overview of the research design is shown in the following figure.

Table 1. One group pretest-posttest design

Group	Pre-test (T ₁)	Treatment (X)	Post-test (T ₂)
Experimental	environmental understanding	Learning with a rational decision-making learning model supported by interactive digital multimodal teaching materials based on socio-scientific issues	Same tests as pre-test

Annotations:

T₁ = Pre-test before learning intervention

X = Learning with a rational decision-making learning model supported by interactive digital multimodal teaching materials based on socio-scientific issues

T₂ = Post-test after learning intervention

Population and Sample

The population of this study was fifth-grade elementary school students in Cimahi City. The sample consisted of fifth-grade students from three schools: one class in the Central Cimahi sub-district, one in the North Cimahi sub-district, and one in the South Cimahi sub-district, for a total of 75 students. The sample selection used purposive sampling. The reason for using this technique was to ensure that the sample was consistent with the study's objectives and criteria. The sample criteria were fifth-grade students from schools whose environments were relevant to the socio-scientific issues studied, had the same initial environmental understanding abilities, and shared similar school characteristics, such as similar facilities and infrastructure.

Research Procedures

The research procedure consists of three main stages: the planning stage, with activities such as analyzing relevant research, analyzing literature on environmental understanding, preparing interactive digital multimodal teaching materials based on socio-scientific issues, and developing learning tools using a rational decision-making learning model. The implementation stage, with its activities, includes pretests on students' environmental understanding, learning with a rational decision-making learning model assisted by interactive digital multimodal teaching materials based on socio-scientific issues over three meetings, and posttests on students' environmental understanding. The third stage is analysis and evaluation, with its activities including analyzing data obtained during the research and evaluating the data analysis.

Instrument and Validation

The research instrument used was a written test sheet in accordance with the environmental understanding indicators: 1) systems knowledge, namely the ability to understand the components, processes, and interrelationships between ecosystem components and the impact of human behavior on the environment; 2) action knowledge, namely an understanding of various human activities that can cause environmental damage or sustainability, as well as efforts that can be taken to minimize negative impacts; 3) effectiveness knowledge, namely the ability to assess the extent to which a chosen method or solution has a real impact on improving environmental conditions based on facts or scientific evidence; and 4) systemic and causal thinking skills, namely the ability to analyze cause-and-effect relationships, make predictions of change, and understand the long-term consequences of environmental change, so that students can map problems and identify relevant solutions (Demirci et al., 2025; Jaime et al., 2023; Zsóka et al., 2013).

Before use, the instrument was validated to ensure it met validity and reliability criteria so that the measurement results could be scientifically accounted for (Mohamad et al., 2015; Kimberlin & Winterstein, 2008). In this study, the validation process was conducted by three experts: (1) a lecturer expert in elementary education, (2) a lecturer expert in the context of learning socioscientific issues, and (3) a certified teacher practitioner who teaches as a fifth-grade elementary school teacher (Zondervan-Zwijenburg et al., 2017). The instruments are presented in detail in the following grid to ensure methodological clarity and transparency.

Table 2. Detail of instrument

Indicators	Sub Indicator	SSI Context	Assessment Focus	Validity & Reliability Evidence
System Knowledge	Analyzing ecosystem relationships	Water pollution	Explain interactions among ecosystem components	I-CVI=0.92; Loading=0.73; α =0.85

Indicators	Sub Indicator	SSI Context	Assessment Focus	Validity & Reliability Evidence
System Knowledge	Analyzing human impacts	Deforestation	Identify ecological consequences	I-CVI=0.90; Loading=0.75; $\alpha=0.86$
Action Knowledge	Evaluating human actions	Plastic waste	Assess the sustainability of actions	I-CVI=0.89; Loading=0.78; $\alpha=0.87$
Action Knowledge	Designing solutions	Air pollution	Propose environmental solutions	I-CVI=0.91; Loading=0.80; $\alpha=0.88$
Effectiveness Knowledge	Evaluating solutions	Recycling	Judge effectiveness based on evidence	Loading=0.77; $\alpha=0.86$
Effectiveness Knowledge	Comparing solutions	Plastic reduction	Select the best solution with reasoning	Loading=0.79; $\alpha=0.88$
Systems Thinking	Analyzing cause-effect	Flooding	Identify causal relationships	Loading=0.81; CFI=0.93; RMSEA=0.05
Systems Thinking	Predicting impacts	Climate change	Predict long-term impacts and solutions	Loading=0.83; CFI=0.94; RMSEA=0.04

Data Analysis

The research data were then analyzed using quantitative methods. The data obtained in this study were pretest and posttest data on students' environmental understanding. The data on students' environmental understanding obtained at the pretest and posttest stages were analyzed using a normality test to ensure that the distribution of student scores was normal. Next, a mean difference test was conducted, namely the Wilcoxon test, because the data were not normally distributed, to determine the significance of the average difference in environmental understanding before and after learning, and finally, the N-gain test to determine the increase in students' environmental understanding after implementing learning using a rational decision-making learning model assisted by multimodal digital learning materials based on socio-scientific issues.

Results and Discussion

The results of the study using a decision-making learning model assisted by interactive digital multimodal teaching materials based on socioscientific issues proved effective in improving students' environmental understanding. The data in the following table refer to the results of the pretest and posttest analyses of students' environmental understanding.

Table 3. Initial and Final Data of Students' Environmental Understanding

Data	Pretest	Posttest
Number of Data	75	75
Minimum Score	4	9
Maximum Score	9	14
Mean Score	6.7	11.8
Normality	0.000 (not normally distributed)	0.000 (not normally distributed)
Wilcoxon test	0.000 (Significantly different)	
N-gain	0.72 (High Category)	

The statistical results in Table 1 indicate that the improvement in students' learning is both statistically significant ($p = 0.000$) and educationally meaningful, as reflected by the high N-gain value (0.72). This finding suggests not merely an increase in scores, but a qualitative shift in students' understanding. The improvement can be attributed, in theory, to the characteristics of SSI-based instruction, which engages students in real-world contexts and promotes analytical and evaluative thinking. The high N-gain further indicates that students were able to reconstruct prior knowledge and develop more advanced reasoning in interpreting environmental problems and proposing solutions. Additionally, the use of digital multimodal materials likely enhanced cognitive processing through diverse representations. Overall, this combination aligns with environmental literacy frameworks that emphasize systems thinking, evidence-based reasoning, and decision-making, indicating a meaningful advancement in students' environmental understanding.

Based on the analysis results, the improvement in each indicator of students' environmental understanding is as follows.

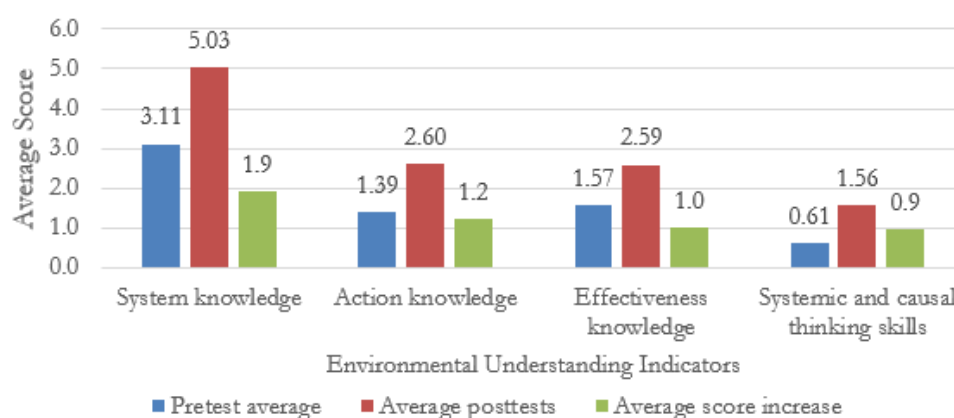


Image 1. Data Analysis of Students' Environmental Understanding Indicators

Referring to Image 1, the rational decision-making learning model, supported by interactive digital multimodal teaching materials based on socioscientific issues, encouraged comprehensive improvement in environmental understanding among fifth-grade elementary school students across all indicators.

The indicator with the greatest improvement was systems knowledge, which refers to students' ability to understand environmental issues, including their causes and impacts. This improvement indicates that the implementation of the rational decision-making learning model, supported by interactive digital multimodal teaching materials based on socioscientific issues, is effective in stimulating students' cognitive engagement with complex environmental issues (Purnadewi & Widana, 2023).

These findings demonstrate that integrating digital multimodal tools, such as instructional videos, interactive whiteboards, and quizzes, significantly enhances students' conceptual understanding. Videos provide visual and contextual experiences that help students concretely recognize environmental problems, while interactive whiteboards facilitate collaborative concept elaboration and strengthen the social construction of knowledge through technology-mediated interaction (Fazio et al., 2022). In addition, digital quizzes support reflective, engaging evaluation by offering immediate feedback, enabling students to correct misconceptions about the causal relationships between human activities and environmental impacts. This aligns with evidence that combining

verbal and visual representations improves cognitive processing and deepens conceptual understanding (Machin-Mastromatteo, 2021; S. Rahayu et al., 2025).

Furthermore, integrating socio-scientific issues (SSI) allows students to connect scientific knowledge to real-life contexts, enabling them to understand not only factual aspects but also the relationships among the causes, processes, and impacts of environmental phenomena. The significant improvement in systems knowledge indicates that this learning approach effectively fosters systemic thinking skills. These results reinforce prior findings that SSI-based learning promotes scientific literacy while enhancing social and environmental awareness (Kinskey & Zeidler, 2021; G. D. S. Rahayu et al., 2022). Therefore, the use of interactive digital multimodal materials, combined with a rational decision-making model, not only improves conceptual understanding but also strengthens students' ability to analyze environmental issues systematically and evidence-based.

The knowledge indicator indicates an increase in students' ability to critically reflect on human behavior and suggest appropriate environmental actions. This indicates that learning activities not only convey knowledge but also engage students in reflective thinking and focus on decision-making (Evi Yupani & Widana, 2023). Moderate improvement in this dimension may indicate that although students can identify appropriate actions, the transition from understanding to designing optimal solutions still requires more in-depth support. This is in line with the idea that competency-oriented actions involve not only knowledge acquisition but also value judgments and contextual punishments.

The observed improvement in students' action knowledge following the SSI-based digital multimodal learning intervention reflects a substantive development in their capacity for reflective judgment and values-based environmental decision-making. Action knowledge, as conceptualized within the environmental education literature, encompasses more than the mere recognition of pro-environmental behaviors; it requires students to critically evaluate competing courses of action, weigh trade-offs, and justify their choices based on scientific evidence and ethical reasoning (Mayer, 2017). This aligns with Zeidler et al. (2005), who argue that SSI-based instruction fosters moral reasoning and responsible action by positioning students as active agents who navigate real-world complexity rather than passively absorbing environmental norms. Nevertheless, the moderate magnitude of the observed gains indicates that action competence develops gradually as a continuum rather than a fixed outcome.

As noted by Sadler (2004), designing contextually appropriate and ethically grounded solutions requires higher-order reasoning, including integrating multiple information sources, anticipating long-term consequences, and balancing environmental, social, and economic considerations, capacities that are unlikely to be fully achieved within a single intervention. Furthermore, the development of action knowledge is influenced not only by cognitive factors but also by affective engagement and perceived environmental self-efficacy, as students who feel capable of contributing meaningfully are more likely to construct more sophisticated action strategies (Palmer et al., 2017; Widana et al., 2024). These findings have important implications for the design of future environmental learning interventions. While SSI-based digital multimodal instruction proves effective in fostering action knowledge, it also highlights the need for explicit instructional scaffolding, such as structured argumentation tasks, collaborative deliberative discussions, and guided reflection on the consequences of alternative solutions (Gough, 2002). Future research should also examine the extent to which gains in action knowledge are sustained over time and transferred to new environmental contexts, as this evidence is essential for assessing the depth and generalizability of competencies developed through SSI-based multimodal learning environments.

The observed effectiveness knowledge indicator reflects students' increased ability to assess the impact and feasibility of environmental solutions. This dimension is highly significant because it requires evaluative thinking grounded in evidence rather than intuitive judgment. The results indicate that students are beginning to distinguish between superficial and impactful solutions, indicating progress toward more informed decision-making. However, the relatively lower improvement compared to systems knowledge may imply that effectiveness evaluation remains cognitively demanding, as it involves weighing multiple variables and potential outcomes.

This pattern of moderate improvement in effectiveness knowledge is consistent with prior research demonstrating that evaluative thinking in the context of environmental problem-solving is among the most cognitively demanding competencies within environmental literacy frameworks. Evaluating the effectiveness of environmental solutions requires students to engage in higher-order reasoning that integrates systems thinking, evidence appraisal, and consequence anticipation cognitive processes that extend well beyond the recall or application of factual knowledge (Badertscher, 2006). Furthermore, Moss (2001) argued that scientifically literate citizens must develop the ability to distinguish between evidence-based claims and rhetorically persuasive but empirically weak arguments, a distinction that lies at the heart of effectiveness evaluation and that requires sustained instructional support to develop. The relatively lower gain observed in this indicator compared to systems knowledge thus reflects the inherent cognitive complexity of effectiveness evaluation rather than a shortcoming of the intervention itself.

The role of digital multimodal learning in supporting effective knowledge development is also worth considering in light of prior empirical evidence. Studies have shown that multimedia-rich learning environments can scaffold students' evaluative reasoning by presenting solution scenarios across multiple representational formats, including data visualizations, simulation-based comparisons, and expert commentary, thereby enabling learners to examine the consequences of different environmental actions from varied analytical perspectives (Fauville et al., 2020). This form of representational scaffolding is particularly important for effectiveness evaluation, as it allows students to move beyond surface-level impressions of environmental solutions and engage with the underlying empirical and systemic factors that determine their actual impact. Nonetheless, cautions that exposure to multimodal evidence alone is insufficient to foster genuine evaluative competence; students also require explicit guidance in identifying the criteria by which solution effectiveness should be judged, including considerations of scalability, ecological impact, social equity, and economic viability (Cairncross & Mannion, 2001). These findings collectively suggest that future iterations of SSI-based digital learning interventions should incorporate more structured evaluative tasks, such as comparative solution analysis, evidence-based argumentation, and criteria-weighted decision frameworks, to more systematically develop students' capacity for evidence-based judgments of effectiveness.

Meanwhile, the lowest improvement was found in systemic and causal thinking skills, including the ability to analyze cause-and-effect relationships, predict changes, and understand long-term environmental impacts. Although the SSI-based rational decision-making model supported by digital multimodal materials improved overall understanding, students were not yet optimal in developing long-term predictions. This may be due to the higher cognitive demands of futures thinking, which require deeper reflection and scenario construction. As noted by Uskola and Puig (2023), such skills develop gradually through explicit and sustained learning activities. While digital tools such as videos, interactive whiteboards, and quizzes support metacognitive scaffolding, limited reflective time often leads students to make brief, immediate predictions. This aligns with Chan & Eduran (2025), who emphasize that futures literacy requires "infusing scenarios that prompt students' creativity and willingness to evaluate preventive actions in the long term."

Therefore, additional instructional scaffolding, extended time, and collaborative reflection are needed to enhance systemic-causal reasoning.

These findings also have important theoretical and practical implications. The improvement in systems knowledge confirms the effectiveness of digital multimodal integration in supporting contextual learning and knowledge construction through multiple representations (Blyznyuk & Kachak, 2024; Cairncross & Mannion, 2001). However, the lower gains in systemic-causal thinking indicate that this competency is a higher-order one, requiring long-term, iterative instructional approaches, including scenario-based inquiry and future-oriented reflection (Mambrey et al., 2020). This is consistent with previous studies showing that systemic and futures thinking are key 21st-century skills developed through sustained, collaborative, and reflective learning processes (Pauffer et al., 2020; Yulianto et al., 2025).

Table 4. Environmental Understanding Gains and Implications

Indicators	Improvement	Interpretation	Instructional Implications
Systems Knowledge	High	Great improvement in understanding concepts, causes, and environmental impacts	Maintain use of SSI and multimodal digital tools to support conceptual understanding
Action Knowledge	Moderate	Students can select and reflect on actions, but struggle to design optimal solutions	Provide scaffolding through argumentation, collaborative discussion, and reflective tasks
Effectiveness Knowledge	Moderate	The ability to evaluate solutions is developing, but it remains cognitively demanding	Incorporate evidence-based evaluation tasks and comparative analysis of solutions
Systemic-Causal Thinking Skills	Low	Limited ability in long-term prediction and system-based reasoning	Strengthen futures thinking through scenario-based learning, reflection, and extended time

From a practical perspective, the findings emphasize the need to adapt learning strategies to strengthen the predictive and causal dimensions of systemic thinking. Teachers can extend the reflection phase in rational decision-making models by engaging students in analyzing the long-term impacts of environmental decisions, while digital technology should function not only as a source of information but also as a medium for simulative exploration, such as interactive modeling or digital storytelling. Compared with previous studies, these results show a consistent pattern while offering new contributions at the elementary level. Sadler and Zeidler (2005) demonstrated improvements in scientific argumentation and moral awareness through SSI-based learning, whereas Fauville et al. (2020) highlighted the role of interactive media in enhancing causal understanding, both of which align with the systems knowledge gains found in this study. However, this study further indicates that although digital multimodal learning effectively supports conceptual understanding, long-term and causal reasoning still require additional reflective intervention. Thus, the integration of rational decision-making models with SSI-based digital multimodal materials not only enhances scientific literacy but also provides an initial foundation for developing futures literacy and systemic thinking skills in elementary school students.

Conclusion

This study demonstrates that a rational decision-making learning model integrated with interactive digital multimodal materials grounded in socioscientific issues effectively improves elementary school students' cognitive abilities, particularly in systems knowledge encompassing understanding of environmental problems, their causes, and impacts. The incorporation of multimodal elements, including learning videos, interactive boards, and digital quizzes, stimulated cognitive engagement, supported social knowledge construction, and strengthened students' scientific literacy and ecological awareness. However, the lowest gains were observed in systemic and causal thinking indicators, suggesting that the ability to analyze cause-and-effect relationships and predict long-term consequences requires more reflective and in-depth instructional strategies. Therefore, it is recommended that teachers and learning designers enrich this model with collaborative reflection phases, future-oriented scenarios, and dynamic digital tools, such as simulations and interactive modeling, to strengthen metacognitive scaffolding and predictive reasoning. Longitudinal studies are also encouraged to assess the sustainability of this model's impact across educational levels, and future research may explore AI-assisted rational decision-making learning in socioscientific contexts to examine how adaptive digital experiences can deepen students' reflective, predictive, and collaborative reasoning in elementary education.

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