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Research Article

Digital literacy and science literacy as predictors of conservation attitude: Reconsidering the mediating role of scientific argumentation

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Rapid digitalization and growing environmental challenges require students to critically evaluate scientific information and develop responsible conservation attitudes. Limited empirical evidence explains whether scientific argumentation mediates the relationships between digital and science literacy and students' conservation attitudes**.** This study examined the structural relationships between digital literacy and science literacy and students' conservation attitudes, with scientific argumentation positioned as a potential mediator. A cross-sectional survey was conducted in February 2026 involving 314 senior high school students in Pangkep Regency, Indonesia. Participants were selected using purposive sampling. Data were collected using a self-report questionnaire and analyzed through partial least squares structural equation modeling using SmartPLS 4. The measurement model demonstrated acceptable reliability and convergent validity. Digital literacy and science literacy were positively associated with both scientific argumentation and conservation attitudes. However, scientific argumentation was not significantly associated with conservation attitudes and did not mediate the relationships between either digital literacy or science literacy and conservation attitudes. These findings suggest that digital literacy and science literacy are directly associated with conservation attitudes, whereas scientific argumentation is more appropriately understood as a cognitive outcome of literacy competencies rather than as a mediating mechanism. Accordingly, instruction and school policy should integrate digital and scientific literacy, value reflection, ecological concern, and authentic conservation activities to improve educational quality.

Keywords: Conservation attitude; Digital literacy; Science literacy; Scientific argumentation; Students

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1. Introduction

Environmental conservation is not solely a matter of scientific knowledge; it also involves how students interpret environmental information, evaluate evidence, and develop a sense of responsibility toward nature (Landolfi, 2023; Qhobela et al., 2026). In contemporary educational contexts characterized by increasingly complex ecological challenges and diverse sources of

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scientific and digital information, students need competencies that enable them to engage critically with environmental issues while developing positive dispositions toward environmental protection. Scientific literacy can support informed judgment and critical engagement with science-related issues, whereas environmental learning experiences can foster awareness, reflection, and responsibility toward the natural world (Landolfi, 2023; Saputri et al., 2026; Uluçınar & Sezer, 2026). Accordingly, meaningful science and environmental education should connect the critical interpretation of information and evidence with contextual, reflective, and action-oriented learning experiences that encourage environmentally responsible attitudes (Qhobela et al., 2026; Saputri et al., 2026). Understanding how these cognitive and dispositional competencies relate to conservation attitudes is therefore important for designing science and environmental education that moves beyond knowledge acquisition toward informed and responsible engagement with environmental issues.

Conservation attitude is an important outcome of science and environmental education because it reflects students' awareness, concern, responsibility, and disposition to support environmental preservation (Ardoin et al., 2020; van de Wetering et al., 2022). In this study, conservation attitude is conceptualized as students' affective-evaluative disposition toward environmental preservation, rather than as actual conservation behavior. Accordingly, conservation attitude reflects concern, support, and normative readiness for conservation, but does not necessarily translate directly into concrete action. In the context of escalating ecological crises, education is expected not only to equip students with scientific knowledge but also to foster responsible attitudes toward sustainability (Ardoin et al., 2020; Børresen et al., 2023). Conservation issues are complex because they involve scientific, social, ethical, and value-laden dimensions (Högström et al., 2025; Washington et al., 2024). Therefore, the development of conservation attitudes cannot be separated from students' ability to understand information, evaluate evidence, and interpret the consequences of human actions for the environment.

The transition toward Industry 4.0 has intensified the use of artificial intelligence, the Internet of Things, big-data analytics, and digitally connected systems, thereby transforming how scientific and environmental information is produced, circulated, accessed, and evaluated (Abulibdeh et al., 2024). Society 5.0 extends this technological transformation by placing human well-being, social responsibility, and sustainability at the center of technological innovation (Carayannis & Morawska, 2022). In education, these developments require students not only to use digital technologies but also to evaluate information critically, interpret scientific evidence, and respond responsibly to sustainability challenges (Abulibdeh et al., 2024; Audrin & Audrin, 2022). However, wider access to technology does not automatically ensure scientific understanding, evidence-based argumentation, or conservation-oriented attitudes. This unresolved relationship strengthens the need to examine digital literacy, science literacy, scientific argumentation, and conservation attitude within an integrated structural model.

Digital literacy has become an essential competence in the formation of conservation attitudes, particularly because students today obtain much of their environmental information through digital media (Ika Sari et al., 2024; Polizzi, 2020). Digital literacy is not limited to the ability to access technology; it also encompasses the ability to select information, evaluate source credibility, understand digital messages, and use information responsibly. In relation to environmental issues, these abilities enable students to identify valid information, distinguish facts from misinformation, and respond critically to various conservation narratives circulating in digital spaces (Kresin et al., 2024; Nygren et al., 2022). Thus, digital literacy may be directly associated with conservation attitudes through exposure to environmental issues, the ability to verify information, and awareness of ecological risks acquired through digital environments.

In addition to digital literacy, science literacy provides an important foundation for understanding conservation issues in an evidence-based manner (Downey et al., 2021; Kumar et al., 2024; Landolfi, 2023). Science literacy enables students to understand scientific concepts, interpret data, evaluate evidence, and apply scientific reasoning to environmental problems. In the context of conservation, students need to understand phenomena such as ecosystem degradation, biodiversity loss, pollution, climate change, and the impacts of human activities on the environment (Högström et al., 2025; Kang & Teig, 2025). Such scientific understanding can help students develop more rational judgments regarding the urgency of conservation. However, conservation attitudes are not shaped solely by formal scientific knowledge, but also by the ways in which students connect such knowledge with concern, environmental values, contextual experiences, and social responsibility (Garrecht, 2026; Liu et al., 2020).

Scientific argumentation is often regarded as a potential cognitive mechanism linking literacy to conservation attitudes (Allchin, 2020; Kumar et al., 2024). Scientific argumentation involves the ability to formulate claims, use evidence, provide reasoning, and evaluate positions based on data and logical reasoning (Arslan et al., 2023; Dawson, 2024). In science education, this competence is important because it encourages students not merely to accept information, but also to examine, compare, and justify viewpoints rationally (Allchin & Zemplén, 2020; van der Leij et al., 2022). Although scientific argumentation can enhance the quality of students' reasoning, conservation attitudes involve affective, moral, experiential, and value-based dimensions (Tamar et al., 2021; van der Leij et al., 2022; Vig, 2025). Therefore, scientific argumentation may function more strongly as a cognitive outcome of literacy than as a mediating pathway toward conservation attitudes. Accordingly, the role of scientific argumentation in the relationship between literacy and conservation attitudes requires empirical examination rather than deterministic assumption.

A research gap remains because most previous studies have tended to examine digital literacy, science literacy, scientific argumentation, and environmental attitudes separately. Some studies have emphasized that digital literacy and science literacy are associated with critical thinking skills and environmental awareness, whereas others have shown that scientific argumentation can strengthen conceptual understanding and evidence-based decision-making (Casas-quiroga & Crujeiras-pérez, 2020; Hu & Bi, 2025). However, the current literature has not sufficiently explained whether digital literacy and science literacy are associated with conservation attitudes directly or indirectly through scientific argumentation as a mediating mechanism. Moreover, empirical evidence remains limited regarding whether scientific argumentation truly serves as a mediator between literacy competencies and conservation attitudes. This gap is important because conservation attitude is not a purely cognitive construct; it is also affective, evaluative, and value-laden.

Based on this gap, the present study aims to examine the structural relationships between digital literacy and science literacy and conservation attitudes, both directly and indirectly through scientific argumentation as a potential mediator. The novelty of this study lies in its examination of an integrative model that positions digital literacy and science literacy as literacy competencies, scientific argumentation as an evidence-based reasoning process, and conservation attitude as an affective-evaluative outcome in science and environmental education. Unlike approaches that assume scientific argumentation to be the primary pathway in attitude formation, this study allows for the possibility that scientific argumentation may be better understood as a parallel cognitive outcome of digital literacy and science literacy (Allchin & Zemplén, 2020; Dawson, 2024). In doing so, this study is expected to make a theoretical contribution by clarifying the relationships among literacy, scientific argumentation, and conservation attitudes, as well as a practical contribution to the design of science learning that integrates digital information evaluation, scientific understanding, value reflection, and authentic conservation experiences.

2. Conceptual Framework and Hypothesis Development

This study is grounded in three main theoretical foundations: constructivist learning theory, the socioscientific issues framework, and attitude formation theory. From a constructivist perspective, knowledge is not passively received but actively constructed through students' interactions with information, experiences, evidence, and learning contexts (Almulla, 2023; Fırat et al., 2021; Osei et al., 2025). In this study, digital literacy and science literacy are positioned as cognitive resources that enable students to access, evaluate, interpret, and construct knowledge related to environmental issues. Meanwhile, scientific argumentation is understood as a higher-order reasoning process that enables students to formulate claims, use evidence, provide reasoning, and evaluate positions rationally (see Figure 1).

The socioscientific issues framework is particularly relevant because environmental conservation is not merely a scientific matter, but is also closely connected to values, ethics, risk, social responsibility, and real-world decision-making (Högström et al., 2025; van der Leij et al., 2022). In this context, students need to understand scientific information while also considering the social and ecological consequences of human actions toward the environment. Therefore, conservation attitude cannot be understood solely as a cognitive outcome, but rather as an affective-evaluative construct that also involves values, concern, social norms, experience, and students' connectedness to the environment.

In addition, attitude formation theory and the value-belief-norm perspective emphasize that pro-environmental attitudes emerge through the interaction of knowledge, beliefs, values, personal norms, concern, and experience (Helferich et al., 2023; Jebarajakirthy et al., 2024; Nascimento & Loureiro, 2024). Accordingly, the relationships among literacy, scientific argumentation, and conservation attitude are not necessarily linear. Scientific argumentation may strengthen the quality of evidence-based reasoning, but it does not automatically lead to conservation attitudes because attitudes also encompass affective, moral, and value-based dimensions. Thus, scientific argumentation is proposed in this study as a potential mediator, rather than as a deterministic mechanism.

To clarify the conceptual boundaries of the constructs, the four variables were operationalized according to the specific scope and indicators examined in this study. Digital Literacy was limited to students' self-perceived ability to formulate appropriate search keywords, select credible digital sources, use digital platforms to locate relevant information, evaluate source credibility, and verify the authenticity of information (Son & Ha, 2025). Science Literacy covered students' self-perceived ability to connect natural phenomena with scientific concepts, identify scientifically explainable phenomena, draw conclusions from data, communicate investigation results, and evaluate experimental findings (Zhang et al., 2023). Scientific Argumentation encompassed students' self-perceived ability to formulate claims, select relevant evidence, explain the connection between evidence and claims, provide logical scientific justification, and construct reasoning consistent with scientific principles (Guo et al., 2026). Conservation Attitude referred to students' concern for environmental preservation and their intention to support conservation, as reflected in concern about environmental degradation, willingness to undertake preservation actions, support for school conservation programs, and willingness to encourage others to protect nature (Atik et al., 2022). Conservation Attitude was therefore treated as an affective-evaluative disposition rather than as actual conservation behavior. These conceptual boundaries distinguish digital information evaluation, scientific understanding, evidence-based reasoning, and conservation-oriented disposition while recognizing their possible structural relationships

2.1. Digital Literacy and Scientific Argumentation

Digital literacy refers to students' ability to access, evaluate, select, and use information in digital environments critically and responsibly. In science and environmental learning, students with higher levels of digital literacy are more likely to assess the credibility of information, compare multiple sources, identify relevant information, and construct evidence-based understanding (Marttunen et al., 2021; Pimentel, 2025; Svedholm-Häkkinen et al., 2025). These abilities constitute an important prerequisite for scientific argumentation, as the development of arguments requires valid information, credible evidence, and logical reasoning.

Previous studies provide relevant but incomplete evidence for this relationship. Marttunen et al. (2021) examined upper-secondary students' evaluation of the credibility and argumentative content of online sources, whereas Pimentel (2025) changes in students' evaluation of online scientific information following an instructional intervention. These studies connect digital information evaluation with evidence-based reasoning, but they do not directly examine Digital Literacy as a structural predictor of broader Scientific Argumentation. The present hypothesis extends this evidence by testing whether students' perceived digital information competencies are positively associated with their ability to formulate evidence-based scientific arguments. Therefore, the first hypothesis is formulated as follows.

H1: Digital literacy is positively associated with scientific argumentation.

2.2. Science Literacy and Scientific Argumentation

Science literacy reflects students' ability to understand scientific concepts, interpret data, evaluate evidence, and apply scientific reasoning to explain natural phenomena and environmental problems (Guerrero & Sjöström, 2025; Mesci et al., 2025). In the process of scientific argumentation, students require not only logical thinking skills but also an adequate conceptual foundation so that the claims and justifications they construct are scientifically grounded (Casas-quiroga & Crujeiras-pérez, 2020; Zhang & Browne, 2023). The higher students' science literacy, the more likely they are to construct coherent, evidence-based arguments that are consistent with scientific principles.

Casas-quiroga and Crujeiras-pérez (2020) examined the epistemic operations performed by high school students during argumentation and decision-making activities, while Guo et al. (2026) distinguished students' abilities to construct and critique claims and supporting grounds. These studies demonstrate that scientific concepts, evidence, and epistemic operations are essential components of argumentation. However, they primarily examined task-specific argumentation performance and did not directly test the structural relationship between students' overall Science Literacy and Scientific Argumentation. Therefore, the present study examines whether students' perceived understanding and evaluation of scientific evidence are positively associated with their perceived argumentation competence. Thus, the second hypothesis is formulated as follows.

H2: Science literacy is positively associated with scientific argumentation.

2.3. Digital Literacy and Conservation Attitude

Digital literacy is also predicted to have a direct relationship with conservation attitude. Students with higher digital literacy are better able to access information about environmental issues, conservation, ecosystem degradation, climate change, and sustainability practices (Nygren et al., 2022; Polizzi, 2020). The ability to evaluate digital information can help students distinguish valid environmental information from misleading information, thereby strengthening their awareness of and concern for conservation (Kresin et al., 2024; Mellberg et al., 2025). In this context, digital literacy may be associated with conservation attitude through exposure to environmental information, the ability to verify digital narratives, and increased awareness of ecological risks.

Nygren et al. (2022) emphasized the importance of evaluating and corroborating digital information, while Kresin et al. (2024) examined the criteria students use to evaluate scientific information about climate change on social media. Although these studies demonstrate the importance of credibility evaluation in digital environments, they focus mainly on information judgment and do not establish whether Digital Literacy is directly associated with Conservation Attitude. The present hypothesis therefore extends previous research by examining whether students' ability to evaluate environmental information in digital spaces is associated with their concern for and support of environmental conservation. Accordingly, the third hypothesis is formulated as follows.

H3: Digital literacy is positively associated with conservation attitude.

2.4. Science Literacy and Conservation Attitude

Science literacy is expected to be associated with conservation attitude because scientific understanding helps students recognize the relationship between human activities and environmental change. Through science literacy, students can understand the impacts of pollution, resource exploitation, climate change, and biodiversity loss on ecosystem sustainability

(Högström et al., 2025; Kang & Teig, 2025). Such evidence-based understanding may strengthen students' rational evaluation of the importance of conservation and environmental responsibility. However, this relationship is interpreted as a structural association within a cross-sectional design, rather than as strong causal evidence.

Previous findings support this relationship but also suggest that it may not be uniform. Kang and Teig (2025) showed that different science disciplines contribute differently to students' environmental attitudes and behaviors, indicating that not all forms of scientific knowledge have the same environmental relevance. Moreover, Liu et al. (2020) demonstrated that environmental knowledge is connected to pro-environmental outcomes through attitudes and behavioral intentions. These findings support a positive relationship between scientific understanding and environmental attitudes, but they also indicate that knowledge alone may be insufficient without values, concern, and contextual relevance Therefore, H4 tests the specific association between students' Science Literacy and Conservation Attitude. Therefore, the fourth hypothesis is formulated as follows.

H4: Science literacy is positively associated with conservation attitude.

2.5. Scientific Argumentation and Conservation Attitude

Scientific argumentation is positioned as a reflective process that may be associated with conservation attitude. Through scientific argumentation, students can evaluate evidence, consider competing claims, and rationally justify their positions on environmental issues (Ariely & Yarden, 2026; Kumar et al., 2024). Nevertheless, because conservation attitude is also influenced by values, ecological emotions, direct experience, social norms, and moral concern, the ability to construct evidence-based arguments does not necessarily produce strong conservation attitudes automatically.

The available literature does not provide unequivocal evidence for this relationship. Allchin and Zemplén (2020) positions scientific argumentation primarily as an epistemic practice that strengthens evidence-based reasoning. In contrast, the review by van der Leij et al. (2022) indicates that moral and value-related dimensions in science education have not always been explicitly conceptualized. Thus, previous studies support the role of argumentation in rational evaluation but provide limited direct evidence that argumentation alone is associated with conservation-oriented attitudes. H5 therefore tests this relationship empirically rather than assuming that improved reasoning automatically produces a stronger Conservation Attitude. Taking this possibility into account, the fifth hypothesis is formulated as follows.

H5: Scientific argumentation is positively associated with conservation attitude.

2.6. Mediating Role of Scientific Argumentation between Digital Literacy and Conservation Attitude

Scientific argumentation is also proposed as a potential mediator in the relationship between digital literacy and conservation attitude. Digital literacy may provide access to environmental information and the ability to evaluate digital sources, while scientific argumentation may help students transform such information into evidence-based claims and reasoning (Audrin & Audrin, 2022; Pimentel, 2025). However, because conservation attitude is not shaped solely by cognitive reasoning, digital literacy may also be directly associated with conservation attitude through exposure to environmental information, ecological awareness, and digital experiences without necessarily operating through scientific argumentation.

The systematic review by Audrin and Audrin (2022) identified information literacy, digital learning, and twenty-first-century digital skills as central streams of digital literacy research. Meanwhile, Pimentel (2025) demonstrated the educational relevance of evaluating online scientific information. Nevertheless, these studies do not establish a complete mediating pathway in which Digital Literacy strengthens Scientific Argumentation and subsequently Conservation Attitude. H6 addresses this gap by testing Scientific Argumentation as a potential rather than predetermined mediator. Therefore, the sixth hypothesis is formulated as follows.

H6: Scientific argumentation mediates the relationship between digital literacy and conservation attitude.

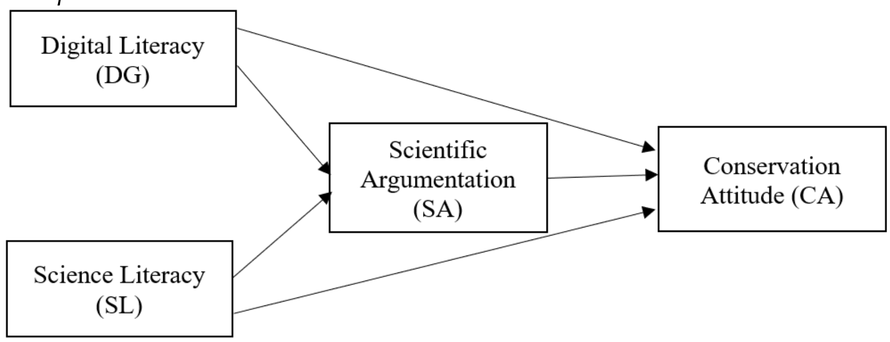
2.7. Mediating Role of Scientific Argumentation between Science Literacy and Conservation Attitude

Scientific argumentation is also predicted to serve as a potential mediator in the relationship between science literacy and conservation attitude. Science literacy provides a conceptual foundation and evidence-based understanding, whereas scientific argumentation enables students to use that foundation to evaluate conservation issues rationally (Guerrero & Sjöström, 2025). However, because conservation attitude also involves environmental values, personal norms, ecological concern, direct experience, and emotional connectedness to nature, the mediating role of scientific argumentation needs to be empirically tested rather than assumed as a definite pathway.

The systematic review conducted by Kumar et al. (2024) showed that argumentation and decision-making are among the most frequently targeted competencies in environmental socioscientific-issue learning. However, the review also identified limited attention to cultural values and contextual factors, indicating that scientific reasoning does not necessarily translate directly into conservation-oriented attitudes. Previous evidence therefore supports the conceptual connection among Science Literacy, argumentation, and environmental decision-making, but it does not confirm Scientific Argumentation as a mediating mechanism. H7 empirically examines this unresolved pathway. Accordingly, the seventh hypothesis is formulated as follows.

H7: Scientific argumentation mediates the relationship between science literacy and conservation attitude.

Figure 1
Conceptual Framework



3. Methods

3.1. Research Design

This study used a cross-sectional survey design, in which data were collected from respondents at a single point in time. Data collection was conducted from 1 to 28 February 2026 (28 days). The conceptual model was analyzed using partial least squares structural equation modeling [PLS-SEM], as this technique is appropriate for prediction-oriented research involving multiple latent variables and the testing of mediating relationships. PLS-SEM was also selected because of its flexibility in handling complex theoretical models and its capacity to explain variance in endogenous constructs (Becker et al., 2023; Cepeda et al., 2024). However, within the cross-sectional design of this study, PLS-SEM was not used to make deterministic causal claims, but rather to examine the strength and significance of structural relationships among constructs in the research model.

3.2. Research Participants

The participants in this study were 314 senior high school students in Pangkep Regency who had received science instruction and had experience using digital information sources in their learning activities. The respondents were drawn from three senior high schools in Pangkep Regency, were aged 16–17 years, and included both male and female students. Participants were selected using purposive sampling because the study required students who were relevant to the constructs of digital literacy, science literacy, scientific argumentation, and conservation attitude. Purposive sampling involves the intentional selection of participants who meet predefined characteristics relevant to the research objectives (Busetto et al., 2020). Accordingly, this technique was appropriate because the study required students who had received science instruction and had experience using digital information sources in their learning activities

The inclusion criteria were as follows: (1) being enrolled as a senior high school student in Pangkep Regency; (2) being aged 16–17 years; (3) having received science instruction; (4) having experience using digital information sources in learning activities; and (5) being willing to participate voluntarily. The exclusion criteria included incomplete responses, duplicate responses, or responses showing inconsistent answer patterns.

A total of 314 initial responses were collected. After data screening, all responses were found to meet the eligibility criteria; therefore, no data were excluded from the analysis. Accordingly, the final sample analyzed in this study consisted of 314 students. Sample adequacy was further assessed using a statistical power criterion. Based on the largest number of predictors directed toward an endogenous construct in the model, namely three predictors, a significance level of 0.05, statistical power of 0.80, and a medium effect size of $f^2 = 0.15$, the minimum required sample was approximately 77 respondents. Therefore, the final sample of 314 students exceeded this minimum requirement. This assessment is consistent with contemporary PLS-SEM recommendations that sample adequacy should be evaluated in relation to statistical power and model complexity (Hair et al., 2024; Sarstedt et al., 2022). This sample size was considered adequate for PLS-SEM because it met the requirements for estimating structural paths and testing mediation effects in the research model. Sample adequacy was also considered in relation to model complexity, the number of latent constructs, the number of indicators, and the number of structural paths tested.

Pangkep Regency was selected because it represented the intended educational context of the study and provided access to senior high schools that met the research requirements. The participating schools provided science instruction, and their students had experience using digital information sources in learning activities, making the location relevant to the constructs examined in this study. Conducting the study within one regency also maintained consistency in the regional educational context when examining the relationships among digital literacy, science literacy, scientific argumentation, and conservation attitude.

Schools were selected based on their contextual suitability for the study, namely schools that provided science instruction and granted permission for data collection. The questionnaire link was distributed to students in coordination with the school authorities or relevant teachers. All students who met the inclusion criteria were given the opportunity to participate voluntarily.

3.3. Research Instrument

The research instrument was a structured questionnaire developed from indicators used in previous studies and adapted to the context of senior high school students. The questionnaire consisted of four main constructs: digital literacy, science literacy, scientific argumentation, and conservation attitude. Each construct was measured using five items, resulting in a total of 20 statement items.

The structure of the research instrument, including the operational scope, questionnaire indicators, item codes, number of items, and adaptation sources, is summarized in Table 1. The instrument used a five-point Likert scale, ranging from 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, to 5 = strongly agree. The questionnaire instructions emphasized that there were no right or wrong answers, that respondents were expected to answer according to their actual conditions, and that all responses would be kept confidential. These provisions were included in the scientific argumentation, digital literacy, science literacy, and conservation attitude questionnaires used in this study.

Table 1
Summary and Operationalization of Research Instruments

Construct	*Operational scope*	*Questionnaire indicators*	*Item codes*	*Number of items*	*Source*
Digital Literacy	Students' perceived ability to search for digital information and select trustworthy digital sources	Ability to search for digital information; ability to select trustworthy digital sources	DG1 and DG3; DG2, DG4, and DG5	5	Son and Ha (2025)
Science Literacy	Students' perceived ability to identify scientific phenomena and draw conclusions based on scientific evidence	Ability to identify scientific phenomena; ability to draw conclusions based on scientific evidence	SL1–SL2; SL3–SL5	5	Zhang et al. (2023)
Scientific Argumentation	Students' perceived ability to construct evidence-supported claims and provide scientific reasoning or justification	Ability to construct claims supported by evidence; ability to explain and connect reasons or justifications	SA1–SA2; SA3–SA5	5	Guo et al. (2026)
Conservation Attitude	Students' concern for environmental preservation and intention to support conservation behavior	Concern for environmental preservation; intention to support conservation behavior	CA1–CA2; CA3–CA5	5	Atik et al. (2022)

Note. DG = Digital Literacy; SL = Science Literacy; SA = Scientific Argumentation; CA = Conservation Attitude.

Digital literacy was measured as students' self-perceived ability to search for digital information and select credible digital sources (Audrin & Audrin, 2022; Son & Ha, 2025). The indicators of digital literacy included the ability to use appropriate keywords, distinguish credible from non-credible digital information sources, use digital platforms to search for relevant information, evaluate source credibility, and verify the authenticity of information. The digital literacy instrument was adapted from Son and Ha (2025).

Science literacy was measured as students' self-perceived ability to identify scientific phenomena and draw conclusions based on scientific evidence (Guerrero & Sjöström, 2025; Zhang et al., 2023). The instrument items included the ability to connect natural phenomena with scientific concepts, distinguish phenomena that can be explained scientifically, draw conclusions based on data, present the results of research or experiments, and evaluate experimental findings based on data. The science literacy instrument was adapted from Zhang et al. (2023).

Scientific argumentation was measured as students' self-perceived ability to formulate claims supported by evidence and to provide scientific reasoning or justification. The instrument items included the ability to formulate claims based on scientific situations, select relevant evidence, explain the relationship between evidence and claims, provide logical scientific justification, and construct reasoning consistent with scientific principles. The scientific argumentation instrument was adapted from Guo et al. (2026).

Conservation attitude was measured through two main indicators: concern for environmental preservation and the intention to support conservation behavior. The instrument items included concern for protecting the environment, concern about environmental degradation, plans to engage in preservation actions, support for conservation programs at school, and willingness to encourage others to participate in nature protection activities. The conservation attitude instrument was adapted from Atik et al. (2022).

The source instruments were supported by prior psychometric evidence. The digital literacy instrument developed by Son and Ha (2025) was validated using Rasch analysis with 1,194 middle and high school students; its person reliability, item reliability, and Cronbach's alpha coefficients were all above 0.80. The scientific literacy instrument developed by Zhang et al. (2023) demonstrated person reliability of 0.87 and item reliability of 0.99, with person and item separation indices of 2.56 and 11.54, respectively. The scientific argumentation items were adapted from the assessment framework developed and empirically applied to 478 students by Guo et al. (2026). Meanwhile, the environmental attitude instrument used by Atik et al. (2022) was administered to 1,794 secondary school students from nine schools.

Because all constructs were measured using Likert-scale questionnaires, digital literacy, science literacy, and scientific argumentation in this study were interpreted as self-reported competencies, or students' perceptions of their own competencies, rather than as outcomes of actual performance tests. Therefore, the findings represent respondents' perceptions of their literacy and scientific argumentation competencies, not direct measurements of actual ability through objective tests or performance-based tasks.

Prior to use, the instrument was reviewed by experts in science education and/or environmental education to ensure construct appropriateness, item readability, clarity of wording, and relevance to the senior high school context. Revisions were made to the wording of items to suit respondents' level of understanding, maintain terminological consistency, and ensure alignment with the context of science learning and environmental conservation. The questionnaire format was standardized to maintain readability, consistency of completion, and suitability for the research context (Elangovan & Sundaravel, 2021; Masuwai et al., 2024).

3.4. Data Collection Technique

Data were collected from 1 to 28 February 2026 using an online questionnaire administered through Google Forms. The questionnaire link was distributed to eligible students via WhatsApp in coordination with school authorities or authorized teachers at the three participating senior high schools in Pangkep Regency. Before participation, students were informed about the study purpose, voluntary participation, data confidentiality, and that their responses would not affect their academic grades. Google Forms facilitated systematic data recording and screening, and all 314 responses met the eligibility and data-quality criteria (Jaeger & Cardello, 2022; Singh & Sagar, 2021).

To minimize the potential for common method bias, this study implemented several procedural measures, including maintaining respondent anonymity, using neutral response instructions, emphasizing that there were no right or wrong answers, ensuring voluntary participation, and assuring students that their responses would not affect their academic grades. In addition to these procedural measures, potential common method bias was statistically evaluated using the full collinearity VIF approach. Full collinearity VIF values below the conservative threshold of 5.00 were used as an indication that common method bias did not substantially distort the model estimates (Becker et al., 2023; Kock, 2017).

3.5. Ethical Considerations

This study was conducted in accordance with the principles of ethical research in education. Prior to data collection, the researchers coordinated with school authorities or authorized teachers. Because the respondents were school students, participation was voluntary after students had received information about the purpose of the study, questionnaire completion procedures, data confidentiality, and their right to discontinue participation.

Students provided informed assent before completing the questionnaire. Data collection was conducted after permission had been obtained from the schools. Because some respondents were under the age of 18, the mechanism for parental or guardian consent followed the policies of the schools and the procedures applicable at the institutions where data collection took place. Permission for data collection was granted by the authorized school authorities before the questionnaire was distributed to students. Respondents' identities were kept confidential, and the data were reported in aggregate form without disclosing the identities of individual students or schools. Students' participation had no consequences for their academic grades or their relationship with the school.

3.6. Data Analysis Technique

Data were analyzed using partial least squares structural equation modeling. The analysis was conducted in two main stages: evaluation of the measurement model and evaluation of the structural model.

The measurement model was evaluated by assessing indicator reliability, internal consistency reliability, convergent validity, and discriminant validity. Indicator loadings were considered adequate when they exceeded 0.60, although values between 0.40 and 0.60 could be retained if they contributed to composite reliability and average variance extracted [AVE] (Hair et al., 2024). Internal consistency reliability was assessed using Cronbach's alpha and composite reliability, with values between 0.60 and 0.95 considered acceptable (Cheung et al., 2024; Hair et al., 2024). Convergent validity was assessed using AVE, with values above 0.50 indicating adequate convergence (Cheung et al., 2024; Hair et al., 2024).

Discriminant validity was tested using the Fornell–Larcker criterion and cross-loadings. Under the Fornell–Larcker criterion, the square root of the AVE for each construct should be higher than its correlations with other constructs (Cheung et al., 2024; Hair et al., 2024; Sarstedt & Moisescu, 2024). In the cross-loading assessment, each indicator should have its highest loading on the construct it is intended to measure compared with its loadings on other constructs (Hair et al., 2024; Ringle et al., 2023).

The structural model was evaluated after the measurement model had met the required criteria. Collinearity among predictor constructs was assessed using the variance inflation factor [VIF], with values below 5.00 indicating the absence of serious multicollinearity problems (Hair et al., 2024). For the assessment of common method bias, full collinearity VIF values were also examined using the conservative threshold of 3.30 (Kock, 2017). The significance of direct and indirect relationships was tested using a bootstrapping procedure with 5,000 resamples (Hair et al., 2024; Sarstedt & Moisescu, 2024). Relationships among variables were considered significant when the t-value exceeded 1.96 and the p-value was below 0.05 (Guenther et al., 2023; Hair et al., 2024). In addition to t-values and p-values, bootstrapping results may also be reported using 95% confidence intervals to strengthen the interpretation of the significance of direct and indirect paths (Sarstedt & Moisescu, 2024).

The explanatory power of the model was evaluated using the coefficient of determination, R^2, to indicate the proportion of variance in endogenous constructs explained by the predictor constructs in the model (Guenther et al., 2023; Hair et al., 2024). In addition to R^2, effect size, or f^2, was used to assess the relative contribution of each predictor construct to the endogenous constructs (Hair et al., 2024; Sarstedt et al., 2024).

The mediating effect of scientific argumentation was evaluated by testing the significance of indirect relationships and determining the type of mediation based on the presence or absence of significant direct relationships. In this study, scientific argumentation was positioned as a potential mediator; therefore, mediation was interpreted based on the significance of the indirect paths, coefficient direction, *t*-values, *p*-values, 95% confidence intervals, and the direct relationships between the predictor variables and conservation attitude. Because this study used a cross-sectional design and all constructs were measured through self-report questionnaires, the interpretation of mediation effects was undertaken cautiously and was not used to infer strong causal mechanisms.

4. Results

The measurement model evaluation showed that all indicators had outer loading values above 0.60, ranging from 0.731 to 0.916. Outer loading values above 0.708 are generally considered satisfactory because they indicate that the construct explains more than 50% of the variance in its indicators (Hair et al., 2024). Therefore, the outer loading values obtained in this study, ranging from 0.731 to 0.916, satisfied the recommended criterion. This indicates that all indicators contributed adequately to reflecting their respective constructs. Cronbach's alpha values ranged from .854 to .937, while composite reliability values ranged from .896 to .952. CR values between .70 and .95 indicate acceptable internal consistency reliability (Cheung et al., 2024; Hair et al., 2024). Digital Literacy (CR = .909), Science Literacy (CR = .896), and Scientific Argumentation (CR = .924) met this criterion. Conservation Attitude had a CR value of .952, which was slightly above the recommended upper limit of .95 and should therefore be interpreted cautiously.

In terms of convergent validity, the average variance extracted [AVE] values for all constructs exceeded .50, namely .667 for Digital Literacy, .632 for Science Literacy, .709 for Scientific Argumentation, and .799 for Conservation Attitude.Therefore, all constructs met the criteria for convergent validity. However, the composite reliability value for the Conservation Attitude construct, at .952, should be interpreted with caution because it slightly exceeded the .95 threshold. This value indicates very strong internal consistency, but it may also suggest potential similarity among items. Accordingly, future studies should consider diversifying the indicators of Conservation Attitude to more broadly capture dimensions of concern, evaluation, responsibility, and conservation intention

Indicator level collinearity was assessed using outer variance inflation factor values. Outer VIF values below 5.00 indicate that critical collinearity among indicators is not present, whereas 3.30 may be applied as a more conservative criterion (Hair et al., 2024; Kock, 2017). The results of construct reliability, convergent validity, and indicator-level collinearity are presented in Table 2.

Table 2
Construct Reliability, Convergent Validity and Indicator Collinearity

Construct	*Item Variable*	*Outer Loading*	*Outer VIF*	*Cronbach's alpha*	*Composite reliability (rho_c)*	*Average variance extracted (AVE)*
Digital Literacy	DG1	0.821	2.367	.874	.909	.667
	DG2	0.841	2.313			
	DG3	0.872	2.671			
	DG4	0.789	1.924			
	DG5	0.755	1.767			
Science Literacy	SL1	0.832	2.134	.854	.896	.632
	SL2	0.731	1.646			
	SL3	0.820	1.940			
	SL4	0.810	1.916			
	SL5	0.779	1.704			
Scientific Argumentation	SA1	0.845	2.390	.897	.924	.709
	SA2	0.876	2.808			
	SA3	0.840	2.291			
	SA4	0.822	2.274			
	SA5	0.826	2.291			
Conservation Attitude	CA1	0.868	2.749	.937	.952	.799
	CA2	0.916	4.453			
	CA3	0.884	3.068			
	CA4	0.915	4.419			
	CA5	0.885	3.210			

Note. CR values between 0.70 and 0.95 indicate acceptable internal consistency reliability, while values above 0.95 may indicate potential indicator redundancy. AVE values above 0.50 indicate adequate convergent validity. Outer VIF values below 5.00 indicate the absence of critical indicator collinearity, whereas 3.30 represents a more conservative criterion (Cheung et al., 2024; Hair et al., 2024; Kock, 2017).

As shown in Table 2, the outer VIF values ranged from 1.646 to 4.453. All values were below the critical threshold of 5.00, indicating that serious collinearity was not present among the indicators. However, CA2 (VIF = 4.453) and CA4 (VIF = 4.419) exceeded the more conservative threshold of 3.30. Therefore, although both indicators remained acceptable based on the VIF < 5.00 criterion, their potential similarity with other Conservation Attitude indicators should be considered when interpreting the measurement model. These indicator-level VIF results complement the structural collinearity assessment presented in Table 5.

The discriminant validity assessment using the Fornell–Larcker criterion showed that the square root of the AVE was 0.817 for Digital Literacy, 0.796 for Science Literacy, 0.842 for Scientific Argumentation, and 0.894 for Conservation Attitude. According to the Fornell–Larcker criterion, discriminant validity is established when the square root of the AVE of a construct is greater than its correlations with the other constructs in the model (Cheung et al., 2024; Hair et al., 2024).

As shown in Table 3, most constructs had square root AVE values that were higher than their correlations with other constructs. However, discriminant validity based on the Fornell–Larcker criterion was not fully established for the relationship between Science Literacy and Scientific Argumentation. The correlation between Science Literacy and Scientific Argumentation was 0.817, which exceeded the square root of the AVE for Science Literacy, 0.796. This finding indicates a degree of empirical overlap between the two constructs.

Table 3
Fornell–Larcker Criterion

Construct	*Digital Literacy*	*Science Literacy*	*Scientific Argumentation*	*Conservation Attitude*
Digital Literacy	.817			
Science Literacy	.719	.796		
Scientific Argumentation	.761	.817	.842	
Conservation Attitude	.771	.625	.593	.894

Note. Diagonal values represent the square roots of AVE.

The cross-loading assessment showed that all indicators had their highest loading values on the constructs they were intended to measure compared with the other constructs (Hair et al., 2024; Ringle et al., 2023). The Digital Literacy indicators loaded most strongly on the Digital Literacy construct, with values ranging from .755 to .872. The Science Literacy indicators loaded most strongly on the Science Literacy construct, with values ranging from .731 to .832. The Scientific Argumentation indicators loaded most strongly on the Scientific Argumentation construct, with values ranging from .822 to .876. The Conservation Attitude indicators loaded most strongly on the Conservation Attitude construct, with values ranging from 0.868 to 0.916.

Nevertheless, several cross-loading values were relatively high, indicating conceptual and empirical proximity among constructs, particularly between Science Literacy and Scientific Argumentation. For example, SA2 had a cross-loading of .725 on Science Literacy, SA1 had a cross-loading of .714 on Science Literacy, and SL4 had a cross-loading of .699 on Scientific Argumentation. These results further support the Fornell–Larcker finding that the two constructs are closely related empirically.

However, because each indicator still showed its highest loading on its intended construct, the cross-loading results support item-level distinction among the constructs. Thus, discriminant validity can be considered adequate based on the cross-loading assessment, although it should still be interpreted with caution because the Fornell–Larcker criterion was not fully satisfied for the pair of Science Literacy and Scientific Argumentation. The detailed cross-loading results are presented in Table 4.

Table 4
Cross-Loadings

	Digital Literacy	*Science Literacy*	*Scientific Argumentation*	*Conservation Attitude*
DG1	.821	.559	.536	.698
DG2	.841	.596	.623	.675
DG3	.872	.615	.616	.744
DG4	.789	.612	.693	.535
DG5	.755	.556	.647	.474
SL1	.622	.832	.654	.517
SL2	.490	.731	.583	.377
SL3	.602	.820	.670	.572
SL4	.590	.810	.699	.451
SL5	.547	.779	.636	.549
SA1	.653	.714	.845	.479
SA2	.689	.725	.876	.574
SA3	.670	.688	.840	.526
SA4	.591	.647	.822	.427
SA5	.591	.659	.826	.478
CA1	.712	.593	.526	.868
CA2	.681	.531	.476	.916
CA3	.686	.594	.579	.884
CA4	.696	.502	.484	.915
CA5	.668	.572	.586	.885

The collinearity statistics assessment showed that all variance inflation factor values were below the threshold of 5.00 (Hair et al., 2024). The VIF values for the paths from Digital Literacy and Science Literacy to Scientific Argumentation were both 1.673. Meanwhile, the VIF values for the paths leading to Conservation Attitude ranged from 2.149 to 3.294. These results indicate that there was no serious multicollinearity problem in the structural model.

However, the VIF value for the path from Scientific Argumentation to Conservation Attitude was 3.294, which was very close to the conservative threshold of 3.30 (Kock, 2017). Therefore, although the model remains acceptable based on the VIF < 5.00 criterion, the relationship between Scientific Argumentation and Conservation Attitude should be interpreted with caution, particularly because Science Literacy and Scientific Argumentation also showed empirical proximity in the Fornell–Larcker assessment.

Table 5
Collinearity Statistics (VIF)

	Digital Literacy	*Science Literacy*	*Scientific Argumentation*	*Conservation Attitude*
Digital Literacy			1.673	2.149
Science Literacy			1.673	2.825
Scientific Argumentation				3.294
Conservation Attitude				

The results of the direct path analysis showed that Digital Literacy was positively and significantly associated with Scientific Argumentation (β = 0.359, t = 6.900, p < .001). The significance of the structural relationships was determined using a two-tailed criterion, with a t-value greater than 1.96 and a p-value below .05 indicating a statistically significant relationship (Guenther et al., 2023; Hair et al., 2024). therefore, H1 was supported. Science Literacy was also positively and significantly associated with Scientific Argumentation (β = 0.558, t = 11.224, p < .001); thus, H2 was supported. These findings indicate that both digital literacy and science literacy are important structural predictors of scientific argumentation, with Science Literacy showing a stronger association than Digital Literacy.

Furthermore, Digital Literacy was positively and significantly associated with Conservation Attitude (β = 0.710, t = 10.523, p < .001); therefore, H3 was supported. Science Literacy was also positively and significantly associated with Conservation Attitude (β = 0.215, t = 3.155, p = .002); thus, H4 was supported. The coefficient for the relationship between Digital Literacy and Conservation Attitude represented the strongest association in the structural model, indicating that Digital Literacy was the most dominant structural predictor of Conservation Attitude.

However, Scientific Argumentation was not significantly associated with Conservation Attitude (β = −0.122, t = 1.624, p = .104); therefore, H5 was not supported. The negative coefficient for this path should not be interpreted as evidence that Scientific Argumentation reduces Conservation Attitude, because the relationship was not statistically significant. Rather, this result indicates that, after controlling for Digital Literacy and Science Literacy in the model, Scientific Argumentation did not provide a meaningful additional explanation of Conservation Attitude. The results of the direct hypothesized paths are summarized in Table 6.

Table 6
Direct Hypothesized Paths

	Original sample (O)	*Sample mean (M)*	*Standard deviation (STDEV)*	*T statistics (|O/STDEV|)*	*P values*
Digital Literacy → Scientific Argumentation	0.359	0.358	0.052	6.900	<.001
Digital Literacy →Conservation Attitude	0.710	0.712	0.067	10.523	<.001
Science Literacy →Scientific Argumentation	0.558	0.560	0.050	11.224	<.001
Science Literacy →Conservation Attitude	0.215	0.218	0.068	3.155	.002
Scientific Argumentation → Conservation Attitude	−0.122	−0.126	0.075	1.624	.104

The indirect path analysis showed that Scientific Argumentation did not mediate the relationship between Digital Literacy and Conservation Attitude. The indirect effect of Digital Literacy on Conservation Attitude through Scientific Argumentation was negative and not statistically significant (β = −0.044, t = 1.633, p = .103); therefore, H6 was not supported.

Scientific Argumentation also did not mediate the relationship between Science Literacy and Conservation Attitude. The indirect effect of Science Literacy on Conservation Attitude through Scientific Argumentation was negative and not statistically significant (β = −0.068, t = 1.557, p = .120); therefore, H7 was not supported.

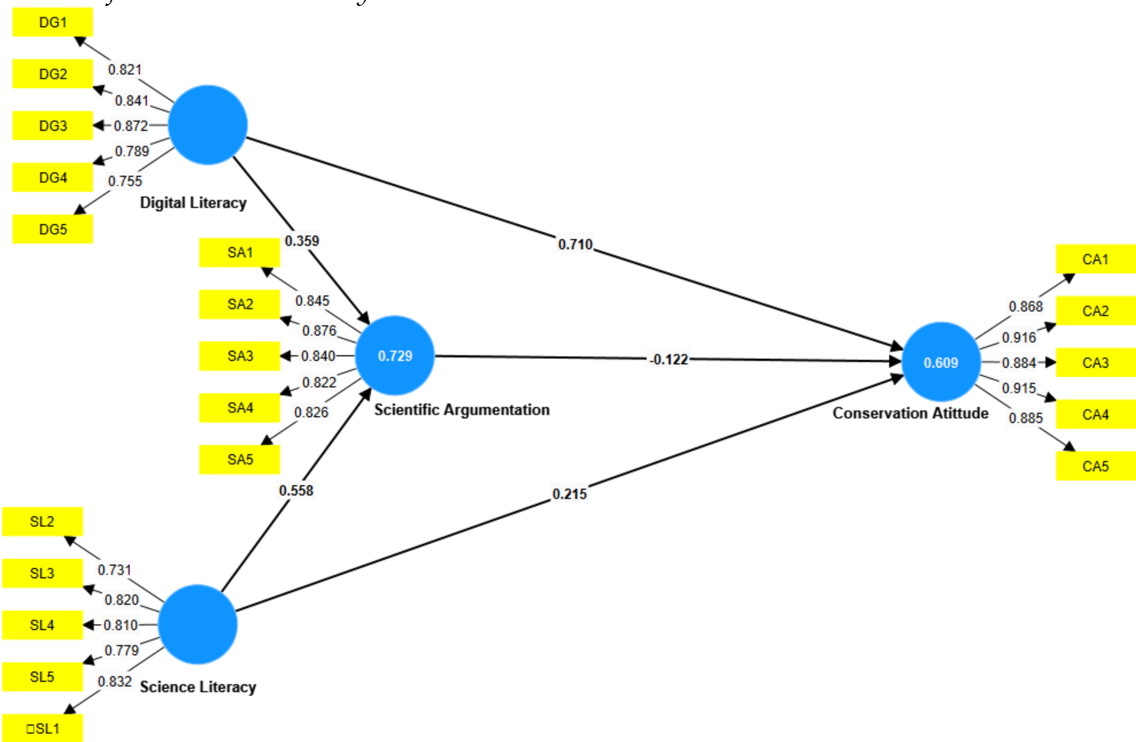
Thus, in this model, the relationships between Digital Literacy and Science Literacy and Conservation Attitude occurred directly, rather than through Scientific Argumentation as a mediator. This finding further supports the interpretation that Scientific Argumentation is better understood as a cognitive outcome of digital literacy and science literacy, rather than as a mediating mechanism linking literacy to conservation attitude. The results of the indirect hypothesized paths are summarized in Table 7.

Table 7
Indirect Hypothesized Paths

	Original sample (O)	*Sample mean (M)*	*Standard deviation (STDEV)*	*T statistics (|O/STDEV|)*	*P values*
Digital Literacy → Scientific Argumentation → Conservation Attitude	−0.044	−0.045	0.027	1.633	.103
Science Literacy → Scientific Argumentation → Conservation Attitude	−0.068	−0.071	0.044	1.557	.120

Figure 2 presents the results of the PLS-SEM structural model, illustrating the relationships among the exogenous and endogenous constructs. The main endogenous constructs showed relatively strong coefficients of determination (R^2). The construct positioned in the middle of the model had an R^2 value of .729, indicating that approximately 72.9% of its variance was explained by its predictor constructs. Meanwhile, the endogenous construct positioned on the right side of the model had an R^2 value of .609, indicating that 60.9% of its variance was explained by the variables included in the model. These values suggest that the explanatory power of the model falls within the moderate to substantial range. The structural path results further indicate meaningful positive relationships among several constructs, as reflected in the path coefficients displayed in the model.

Figure 2
Results of the PLS-SEM Analysis



5. Discussion

The main findings of this study indicate that Digital Literacy and Science Literacy are directly associated with Conservation Attitude, whereas Scientific Argumentation is not significantly associated with Conservation Attitude and does not mediate the relationships between the two forms of literacy and conservation attitude. This pattern suggests that scientific argumentation is more appropriately understood as a cognitive outcome of literacy competencies than as a mechanism that automatically transforms literacy into conservation attitude. Thus, the findings do not indicate a failure of the model; rather, they clarify that the formation of conservation attitude is a multidimensional process that does not depend solely on evidence-based reasoning.

Digital Literacy showed a positive and significant association with Conservation Attitude, with the strongest coefficient in the model. This finding indicates that students' conservation attitudes are closely related to the contemporary ecology of digital information. Students who are more capable of searching for, selecting, verifying, and evaluating digital information are likely to be more frequently exposed to issues of environmental degradation, conservation campaigns, sustainability narratives, and information about ecological risks (Chen et al., 2025; Kresin et al., 2024). Such exposure may strengthen students' concern for and support of environmental preservation. However, the magnitude of this coefficient should be interpreted with caution because all constructs were measured using self-report questionnaires within the same response context. Therefore, the potential influence of common method bias, social desirability bias, and similarity in item wording cannot be entirely dismissed.

The present result is consistent with Chen et al. (2025), who analyzed survey responses from 851 rural residents in Hainan Province using an Ordered Probit model and found that digital literacy promoted eco-friendly behavior partly through improved policy cognition. It is also contextually aligned with Kresin et al. (2024), who examined the criteria students used to evaluate scientific information about climate change on social media, demonstrating the educational relevance of credibility evaluation in digital environments. Although those studies differed from the present study in population, outcome, and analytical method, their common pattern supports the appropriateness of the positive association between Digital Literacy and Conservation Attitude. In the Pangkep context, students who can critically evaluate online environmental information are more likely to recognize local ecological risks and form reasoned support for conservation; nevertheless, the large coefficient should remain interpreted as an association because both constructs were measured through self-report questionnaires.

Science Literacy was also positively and significantly associated with Conservation Attitude, although its coefficient was smaller than that of Digital Literacy. This finding suggests that understanding scientific concepts remains important in shaping students' rational judgments about conservation issues. Through science literacy, students can understand the relationship between human activities and environmental change, including pollution, ecosystem degradation, biodiversity loss, and climate change (Washington et al., 2024). However, the smaller coefficient suggests that formal scientific knowledge alone may not be sufficient to develop conservation attitudes unless it is connected to everyday contexts, local experiences, environmental values, and issues that are personally relevant to students (Molnár et al., 2026; van de Wetering et al., 2022).

Supporting evidence is provided by van de van de Wetering et al. (2022), whose meta-analysis synthesized 169 studies involving 176,007 children and adolescents from 43 countries and found that environmental education significantly improved environmental knowledge and attitudes, although the effect sizes were heterogeneous. Ardoin et al. (2020), through a systematic review of 105 studies, similarly found that environmental education commonly produced cognitive and affective outcomes, particularly when learning was connected to locally relevant issues, partnerships, and action. These findings support the positive association between Science Literacy and Conservation Attitude in the present study while also explaining its smaller coefficient: scientific understanding can contribute to attitude formation, but its influence is likely strengthened when knowledge is connected to locally meaningful and participatory conservation experiences.

Science Literacy had a strong association with Scientific Argumentation. This indicates that the ability to understand scientific concepts, interpret data, and evaluate evidence provides an important foundation for students in formulating claims, reasoning, and scientific justifications (Allchin & Zemplén, 2020; Guo et al., 2026; Osborne et al., 2025). Digital Literacy was also significantly associated with Scientific Argumentation because the ability to access and evaluate digital information can help students obtain relevant evidence for constructing arguments. Thus, both forms of literacy play an important role in strengthening students' cognitive competencies, particularly in the context of evidence-based scientific reasoning.

However, Scientific Argumentation was not significantly associated with Conservation Attitude. The negative coefficient for the path from Scientific Argumentation to Conservation Attitude should not be interpreted as evidence that scientific argumentation reduces conservation attitude, because this path was not statistically significant. Rather, this result indicates that, after controlling for Digital Literacy and Science Literacy in the model, Scientific Argumentation did not provide a meaningful additional explanation of Conservation Attitude. In other words, the ability to formulate claims, use evidence, and provide scientific justification is not necessarily directly associated with stronger conservation attitudes.

The non-significant relationship between Scientific Argumentation and Conservation Attitude can be explained by the differing nature of the two constructs. Scientific Argumentation is a cognitive competence oriented toward the quality of reasoning, the use of evidence, the consistency of explanations, and logical justification (Allchin & Zemplén, 2020; Guo et al., 2026; Osborne et al., 2025). In contrast, Conservation Attitude is an affective-evaluative construct that involves concern, environmental values, personal norms, ecological emotions, direct experience, and connectedness to nature (Castillo-Huitrón et al., 2024; Mikołajczak et al., 2023). Accordingly, students may possess strong scientific argumentation skills but may not necessarily demonstrate emotional engagement, value commitment, or normative readiness to support conservation. A person may be able to reason logically about environmental issues without being personally motivated to support environmental preservation actions (Allchin & Zemplén, 2020; van de Wetering et al., 2022).

The non-significant mediation findings further reinforce this interpretation. Although Digital Literacy and Science Literacy were significantly associated with Scientific Argumentation, this cognitive pathway did not extend significantly to Conservation Attitude. This means that the transformation of evidence-based reasoning into conservation attitude requires additional mechanisms beyond scientific argumentation, such as environmental concern, ecological values, nature connectedness, environmental identity, social norms, direct experience, and participation in conservation activities (Lengieza & Aviste, 2025; Mago et al., 2025; Niemiec et al., 2020). Thus, in this study, scientific argumentation is better understood as a cognitive outcome of literacy, rather than as an attitude-forming mechanism.

Theoretically, this study contributes by demonstrating that Digital Literacy and Science Literacy play dual roles. Both are associated with Scientific Argumentation as a cognitive competence, but they are also directly associated with Conservation Attitude as an affective-evaluative outcome. This finding challenges the linear assumption that increased literacy shapes conservation attitudes primarily through scientific argumentation. Instead, the results suggest that the pathway from literacy to attitude is not always mediated by argumentation, because conservation attitude formation involves knowledge, information evaluation, values, emotions, norms, and experience.

Practically, the findings suggest that science and environmental learning should not be limited to training students to construct scientific arguments. Teachers need to combine evidence-based argumentation activities with value reflection, authentic conservation experiences, and social engagement (Ballard et al., 2024; Molnár et al., 2026). For example, students may be asked to evaluate digital information about coastal ecosystem degradation in Pangkep, distinguish valid information from environmental misinformation, construct data-based arguments, conduct observations of their local environment, design digital conservation campaigns, and reflect on their personal values regarding nature preservation. Approaches such as socioscientific issue-based learning, local conservation projects, citizen science, field observation, reflective value discussion, and argumentation-plus-action projects may help connect scientific reasoning with concern and conservation action (Ballard et al., 2024; Chen et al., 2025; Kumar et al., 2024).

An important implication of these findings is the need to distinguish between cognitive competence and attitudinal formation in conservation education. Scientific Argumentation is important for developing the quality of scientific reasoning, but the formation of Conservation Attitude requires broader engagement, including affective, moral, social, and experiential dimensions (Allchin & Zemplén, 2020; Molnár et al., 2026; Tamar et al., 2021). Therefore, effective conservation learning should not only emphasize conceptual understanding and argumentation, but also integrate authentic experiences, value discussions, ecological concern, and environmental actions that are relevant to students' lives.

6. Conclusion

This study concludes that Digital Literacy and Science Literacy were positively and significantly associated with both Scientific Argumentation and Conservation Attitude among senior high school students, with Digital Literacy emerging as the strongest structural predictor of Conservation Attitude. However, Scientific Argumentation was not significantly associated with Conservation Attitude and did not mediate the relationship between Digital Literacy and Conservation Attitude or between Science Literacy and Conservation Attitude. Therefore, within the tested model, Digital Literacy and Science Literacy were directly associated with Conservation Attitude, whereas Scientific Argumentation was more appropriately interpreted as a cognitive outcome of literacy competencies rather than as a mediating mechanism. These findings indicate that science and environmental learning should integrate digital information evaluation, scientific understanding, value reflection, and authentic conservation experiences to support both evidence-based reasoning and conservation attitudes.

7. Limitations and Directions for Future Research

This study has several limitations. The cross-sectional design limits causal inference, and all data were self-reported, which may introduce bias. Scientific argumentation was measured as perceived competence rather than through performance-based assessments, and the sample was confined to senior high school students in Pangkep Regency, limiting generalizability. Moreover, conservation attitude does not directly reflect actual conservation behavior. Future research should employ longitudinal or experimental designs, incorporate performance-based measures of argumentation, include affective and value-based variables such as environmental concern and nature connectedness, and examine actual conservation behaviors across diverse educational and geographic contexts to enhance the robustness and applicability of findings.

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