

Research Article

Science literacy and digital literacy as predictors of plant awareness: The mediating role of self-regulated learning among biology students

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Plant awareness is an essential component of biology and sustainability education, yet it remains relatively underdeveloped because plants are often overlooked in both formal learning contexts and everyday life. This study aimed to examine the relationships among science literacy, digital literacy, self-regulated learning, and plant awareness among 513 active biology students from higher education institutions in Eastern Indonesia. A quantitative cross-sectional survey design was employed. Data were collected through an online questionnaire administered via Google Forms and distributed through WhatsApp, and were analyzed using Partial Least Squares Structural Equation Modeling. The findings showed that science literacy and digital literacy were positively associated with self-regulated learning and plant awareness. Self-regulated learning was also positively associated with plant awareness and served as a partial mediator in the relationships between both forms of literacy and plant awareness. The mediation model provided a stronger conceptual explanation of how literacy resources are translated into plant awareness, although the direct-effects model showed slightly better predictive accuracy. These findings imply that efforts to strengthen plant awareness should not rely only on biology content delivery, but should also integrate science literacy, digital literacy, and self-regulated learning into contextual learning activities, campus-based plant conservation programs, and higher education policies that support digital, reflective, and sustainability-oriented biology learning.

Keywords: Digital literacy; Plant awareness; Plant blindness; Science literacy; Self-regulated learning

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1. Introduction

Plant awareness is increasingly recognized as a strategic issue in higher education because plants constitute a fundamental basis for the sustainability of life through their roles in oxygen production, food security, human health, climate regulation, and the stability of global ecosystems

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(Kim et al., 2024). Nevertheless, previous studies have shown that modern society, including university students, tends to pay less attention to the existence and functions of plants than to animals or other environmental issues that are more visually salient (Pany et al., 2024). This phenomenon is often associated with plant blindness, namely the tendency to overlook plants as central components of the biosphere. In the present study, the term plant awareness is used to refer to students' attention, understanding, concern, sensitivity, and action orientation toward plants (Stagg et al., 2025). This term was chosen to emphasize the strengthening of positive awareness of plants, rather than merely highlighting an attentional deficit, as is commonly discussed in the concept of plant blindness. The use of plant awareness is also more consistent with emerging international discourse that increasingly avoids disability-based metaphors and instead emphasizes the enhancement of attention to, and appreciation for, the plant world. In an era marked by climate change, deforestation, biodiversity loss, and growing pressure on natural resources, low plant awareness is no longer merely a pedagogical concern, but also a socio-ecological challenge that may hinder the achievement of sustainable development agendas (Parsley, 2020). Therefore, universities have a strategic responsibility to cultivate a generation that is not only knowledgeable but also ecologically aware of the importance of plants.

Biology students represent a particularly relevant population for this study because they have greater academic opportunities to learn about plants through coursework, laboratory practice, field observation, and scientific activities related to biodiversity, ecology, botany, plant physiology, and conservation (Stagg et al., 2025; Stagg & Dillon, 2025). In addition, biology students may become future educators, researchers, conservation practitioners, learning media developers, or agents of environmental literacy in society. However, participation in biology education does not automatically guarantee the development of strong attention to, and concern for, plants, particularly when university biology learning remains centered on concept memorization, taxonomic recognition, morphological description, and laboratory procedures without systematically encouraging students' independent exploration, ecological reflection, digital inquiry, and direct engagement with local plant environments (Guerra et al., 2024; Parsley, 2020). This condition indicates a gap between the expected direction of higher education policies, which increasingly emphasize independent learning, contextual learning experiences, digital transformation, and sustainability-oriented competencies, and the actual learning practices that do not always explicitly position plant awareness as a measurable educational outcome. Accordingly, plant awareness among biology students needs to be examined as a specific educational outcome, rather than assumed to be an automatic consequence of their involvement in the field of biology (Pany et al., 2024; Stagg et al., 2025).

Strengthening plant awareness requires an approach that goes beyond conventional knowledge transmission. Contemporary literature indicates that environmental awareness is shaped by literacy capacities that enable individuals to understand information, evaluate its validity, and use it in decision-making (Guerrero & Sjöström, 2025; Kumar et al., 2024; Landolfi, 2023). In this context, science literacy becomes an important determinant because it equips students with the ability to explain biological phenomena, understand systemic relationships among ecosystem components, and evaluate scientific evidence rationally (Fortus et al., 2022; Zivan & Tsabari, 2025). Students with stronger science literacy are more likely to understand the role of photosynthesis in carbon mitigation, the function of plants in food webs, and the ecological consequences of flora degradation. Thus, science literacy is conceptually associated with the development of plant awareness through the enhancement of evidence-based ecological understanding, rather than through a causal relationship that can be directly inferred from a cross-sectional survey design.

At the same time, the digitalization of education has transformed the landscape of learning and knowledge production. Current technological developments, including learning management systems, mobile learning applications, artificial intelligence-assisted search tools, virtual herbaria, plant identification applications, biodiversity databases, ecological simulations, and social media-based conservation campaigns, have expanded students' opportunities to encounter plant-related

information beyond classroom and laboratory settings (Audrin & Audrin, 2022; Coşkunserçe, 2024; Hackel et al., 2026). Digital literacy is now understood as a multidimensional ability to access, evaluate, integrate, and create information through digital technologies (Audrin & Audrin, 2022; Johnston, 2020). For students, digital literacy provides access to botanical databases, virtual herbaria, species identification applications, ecological simulations, and social media-based conservation campaigns (Coşkunserçe, 2024). Exposure to this digital information ecosystem has the potential to broaden students' perspectives and strengthen their sensitivity to plant-related issues. However, the availability of technology does not necessarily lead to meaningful learning. Without self-directed learning capacities, students may become trapped in superficial information consumption, misinformation, or passive engagement (Alanoglu et al., 2025; Diepeveen & Pinet, 2022). Therefore, the role of lecturers and prospective biology teachers becomes crucial in cultivating digital literacy and guiding the purposeful use of digital technology in biology learning. This role is closely related to educators' technology self-efficacy (Çengel & Acar, 2026), because teachers who believe in their ability to integrate technology are more likely to design meaningful digital learning practices, facilitate students' critical use of digital resources, and connect digital information with authentic biological problems (Uluçınar & Sezer, 2026). This argument is supported by Anwar et al. (2024), who emphasized that technology self-efficacy mediates digital technology practices among teachers in the Industrial Revolution 4.0 context. Therefore, digital literacy should be understood not merely as a technical ability to use digital devices, but also as the capacity to critically select, evaluate, and utilize digital information in developing ecological understanding of plants.

From this perspective, self-regulated learning becomes a highly relevant mechanism. Self-regulated learning refers to students' ability to set learning goals, plan strategies, monitor progress, manage motivation, and reflect on learning outcomes independently (Brandmo et al., 2020). In digital and multi-source learning environments, effective regulation is particularly important because learners must make strategic decisions about how they select, process, integrate, and revisit information. More successful learners tend to demonstrate more purposeful planning, monitoring, and strategic engagement with multiple sources, while research in distance learning similarly emphasizes the importance of adaptive self-regulatory strategies for effective learning (Aksela et al., 2025; Arrafii et al., 2025). Within the present framework, science literacy provides capacities for critically interpreting scientific information and making informed judgments about science-related issues, while digital environments expand the range of information and learning resources with which students can engage (Landolfi, 2023). However, these two forms of literacy do not automatically develop into plant awareness without a process of self-regulation that helps students select relevant information, organize knowledge, monitor understanding, and connect knowledge about plants with ecological responsibility (Danişman et al., 2023). Thus, self-regulated learning can be positioned as a psychopedagogical mechanism that explains how literacy resources may be translated into plant awareness.

Although the relationships among science literacy, digital literacy, and educational outcomes have been widely examined (Rudolph, 2023), several important gaps remain. First, most studies in environmental education continue to position environmental attitude, ecological literacy, or pro-environmental behavior as the main outcomes, whereas plant awareness as a more specific outcome has received relatively limited attention (Stagg et al., 2025). In fact, low attention to plants may hinder students' understanding of biodiversity, flora conservation, ecosystem functions, and environmental sustainability (Parsley, 2020; Stagg & Dillon, 2025). Second, studies that integrate science literacy and digital literacy within a single structural model to explain plant awareness remain limited. This gap becomes more important in the current digital learning era because access to plant-related digital information is increasing rapidly, but empirical evidence remains limited regarding whether students' science literacy and digital literacy are associated with their awareness of plants. Third, the mediating role of self-regulated learning in explaining the relationships between these two forms of literacy and plant awareness has not been widely tested

empirically, particularly among biology students in developing-country contexts (Lan et al., 2025; Pany et al., 2024). Fourth, existing policy directions toward independent, digital, and sustainability-oriented learning have not been sufficiently examined in relation to plant awareness as a specific outcome of biology education. These gaps indicate the need for a more comprehensive analytical framework to explain how scientific competence, digital competence, and self-regulated learning are associated with the development of plant awareness in higher education.

Based on these arguments, this study aims to analyze the structural relationships among science literacy, digital literacy, self-regulated learning, and plant awareness among biology students in Eastern Indonesia using a PLS-SEM approach. Specifically, this study compares a mediation model that includes self-regulated learning as a mediator with a direct-effects model without the mediator in order to assess the contribution of self-regulated learning as an explanatory mechanism in the development of plant awareness. The main novelty of this study lies in the development of an integrative model that combines scientific competence, digital competence, and self-regulated learning to explain plant awareness as a strategic outcome of biology education. Theoretically, this study extends the literature on ecological awareness by focusing on plants as objects that have often been marginalized in environmental education research. Practically, the findings are expected to provide a basis for designing biology curricula, digital learning strategies, lecturer-guided technology integration, campus-based plant conservation activities, and higher education policies that more effectively foster students' awareness of the importance of plants for the sustainability of life.

2. Conceptual Framework and Hypothesis Development

This study develops a conceptual model that explains the relationships among science literacy, digital literacy, self-regulated learning, and plant awareness among biology students (Figure 1). The model positions science literacy and digital literacy as exogenous constructs, self-regulated learning as a mediator, and plant awareness as an endogenous construct. The conceptual framework is grounded in social cognitive theory and self-regulated learning theory, which explain that students' awareness and learning behavior are shaped through the interaction between personal cognitive resources, digital information environments, and self-regulatory processes (Eliyahu & Bernacki, 2026). Thus, this section focuses on the theoretical basis for the relationships among the constructs, while the technical explanation of PLS-SEM procedures is presented in the methodology section.

In this study, plant awareness refers to students' attention, ecological understanding, conservation concern, sensitivity, and action orientation toward plants (Pany et al., 2024). These five dimensions show that plant awareness is not treated merely as knowledge about plant structures or plant names, but as a more specific educational outcome that includes cognitive, affective, and action-oriented aspects. This construct is positioned as a specific outcome of biology education because attention to plants is often lower than attention to animals or other environmental issues that are more easily observed (Parsley, 2020). Although previous studies on plant blindness and plant awareness have emphasized the problem of low attention to plants, they have not sufficiently explained how students' literacy resources and learning regulation may support the development of such awareness. Thus, plant awareness does not merely indicate students' knowledge of plants, but also reflects their capacity to recognize the ecological, social, and conservation value of plants in human life and ecosystem sustainability (Stagg et al., 2025).

Science literacy refers to students' ability to understand scientific concepts, evaluate evidence, apply scientific reasoning, and relate scientific knowledge to real-world issues (Fortus et al., 2022; Landolfi, 2023). In the context of this study, the scope of science literacy includes students' ability to understand biological concepts, interpret scientific information, evaluate evidence, and connect scientific explanations with ecological problems related to plants. In biology learning, science literacy helps students understand the role of plants in photosynthesis, the carbon cycle, food webs, biodiversity, ecosystem stability, and conservation (Eriksson et al., 2026). Studies on science

literacy have shown that scientific reasoning and evidence evaluation are important for meaningful learning; however, these studies often discuss science literacy as a broad educational competence rather than linking it specifically to plant awareness. Students with stronger science literacy are likely to possess a stronger cognitive foundation for managing their learning independently because they are better able to understand conceptual structures, evaluate evidence, and monitor the development of their own understanding (Doshi et al., 2024). Science literacy and self-regulated learning can be viewed as closely related cognitive resources, as understanding scientific concepts and evaluating evidence interact conceptually with learners' capacity to monitor and regulate their own understanding (Asiedu Menlah & Boateng, 2025; Landolfi, 2023). Therefore, science literacy may support self-regulated learning because students who understand scientific concepts and evidence are more prepared to set learning goals, select relevant sources, and evaluate their own understanding.

H1: Science literacy is positively associated with self-regulated learning.

Digital literacy refers to students' ability to access, evaluate, manage, integrate, and use information through digital technologies (Govender, 2025). In this study, digital literacy is limited to educational and scientific uses of digital technology, including the ability to access digital learning resources, evaluate the credibility of online information, manage digital materials, and use digital tools to support biology learning. In biology learning, digital literacy enables students to access scientific articles, botanical databases, digital herbaria, instructional videos, plant identification applications, ecological simulations, and online conservation resources (Sánchez, 2020). Previous studies have emphasized the importance of digital literacy in learning, but they also indicate that digital access alone does not guarantee deep understanding when students lack the ability to evaluate information and regulate their learning processes. This ability may support self-regulated learning because digitally literate students are better able to locate relevant learning resources, organize tasks, select learning strategies, monitor their progress, and evaluate the quality of information (Ramdana et al., 2026). Accordingly, digital literacy is theoretically connected to self-regulated learning because students who can use digital resources critically are more likely to manage their learning independently and strategically.

H2: Digital literacy is positively associated with self-regulated learning.

Science literacy is also expected to be directly associated with plant awareness. Students who understand biological and ecological concepts more effectively are more likely to recognize the functions of plants in supporting life, maintaining ecosystem balance, and sustaining environmental resilience (Oliver & Adkins, 2020). Such scientific understanding helps students view plants not as passive objects, but as central components of the biosphere that play essential roles in food systems, climate regulation, health, and biodiversity conservation (Stagg et al., 2025; Stroud et al., 2022). This argument is important because plant awareness requires more than visual attention to plants; it also requires students to understand why plants are scientifically and ecologically significant. Although plant awareness research has documented the tendency of students to overlook plants, fewer studies have examined whether science literacy provides a cognitive pathway for strengthening students' concern and sensitivity toward plants. Thus, science literacy can serve as an important foundation for the development of attention to, and concern for, plants.

H3: Science literacy is positively associated with plant awareness.

Digital literacy is expected to be directly associated with plant awareness because access to, and use of, digital information can broaden students' learning experiences related to plants (Audrin & Audrin, 2022). Students with stronger digital literacy can explore digital resources concerning species identification, flora conservation, habitat change, extinction threats, and plant conservation practices (Coşkunserçe, 2024; Shi et al., 2023). In the present study, this relationship is understood through the role of digital resources in making plant-related information more visible, accessible, and connected to students' everyday learning contexts. However, the contribution of digital

literacy to plant awareness does not depend solely on the amount of information accessed, but also on students' ability to assess source credibility, connect digital information with ecological contexts, and use technology to deepen their understanding of plants (Kiili et al., 2022). This critical point addresses the limitation of previous digital literacy studies, which often focus on students' technical ability to use digital tools without sufficiently examining how such ability may contribute to specific ecological outcomes such as plant awareness. Therefore, digital literacy is expected to be positively associated with plant awareness.

H4: Digital literacy is positively associated with plant awareness.

Self-regulated learning refers to students' ability to set learning goals, plan strategies, monitor progress, manage motivation, evaluate outcomes, and reflect on the learning process independently (Theobald, 2021). The scope of self-regulated learning in this study includes goal setting, learning planning, strategy use, monitoring of understanding, persistence, self-evaluation, and reflection. In the context of plant awareness, students with stronger self-regulated learning are more likely to actively seek additional information about plants, connect biological concepts with environmental phenomena, and reflect on the importance of plants for sustainability (Stagg et al., 2025). Self-regulated learning is therefore positioned as a learning process that enables students to transform scientific and digital information into meaningful ecological awareness. Self-regulation enables students to move beyond merely knowing information about plants toward a more reflective and meaningful understanding. Although self-regulated learning has been widely examined in relation to academic achievement, its role in explaining specific environmental and plant-related awareness remains underexplored. Therefore, self-regulated learning is expected to be positively associated with plant awareness.

H5: Self-regulated learning is positively associated with plant awareness.

In this model, self-regulated learning is positioned as a mediator because science literacy and digital literacy provide cognitive and informational resources, but these resources do not automatically develop into plant awareness. Students require self-regulatory processes to set learning goals, select relevant sources, monitor understanding, evaluate information, and connect knowledge about plants with ecological responsibility (Theobald, 2021). In other words, science literacy helps students understand the scientific foundations of plant-related knowledge, while digital literacy expands access to information and learning resources (Fortus et al., 2022). However, both forms of literacy may remain fragmented if students do not regulate how information is selected, organized, interpreted, and reflected upon. Self-regulated learning then functions as a psychopedagogical mechanism that governs how these resources are selected, processed, internalized, and translated into plant awareness (Stagg et al., 2025).

Conceptually, students with strong science literacy are better able to understand scientific information about plants (Fortus et al., 2022). Nevertheless, scientific understanding does not automatically become plant awareness unless students actively monitor their comprehension, evaluate the meaning of scientific information, and connect that information with ecological responsibility. Through self-regulated learning, students can deepen conceptual understanding, monitor their comprehension, and reflect more purposefully on the ecological meaning of plants (Theobald, 2021). Thus, self-regulated learning provides a theoretical bridge between science literacy as a cognitive resource and plant awareness as an ecological educational outcome. Therefore, self-regulated learning is expected to mediate the relationship between science literacy and plant awareness.

H6: Self-regulated learning mediates the relationship between science literacy and plant awareness.

Similarly, students with strong digital literacy have broader access to information about plants, but digital access does not necessarily lead to deep awareness unless it is accompanied by the ability to regulate learning. Self-regulated learning helps students select credible digital information, organize knowledge, evaluate understanding, and connect digital information with

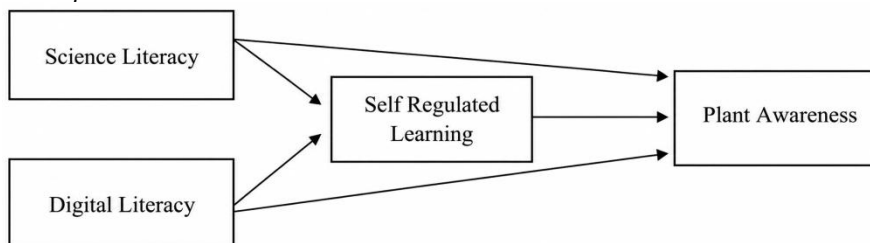
issues of conservation and plant sustainability (Kiili et al., 2022; Stagg et al., 2025). This mediation pathway is theoretically important because digital literacy may expose students to botanical and ecological information, while self-regulated learning determines whether such information is critically processed and transformed into awareness. Therefore, self-regulated learning is expected to mediate the relationship between digital literacy and plant awareness.

H7: Self-regulated learning mediates the relationship between digital literacy and plant awareness.

Based on these hypotheses, the conceptual model of this study examines two main pathways in the development of plant awareness: the direct pathways from science literacy and digital literacy to plant awareness, and the indirect pathways through self-regulated learning. Thus, self-regulated learning is not positioned as the sole explanation for plant awareness, but as a partial mediator that helps explain how scientific competence and digital competence are associated with increased student awareness of plants (Theobald, 2021). The proposed framework therefore contributes to plant awareness literature by integrating three interrelated domains: cognitive competence through science literacy, informational competence through digital literacy, and learning-process competence through self-regulated learning. The conceptual framework is presented in Figure 1.

Figure 1

Conceptual Framework



3. Methods

3.1. Research Design

This study employed a quantitative cross-sectional survey design with an explanatory-predictive orientation. This design was selected because the study examined the structural relationships among science literacy, digital literacy, self-regulated learning, and plant awareness at one period of data collection. The explanatory orientation was used to understand how science literacy and digital literacy were associated with plant awareness, both directly and indirectly through self-regulated learning, whereas the predictive orientation was used to assess the explanatory and predictive relevance of the proposed PLS-SEM model.

The research model positioned science literacy and digital literacy as exogenous variables, self-regulated learning as a mediating variable, and plant awareness as an endogenous variable. The use of a cross-sectional survey was appropriate because the study aimed to collect data from a relatively large number of biology students efficiently and to test theory-based relationships among latent constructs. However, because the data were collected at one point in time, the relationships identified in this study were interpreted as structural and predictive associations rather than causal effects.

3.2. Participants

This study employed a purposive-convenience sampling technique. Purposive sampling was used because the respondents had to meet specific criteria relevant to the research objectives, namely being active students in Biology or Biology Education Study Programs and having academic learning experience related to biology, plants, ecology, biodiversity, or environmental science. Convenience sampling was also applied because access to respondents depended on institutional coordination, lecturer networks, student organizations, class-based communication groups, and

students' willingness to complete the online questionnaire. Therefore, this study did not use probability or random sampling because a complete sampling frame of all biology students in Eastern Indonesia was not available to the researchers.

The population of this study consisted of active undergraduate students enrolled in Biology or Biology Education Study Programs at higher education institutions in Eastern Indonesia. The participating universities were selected based on four considerations: they were located in Eastern Indonesia, had active Biology or Biology Education Study Programs, offered courses related to plants, ecology, biodiversity, or environmental science, and were accessible for academic coordination during the data collection period. These considerations ensured that the selected institutions were relevant to the research problem and that the respondents had sufficient academic exposure to plant-related learning.

The inclusion criteria were as follows: respondents had to be active biology students, had taken or were taking courses related to biology, plants, ecology, biodiversity, or environmental science, and agreed to participate voluntarily. Students from non-biology study programs were excluded. A total of 513 biology students participated in the study, and all valid responses were included in the analysis after data screening. The respondents consisted of 86.2% female students and 13.8% male students. Because this study used purposive-convenience sampling, the findings should be interpreted in relation to active biology students who met the inclusion criteria and should not be generalized statistically to all university students in Eastern Indonesia.

3.3. Instruments

The instrument used in this study was a closed-ended questionnaire developed based on four research constructs: science literacy, digital literacy, self-regulated learning, and plant awareness. The questionnaire was designed to measure students' perceptions, abilities, and learning tendencies related to the variables examined in the conceptual model. All items were measured using a five-point Likert scale, ranging from 1 = strongly disagree to 5 = strongly agree.

Table 1 presents the structure of the research instrument, including the measured construct, scope of indicators, number of items, and measurement scale.

Table 1
Research Instrument Structure

<i>Construct</i>	<i>Scope of Indicators</i>	<i>Number of Items</i>	<i>Scale</i>
Science Literacy	Understanding scientific concepts, evaluating evidence, applying scientific reasoning, and relating scientific knowledge to biological and ecological issues	7	Five-point Likert scale
Digital Literacy	Accessing digital resources, evaluating digital information, managing digital materials, integrating information, and using digital technology for biology learning	6	Five-point Likert scale
Self-Regulated Learning	Goal setting, learning planning, strategy use, monitoring, persistence, self-evaluation, and reflection	10	Five-point Likert scale
Plant Awareness	Attention to plants, ecological understanding, conservation concern, sensitivity to the presence of plants, and action orientation toward plant conservation	5 final items	Five-point Likert scale

The plant awareness construct was initially developed with seven indicators. After the measurement model evaluation, two indicators were removed because they did not meet the required loading criteria and did not improve the reliability and validity of the construct. The final plant awareness construct retained five indicators representing attention to plants, ecological understanding, conservation concern, sensitivity to the presence of plants, and action orientation.

The questionnaire was validated through expert judgment and readability review. Expert validation was conducted to assess the relevance of each item to the construct being measured, the suitability of the indicators, and the clarity of the language used in the questionnaire. The

readability review was conducted to ensure that respondents could understand the items appropriately. Although a separate limited pilot test was not conducted before the main data collection, the psychometric quality of the instrument was further evaluated through PLS-SEM measurement model analysis, including outer loadings, Cronbach's alpha, composite reliability, Average Variance Extracted, cross loadings, and the Heterotrait-Monotrait Ratio.

3.4. Data Collection

Data were collected online using Google Forms from February to April 2026. The online questionnaire link was distributed through official academic networks, lecturer coordination, student organizations, and class WhatsApp groups in the selected Biology Study Programs. WhatsApp was used because it is widely used by students, enables rapid communication, supports access across different locations, and is practical for reaching respondents in Eastern Indonesia.

Before completing the questionnaire, respondents received an introductory statement explaining the purpose of the study, the voluntary nature of participation, the estimated completion time, confidentiality of the data, and their right to withdraw before submitting the questionnaire. Respondents' identities were not collected or presented in the report. The data were analyzed in aggregate form and used only for academic purposes.

Several procedures were applied to improve data quality. First, the questionnaire was set so that each account could submit only one response. Second, all items were made mandatory to avoid missing data. Third, screening questions were used to ensure that respondents met the inclusion criteria. Fourth, reminders were sent periodically during the data collection period. Fifth, responses were screened after data collection to identify duplicate responses, extreme identical response patterns, inconsistent responses, and irrational outliers. These procedures were used to strengthen the accountability of online data collection.

3.5. Data Analysis

Data were analyzed using Partial Least Squares Structural Equation Modeling [PLS-SEM]. PLS-SEM was selected because the study examined latent constructs, direct and indirect relationships, mediation effects, and predictive relevance within an explanatory-predictive model. PLS-SEM is suitable for research oriented toward explaining the variance of endogenous constructs, testing relationships among latent variables, examining mediation effects, and comparing structural model configurations (Ismail, Hala, et al., 2026; Ismail, Jamaluddin, et al., 2026). The analysis was conducted in two main stages: measurement model evaluation and structural model evaluation.

The measurement model was evaluated using outer loadings, Cronbach's alpha, composite reliability, Average Variance Extracted, cross loadings, and the Heterotrait-Monotrait Ratio. Outer loadings of .60 or higher were considered acceptable when the indicators had conceptual relevance and the construct reliability and validity remained adequate. Cronbach's alpha and composite reliability values of .70 or higher were used to indicate internal consistency reliability. Average Variance Extracted values of .50 or higher were used to indicate convergent validity. Discriminant validity was assessed using cross loadings and HTMT values, with HTMT values below .90 considered acceptable (Hair & Alamer, 2022).

The structural model was evaluated using the Variance Inflation Factor, path coefficients, coefficient of determination, predictive relevance, and mediation testing. VIF values below 3.30 were used to indicate that there was no serious collinearity problem among the predictor constructs (Kock, 2015). The significance of direct and indirect effects was examined using bootstrapping with 5,000 subsamples at a significance level of $p < .05$. A relationship was considered significant when the t-statistic was greater than 1.96 and the p -value was below .05 (Hair & Alamer, 2022).

Because this study used a self-report questionnaire at a single point in time, common method bias was also considered. Procedurally, the questionnaire used neutral instructions, assured anonymity, avoided right-or-wrong answer framing, and separated constructs into different

sections. Statistically, collinearity was examined through VIF values. However, because a full collinearity VIF test specifically for common method bias was not calculated separately, the possibility of common method bias is acknowledged as a limitation of the study.

The comparison between the mediation model and the direct-effects model was conducted using R^2 , $Q^2_{predict}$, RMSE, MAE, and the significance of the indirect effects. The mediation model included self-regulated learning as a mediator, whereas the direct-effects model excluded the mediator. This comparison was used to determine whether self-regulated learning strengthened the conceptual explanation of the relationships between science literacy, digital literacy, and plant awareness.

4. Results

4.1. Measurement Model: Reliability and Validity of the Scales

Table 2 presents the results of the measurement model evaluation for science literacy, digital literacy, self-regulated learning, and plant awareness. The table also includes the criteria used to determine whether each construct met the required standards for indicator reliability, internal consistency reliability, convergent validity, and indicator-level collinearity.

Table 2

Construct Reliability, Validity, dan Indicator VIF

Construct and Item Variable	Outer Loadings	Indicator VIF	Cronbach's alpha	Composite reliability	AVE
Science Literacy			.865	.896	.551
SL1	.721	3.706			
SL2	.757	3.917			
SL3	.752	1.400			
SL4	.706	1.464			
SL5	.750	1.575			
SL6	.741	1.662			
SL7	.767	1.885			
Digital Literacy			.834	.879	.549
DL1	.799	1.659			
DL2	.818	1.484			
DL3	.651	1.390			
DL4	.683	1.655			
DL6	.741	1.913			
DL7	.739	1.763			
Self Regulated Learning			.892	.912	.509
SRL1	.691	1.963			
SRL2	.769	2.248			
SRL3	.765	2.068			
SRL4	.760	1.789			
SRL5	.694	1.706			
SRL6	.748	1.995			
SRL7	.612	2.080			
SRL8	.653	2.250			
SRL9	.738	2.321			
SRL10	.687	1.744			
Plant Awareness			.782	.851	.535
PA1	.723	1.915			
PA2	.784	1.482			
PA3	.723	1.855			
PA6	.725	2.025			
PA7	.697	1.435			

As shown in Table 2, all retained indicators had outer loading values ranging from .612 to .818, exceeding the minimum acceptable threshold of .60. Several indicators, namely DL3, DL4, SRL7, SRL8, SRL10, and PA7, had loading values between .60 and .70. These indicators were retained because they remained conceptually relevant to their constructs and did not reduce the overall reliability and validity of the measurement model.

The internal consistency reliability of all constructs was satisfactory. Cronbach's alpha values ranged from .782 to .892, while composite reliability values ranged from .851 to .912. These values exceeded the recommended threshold of .70, indicating that each construct had adequate internal reliability. The AVE values ranged from .509 to .551, exceeding the minimum threshold of .50, which confirmed convergent validity.

The indicator VIF values generally indicated acceptable indicator-level collinearity. Most indicator VIF values were below the conservative threshold of 3.30. However, two science literacy indicators, SL1 and SL2, had VIF values of 3.706 and 3.917, respectively. Although these values exceeded the conservative threshold of 3.30, they remained below the general threshold of 5.00. Therefore, the level of indicator collinearity was not considered severe. SL1 and SL2 were retained because their outer loadings were adequate and the science literacy construct met the required reliability and convergent validity criteria. Overall, the measurement model demonstrated adequate indicator reliability, internal consistency reliability, convergent validity, and acceptable indicator-level collinearity.

4.2. Discriminant Validity

Table 3 presents the results of discriminant validity testing using the Heterotrait–Monotrait Ratio. HTMT was used to examine whether the constructs were empirically distinct from one another.

Table 3
HTMT Results

<i>Construct</i>	<i>Science Literacy</i>	<i>Digital Literacy</i>	<i>Self Regulated Learning</i>	<i>Plant Awareness</i>
Science Literacy				
Digital Literacy	.696			
Self Regulated Learning	.631	.666		
Plant Awareness	.640	.674	.694	

As presented in Table 3, the HTMT values ranged from .631 to .696. The HTMT value between science literacy and digital literacy was .696, between science literacy and self-regulated learning was .631, between digital literacy and self-regulated learning was .666, between science literacy and plant awareness was .640, between digital literacy and plant awareness was .674, and between self-regulated learning and plant awareness was .694. All values were below the recommended threshold of .90. These findings indicate that the constructs were empirically distinct from one another and that the measurement model met the requirement for discriminant validity based on the HTMT criterion.

Table 4 presents the cross-loading results for all retained indicators. Cross-loading analysis was conducted to verify whether each indicator loaded more strongly on its intended construct than on the other constructs in the model. As shown in Table 4, all indicators had their highest loading values on their intended constructs compared with the other constructs in the model. The science literacy indicators loaded most strongly on science literacy, the digital literacy indicators loaded most strongly on digital literacy, the self-regulated learning indicators loaded most strongly on self-regulated learning, and the plant awareness indicators loaded most strongly on plant awareness. These results further support the discriminant validity of the measurement model.

4.3. Collinearity and Predictive Relevance

Table 5 presents the structural collinearity results based on the Variance Inflation Factor. While Table 1 reports indicator-level VIF, Table 4 reports construct-level VIF for the predictor variables in the structural model.

Table 4
Cross Loading

<i>Item Variable</i>	<i>Science Literacy</i>	<i>Digital Literacy</i>	<i>Self Regulated Learning</i>	<i>Plant Awareness</i>
SL1	.721	.484	.472	.384
SL2	.757	.444	.452	.411
SL3	.752	.499	.547	.445
SL4	.706	.361	.307	.349
SL5	.750	.392	.342	.332
SL6	.741	.413	.376	.352
SL7	.767	.475	.414	.468
DL1	.434	.799	.456	.434
DL2	.415	.818	.458	.394
DL3	.401	.651	.336	.334
DL4	.448	.683	.374	.406
DL6	.446	.741	.506	.468
DL7	.518	.739	.435	.379
SRL1	.362	.431	.691	.438
SRL2	.402	.483	.769	.420
SRL3	.444	.444	.765	.454
SRL4	.466	.471	.760	.393
SRL5	.519	.421	.694	.417
SRL6	.454	.472	.748	.409
SRL7	.327	.350	.612	.397
SRL8	.300	.298	.653	.426
SRL9	.412	.444	.738	.365
SRL10	.367	.314	.687	.412
PA1	.425	.386	.428	.723
PA2	.341	.392	.482	.784
PA3	.327	.379	.439	.723
PA6	.448	.387	.371	.725
PA7	.412	.456	.391	.697

Table 5
Collinearity statistics

<i>Predictor Construct</i>	<i>Endogeneous Construct</i>	<i>VIF</i>	<i>Criterion</i>	<i>Decision</i>
Science Literacy	Self Regulated Learning	1.558	< 3.30	Accepted
Digital Literacy	Self Regulated Learning	1.558	< 3.30	Accepted
Science Literacy	Plant Awareness	1.700	< 3.30	Accepted
Digital Literacy	Plant Awareness	1.800	< 3.30	Accepted
Self Regulated Learning	Plant Awareness	1.721	< 3.30	Accepted

Table 5 shows that all VIF values ranged from 1.558 to 1.800, which were below the conservative threshold of 3.30. These results indicate that there was no serious collinearity among the predictor constructs in the structural model.

Table 6 presents the predictive relevance results of Model I and Model II based on Q^2 predict, RMSE, and MAE. Model I included self-regulated learning as a mediating variable, whereas Model II examined only the direct effects of science literacy and digital literacy on plant awareness.

Table 6
PLSPredict Results

Model	Endogenous Construct	Q^2 predict	RMSE	MAE
Model I	Plant Awareness	.351	0.816	0.594
Model II	Plant Awareness	.354	0.813	0.593

As shown in Table 6, both models had positive Q^2 predict values, indicating predictive relevance for plant awareness. Model I had a Q^2 predict value of .351, while Model II had a slightly higher Q^2 predict value of .354. The prediction error values also showed a small difference between the two models. Model I produced RMSE = 0.816 and MAE = 0.594, whereas Model II produced RMSE = 0.813 and MAE = 0.593. These results indicate that both models had predictive relevance, although Model II showed slightly better out-of-sample predictive accuracy. Therefore, the inclusion of self-regulated learning should be interpreted primarily as strengthening the conceptual explanation of plant awareness rather than automatically improving predictive accuracy.

4.4. Direct Effects

Table 7 presents the direct hypothesis testing results based on bootstrapping. The direct paths examined the relationships among science literacy, digital literacy, self-regulated learning, and plant awareness.

Table 7
Direct Hypothesis Paths

Path	β	Mean	STDEV	t-value	p-value	Decision
Science Literacy → Self Regulated Learning	.349	.350	.047	7.416	< .001	Supported
Science Literacy → Plant Awareness	.211	.209	.074	2.861	.004	Supported
Digital Literacy → Self Regulated Learning	.375	.376	.046	8.119	< .001	Supported
Digital Literacy → Plant Awareness	.235	.236	.053	4.430	< .001	Supported
Self Regulated Learning → Plant Awareness	.321	.324	.042	7.547	< .001	Supported

As presented in Table 7, all direct relationships in the mediation model were positive and statistically significant. Science literacy was positively associated with self-regulated learning, $\beta = .349$, $t = 7.416$, $p < .001$, and plant awareness, $\beta = .211$, $t = 2.861$, $p = .004$. Digital literacy was also positively associated with self-regulated learning, $\beta = .375$, $t = 8.119$, $p < .001$, and plant awareness, $\beta = .235$, $t = 4.430$, $p < .001$. In addition, self-regulated learning was positively associated with plant awareness, $\beta = .321$, $t = 7.547$, $p < .001$.

These findings indicate that students with higher levels of science literacy and digital literacy tended to have stronger self-regulated learning and higher plant awareness. Among the direct predictors of plant awareness in Model I, self-regulated learning showed the strongest coefficient, followed by digital literacy and science literacy. However, because this study used a cross-sectional survey design, the relationships should be interpreted as structural and predictive associations rather than causal effects.

4.5. Indirect Effects and Mediation

Table 8 presents the indirect effect testing results for the mediating role of self-regulated learning. The indirect paths examined whether self-regulated learning mediated the relationships between science literacy and plant awareness and between digital literacy and plant awareness. As shown in Table 8, self-regulated learning significantly mediated the relationship between science literacy

and plant awareness, $\beta = .112$, $t = 5.161$, $p < .001$. Self-regulated learning also significantly mediated the relationship between digital literacy and plant awareness, $\beta = .120$, $t = 5.606$, $p < .001$.

Table 8

Indirect Hypothesis Paths

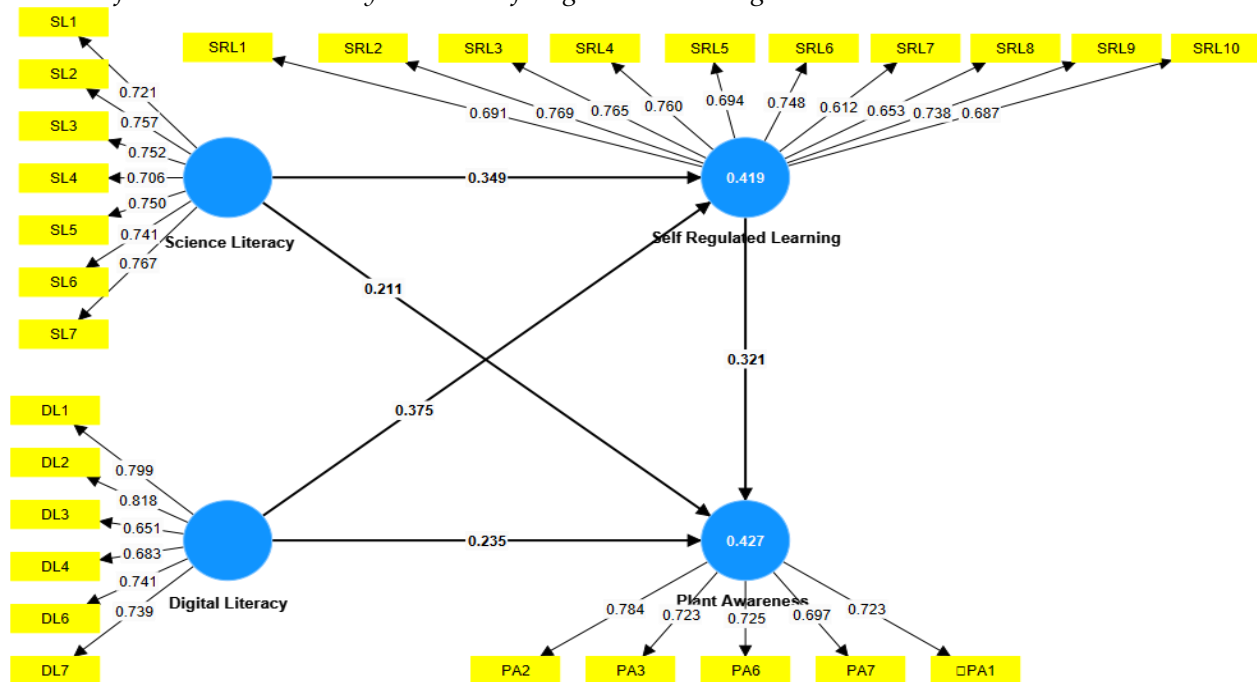
Path	β	Mean	STDE V	t- value	p- values	Decision
Science Literacy → Self Regulated Learning → Plant Awareness	.112	.114	.022	5.161	< .001	Supported
Digital Literacy → Self Regulated Learning → Plant Awareness	.120	.122	.021	5.606	< .001	Supported

Because the direct and indirect paths were both significant, self-regulated learning can be classified as a partial mediator. This means that science literacy and digital literacy were directly associated with plant awareness, while part of their association also operated through students' self-regulated learning.

4.6. Model Comparison

Figure 2 presents the PLS-SEM results for Model I, which includes self-regulated learning as a mediating variable.

Figure 2

Results of the PLS-SEM Analysis with Self-Regulated Learning

As shown in Figure 2, science literacy and digital literacy jointly explained 41.9% of the variance in self-regulated learning, $R^2 = .419$. Furthermore, science literacy, digital literacy, and self-regulated learning jointly explained 42.7% of the variance in plant awareness, $R^2 = .427$. These results indicate that Model I had moderate explanatory power. The strongest direct predictor of plant awareness in this model was self-regulated learning, $\beta = .321$, followed by digital literacy, $\beta = .235$, and science literacy, $\beta = .211$.

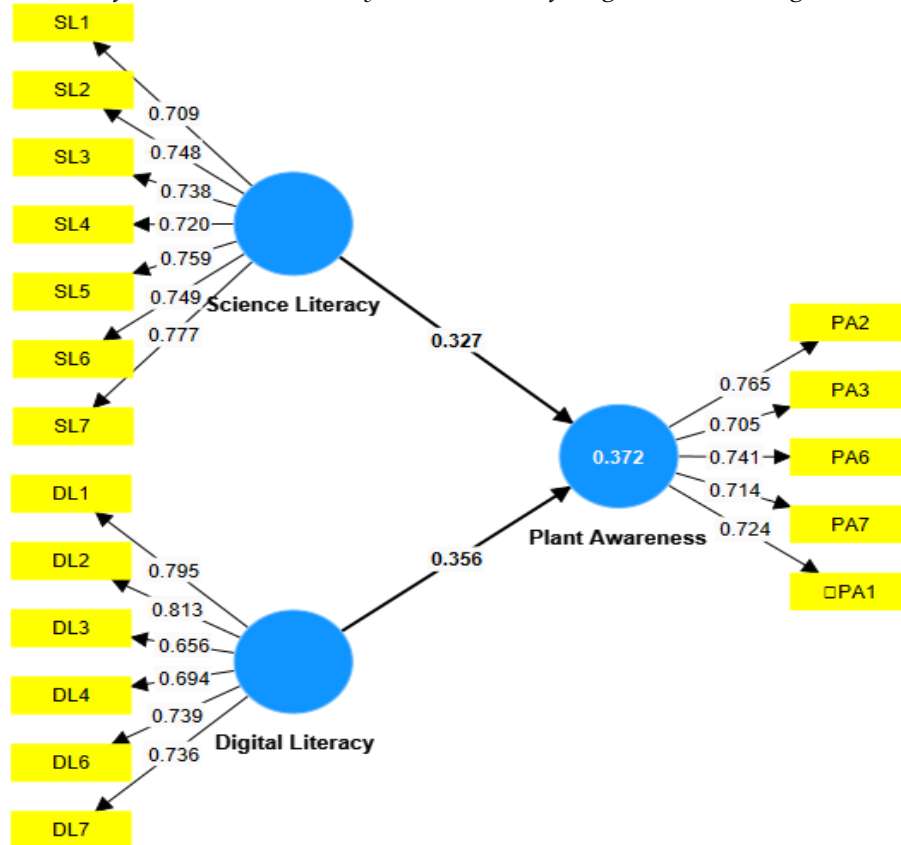
The mediation model provides a more complete explanation of how literacy resources are linked to plant awareness. Science literacy and digital literacy were not only directly associated with plant awareness but were also indirectly associated with plant awareness through self-regulated learning. This supports the role of self-regulated learning as a conceptual mechanism

that explains how students transform scientific and digital literacy resources into stronger plant awareness.

Figure 3 presents the PLS-SEM results for Model II, which excludes self-regulated learning as a mediating variable and examines only the direct relationships between science literacy, digital literacy, and plant awareness.

Figure 3

Results of the PLS-SEM Analysis without Self-Regulated Learning



As shown in Figure 3, science literacy and digital literacy directly predicted plant awareness and explained 37.2% of its variance, $R^2 = .372$. Digital literacy had a slightly stronger direct association with plant awareness, $\beta = .356$, than science literacy, $\beta = .327$. Both path coefficients were positive, indicating that higher levels of science literacy and digital literacy were associated with higher levels of plant awareness.

Compared with Model II, Model I had higher explanatory power because the inclusion of self-regulated learning increased the explained variance in plant awareness from 37.2% to 42.7%. This represents an explanatory gain of 5.5 percentage points. However, the PLSpredict results showed that Model II had a slightly higher Q^2 predict value and slightly lower RMSE and MAE values. Therefore, Model I is stronger in explaining the conceptual process through which literacy is associated with plant awareness, while Model II is slightly better in out-of-sample predictive accuracy.

Overall, the results support all proposed hypotheses. The findings show that science literacy, digital literacy, and self-regulated learning are positively associated with plant awareness, and that self-regulated learning serves as a partial mediator. The comparison between the two models further indicates that adding self-regulated learning strengthens the explanatory power of the model, although it does not automatically improve predictive accuracy.

5. Discussion

The findings of this study indicate that plant awareness among biology students is associated with the combined roles of science literacy, digital literacy, and self-regulated learning. All direct paths in the mediation model showed positive and significant relationships, and self-regulated learning was found to partially mediate the relationships between science literacy and digital literacy and plant awareness. More specifically, the direct association between self-regulated learning and plant awareness was the strongest in the mediation model, followed by digital literacy, and science literacy. This pattern suggests that students' awareness of plants is not only shaped by what they know about science or how they access digital information, but also by how actively they regulate, monitor, and reflect on their learning. This pattern suggests that awareness of plants is not only related to scientific knowledge or access to digital information, but also to students' ability to regulate, monitor, and reflect on their learning processes (Audrin & Audrin, 2022; Fortus et al., 2022). Thus, self-regulated learning can be understood as a psychopedagogical mechanism that helps translate literacy resources into a more specific form of ecological awareness toward plants.

Digital literacy emerged as the strongest predictor of self-regulated learning. The path coefficient from digital literacy to self-regulated learning, was slightly higher than the coefficient from science literacy to self-regulated learning. This result indicates that students who are more capable of accessing, evaluating, managing, and using digital information tend to show stronger independent learning regulation. This finding suggests that students' ability to access, evaluate, manage, and use digital information plays an important role in supporting independent learning (Audrin & Audrin, 2022; Lan et al., 2025). In the context of biology students, digital literacy enables access to various learning resources, such as botanical databases, virtual herbaria, plant identification videos, species recognition applications, conservation articles, and digital ecology materials (Sánchez, 2020). However, digital access does not automatically lead to meaningful learning. Digital information can contribute optimally only when students are able to select credible sources, organize information, monitor their understanding, and use the information to deepen their knowledge of plants (Kiili et al., 2022). Therefore, the relatively strong coefficient between digital literacy and self-regulated learning confirms that digital competence should be understood not merely as technical access to online resources, but as a learning capacity that supports students' planning, monitoring, and evaluation of biology learning. Therefore, digital literacy in this study functions not merely as a technical skill, but also as a learning resource that strengthens students' self-regulation.

Science literacy was also positively associated with self-regulated learning and plant awareness. The direct effect of science literacy on plant awareness shows that students with stronger scientific understanding tend to demonstrate higher attention, concern, and sensitivity toward plants. Although this coefficient was lower than that of digital literacy and self-regulated learning, it remains theoretically important because plant awareness requires an evidence-based understanding of the ecological roles of plants. This finding indicates that scientific understanding of biological, ecological, and plant-related concepts can help students develop stronger awareness of the functions of plants in living systems (Fortus et al., 2022). Students with stronger science literacy are more likely to understand the roles of plants in photosynthesis, the carbon cycle, food webs, biodiversity conservation, and ecosystem stability. Such understanding provides an important basis for viewing plants not merely as objects of learning, but as central components of the biosphere that sustain life (Brkovic et al., 2025). However, the relationship between science literacy and plant awareness occurs not only directly, but also through self-regulated learning. The indirect effect of science literacy on plant awareness through self-regulated learning was significant. This means that scientific literacy contributes to plant awareness partly because scientifically literate students are more able to regulate their learning, evaluate their understanding, and connect scientific concepts with ecological responsibility. This confirms that scientific knowledge needs to be processed through active, purposeful, and reflective learning processes in order to develop into ecological awareness (Theobald, 2021).

In Model I, self-regulated learning was the strongest direct predictor of plant awareness. Its coefficient indicates that students' ability to set goals, select strategies, monitor learning progress, and reflect on outcomes has a substantial role in explaining their awareness of plants. This finding is important because it shows that awareness of plants cannot be adequately developed through exposure to information or mastery of concepts alone, but also requires purposeful learning engagement (Theobald, 2021). Students who are able to set learning goals, seek additional information, monitor their progress, evaluate their understanding, and reflect on learning outcomes are more likely to develop attention to, and concern for, plants. In the context of plant awareness, self-regulated learning helps students move beyond merely knowing plant names, structures, or functions toward a more reflective understanding of the ecological, social, and conservation value of plants (Parsley, 2020; Stagg & Dillon, 2025). This finding implies that biology learning should not only provide plant-related content, but should also train students to plan independent inquiry, use digital and scientific resources critically, and reflect on the relevance of plants to sustainability problems. Thus, self-regulated learning becomes an important process in internalizing plant knowledge into more meaningful awareness.

The mediation results showed that self-regulated learning partially mediated the relationships between science literacy and digital literacy and plant awareness. Partial mediation means that both forms of literacy still have direct contributions to plant awareness, while part of their relationships operates through self-regulated learning (Hair & Alamer, 2022). The indirect effect of digital literacy on plant awareness through self-regulated learning was slightly higher than the indirect effect of science literacy through self-regulated learning. This indicates that digital literacy may become a particularly important entry point for strengthening plant awareness when students are able to regulate how digital information is searched, selected, evaluated, and transformed into ecological understanding. Conceptually, science literacy provides cognitive resources in the form of conceptual understanding and scientific reasoning, whereas digital literacy provides informational resources and access to various learning materials (Audrin & Audrin, 2022; Fortus et al., 2022). Self-regulated learning then regulates how these resources are selected, processed, evaluated, and internalized (Theobald, 2021). Thus, self-regulated learning is not the only pathway to plant awareness, but it represents an important mechanism that clarifies how science literacy and digital literacy are associated with students' awareness of plants.

The comparison between Model I and Model II provides an important methodological insight. Model I, which included self-regulated learning as a mediator, had greater explanatory power for plant awareness than Model II, which excluded the mediator. The mediation model explained 42.7% of the variance in plant awareness, whereas the direct-effects model explained 37.2%. This increase shows that the inclusion of self-regulated learning improved the conceptual explanation of plant awareness by 5.5 percentage points. This indicates that the inclusion of self-regulated learning enriches the theoretical explanation of how science literacy and digital literacy are associated with plant awareness (Hair et al., 2021; Liengaard et al., 2021). However, the PLS predict results suggest a more cautious interpretation: Model II had a slightly higher Q^2 predict value and slightly lower RMSE and MAE values for plant awareness (Hair & Alamer, 2022). The difference was very small, but it indicates that the model with the mediator was not superior in out-of-sample prediction. This means that the mediation model was stronger in explaining the conceptual process, whereas the direct-effects model was slightly better in out-of-sample prediction. This finding confirms that the addition of a statistically significant mediator does not necessarily improve predictive accuracy (Liengaard et al., 2021). In this study, self-regulated learning is more appropriately positioned as an explanatory mechanism rather than a predictive enhancer.

Theoretically, this study extends the literature on plant awareness by integrating three domains that have rarely been examined simultaneously: science literacy, digital literacy, and self-regulated learning. The study demonstrates that plant awareness cannot be explained solely as an outcome of biological knowledge, but is also associated with students' ability to access digital information and regulate their learning independently (Audrin & Audrin, 2022; Fortus et al., 2022; Theobald,

2021). These findings also extend the discussion on plant blindness by showing that low attention to plants can be addressed through a combination of scientific literacy, digital literacy, and reflective learning strategies (Parsley, 2020). The empirical results strengthen this argument because all direct and indirect pathways were significant, showing that plant awareness is better understood as a multidimensional educational outcome involving cognitive, digital, and self-regulatory components. Thus, this study positions plant awareness as a specific outcome of biology education that is distinct from broader constructs such as environmental attitude, ecological literacy, or pro-environmental behavior (Stagg et al., 2025).

Practically, the findings imply that biology learning should be designed to strengthen students' attention to plants through activities that integrate science, technology, and self-regulation (Bernacki et al., 2023; Stagg et al., 2025). Lecturers may develop learning activities such as local plant identification projects, digital herbaria, campus flora observation, reflective journals, digital portfolios, plant identification application-based assignments, and local plant conservation projects (Coşkunserçe, 2024; Hackel et al., 2026; Sánchez, 2020). These activities not only enhance students' knowledge of plants, but also encourage them to seek information independently, evaluate the credibility of digital sources, connect biological concepts with ecological issues, and reflect on the value of plants in everyday life. At the institutional level, the findings also suggest that higher education policies should support plant awareness through campus greening programs, biodiversity documentation, digital herbarium development, lecturer training in technology-integrated biology learning, and assessment systems that value reflective and conservation-oriented student activities. Through this approach, biology learning moves beyond conceptual mastery and contributes to the development of more contextual and applied ecological awareness.

6. Conclusion

This study concludes that science literacy, digital literacy, and self-regulated learning are positively associated with plant awareness among biology students. Science literacy and digital literacy contribute directly to plant awareness, while self-regulated learning serves as a partial mediator that explains how students' scientific understanding and digital competence can be translated into greater attention, concern, sensitivity, and action orientation toward plants. The findings indicate that strengthening plant awareness in biology education requires more than the delivery of plant-related content; it also requires learning strategies that integrate scientific reasoning, critical use of digital resources, independent learning regulation, direct plant observation, reflective activities, and conservation-oriented projects. Therefore, biology curricula and higher education policies should support contextual and technology-integrated learning practices that promote students' awareness of plants as essential components of biodiversity, sustainability, and human life.

7. Limitations and Directions for Future Research

Several limitations of this study should be acknowledged. First, the cross-sectional design does not allow strong causal conclusions; therefore, the relationships among variables should be interpreted as structural, predictive, and associative (Maier et al., 2023). Second, all data were collected through self-report questionnaires, which may introduce common method bias and social desirability bias (Chen & Ding, 2026; Ried et al., 2022). Third, the sample was limited to biology students in Eastern Indonesia, so generalization to non-biology students or other regional contexts should be made cautiously. Fourth, plant awareness was measured based on students' perceptions rather than through actual behavioral observation, performance-based tasks, or action-oriented conservation projects (Koller et al., 2023; Lange, 2022). Future studies are recommended to employ longitudinal designs, learning experiments, performance-based measurement, and cross-disciplinary samples to examine the stability of the model and broaden the generalizability of the findings.

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Data availability: The data that support the findings of this study are available from the corresponding author upon reasonable request. The data are not publicly available due to privacy and ethical considerations related to the confidentiality of the participants.

Declaration of generative AI and AI-assisted technologies: The authors used AI tools, specifically ChatGPT (GPT-5), to support the drafting, wording, and structuring of the manuscript. All scientific content, interpretations, and conclusions were independently generated and verified by the authors, and AI was not involved in data collection, analysis, or decision-making processes.

Declaration of interest: The authors declare that they have no conflict of interest.

Ethics Declaration: This study was conducted in accordance with the ethical principles of educational and social research. Participation in the study was voluntary, and all respondents were informed about the purpose of the research, the procedures of data collection, the confidentiality of their responses, and their right to withdraw from participation at any time. Informed consent was obtained from all participants before they completed the questionnaire. No personal identifying information was collected, and all data were analyzed and reported in aggregate form for academic purposes only.

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