

Species literacy in biology education: A systematic review of concept and dimensions

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Abstract

Given that biology education acts as a key strategy for reducing global biodiversity loss, species literacy (SL) is an essential foundation for conservation and mitigating species extinction. However, SL has not yet been clearly defined and explored to capture its precise dimensions. This systematic literature review (SLR) provided a comprehensive understanding of the conceptual framework and mapping of several dimensions of SL. This SLR used the preferred reporting items for systematic reviews and meta-analyses diagram for inclusion and exclusion criteria and considered articles that met the criteria for further analysis. Of the 619 articles collected, a total of 26 articles were included in this study. According to the SLR results, the concept of SL refers to multidimensional competency that include scientific understanding of species taxonomy and ecology, awareness, and commitment to actualize knowledge into real and sustainable species conservation actions. SL consisted of eight dimensions, including: conceptual knowledge, species diversity and taxonomy, ecology of species, species interest, attitudes towards species, conservation behavior towards species, species identification skills, and species conservation practices. These findings highlighted that SL serves as a potential variable for further exploration in biology education, particularly for strengthening learning and measuring achievements in the biodiversity field.

Keywords: species literacy, species literacy dimensions, biodiversity, biology education

INTRODUCTION

In recent years, the increasing number of endangered species has indicated that biodiversity has reached a critical point (Neumann, 2020). As the most fundamental unit of biodiversity, species have a central role in education and conservation practice (Casetta et al., 2019; Molinari, 2023; Rosselló-Móra & Amann, 2015). The phenomenon of 'species blindness', defined as the inability of students to recognize species in their surrounding environment, has become a major challenge for conservation efforts (Pollock et al., 2015), as students' lack of species identification skills leads to a breakdown in engagement in the field, and consequently impacts biodiversity. In an era where digital identification applications based on artificial intelligence (AI) have become widely available, such applications can effectively help reduce species blindness amongst students (Ceylan & Karakus, 2024). The integration of

digital identification tools with student engagement in learning to identify species using dichotomous keys can develop strong species identification skills in students (Bebber et al., 2026). Consequently, education needs to be designed strategically as a tool that facilitates scientific learning activities which contribute directly to conservation efforts (Robles-Moral et al., 2022). In this context, education functions as a key step in raising awareness and equipping future generations with the capacity to take conservation action to tackle biodiversity loss (Gavrilakis et al., 2024; Qudrat-Ullah, 2025).

Education has an essential role in educating students about the concept of biodiversity through structured biology lessons, particularly the introduction to biodiversity in animals and plants (Moral et al., 2023). The starting point for this introduction involves knowledge of species names and species classification (Oliveira et al., 2019). In practical, students should be

Contribution to the literature

- This study reviews and synthesizes scientific literature on the concept and dimensions of species literacy (SL). Developing an integrative, multidimensional framework that encompasses cognitive, affective, and psychomotor domains is expected to enhance understanding, awareness, and practical skills in species conservation, thereby supporting the sustainability of biodiversity. This conceptual framework for SL represents a foundational step in theoretical development based on the literature, which requires empirical evaluation in future research.
- This systematic literature review (SLR) is confined to the research theme and scope of SL.
- This article proposed a conceptual framework for SL, which biology teachers can utilize to identify topics for study based on issues relating to local biodiversity within the surrounding environment, and to determine teaching approaches and methods such as project-based learning (PjBL), problem-based learning (PBL), and inquiry-based learning (IBL), which support students' learning experiences in the field to engage in investigations and the development of rubric-based assessment tools for conservation practice skills. Furthermore, curriculum developers can restructure the standards for competence achievement and learning objectives relating to biodiversity, ensuring they are responsive to global biodiversity challenges.

able to identify species based on morphological characteristics and taxonomic levels (Palmberg et al., 2019). Species knowledge is a fundamental starting point that enables the development of a deep awareness of the value of biodiversity (Binoy et al., 2021; Hartel et al., 2023). Moreover, knowledge and identification skills serve as necessary prerequisites for effective conservation activities (Buck et al., 2019). More broadly, knowledge of species will help students make informed decisions regarding biodiversity conservation actions (Enzensberger et al., 2022; Wold et al., 2023).

Several studies indicate that the majority of students in Europe struggle to recognize local species in their surrounding environment, and there is a relatively low level of species identification. This is due to limited knowledge of the taxonomy of native local species, a lack of application of scientific practices relating to species classification in teaching, and a lack of direct interaction or experience with species in their natural habitats (Barrutia et al., 2025; Pedrera et al., 2023; White et al., 2018). In Africa, research findings indicate that students also experience difficulties in identifying animal species, which is due to limited direct interaction and knowledge of native species (Panisi et al., 2022). Meanwhile, in Asia, including India, student recognition of mammal species in their region is good, but their knowledge of conservation status and other information regarding these species is limited. These limitations resulted from knowledge acquired passively through the media, rather than through an understanding of the ecological roles of species and the habitats of various species (Binoy et al., 2021). Similarly, findings from Indonesia reported that students' SL remains at a moderate level, due to their limited direct experience with species in their local environment, which consequently restricts their ability to recognize specific aspects of species, such as their role within ecosystems (Aripin et al., 2020; Zukmadini et al., 2024). Research findings by Mohoric et al. (2024) point

out that a lack of knowledge about species fuels skepticism and a pessimistic attitude towards the success of conservation measures. These findings affirm that lack of understanding among students regarding species in their local environment has been identified as a global issue that threatens the future sustainability of biodiversity, thus requiring 'early pedagogical intervention'. These interventions must be designed as participatory learning experiences for students in the identification of local species and the raising of awareness, in order to encourage conservation efforts, thereby empowering students to make informed decisions (Pérez-Flores & López-Martínez, 2025).

Pedagogical interventions in the context of biology education are an urgent necessity for addressing the biodiversity crisis, in which students need to be actively involved in resolving local biodiversity issues in their surrounding communities (Børresen et al., 2023). In order to enhance students' knowledge and awareness of conservation efforts, this approach should be designed to improve the quality of learning (Ajayi et al., 2024; Özyurt et al., 2025). In this context, enhancing the quality of learning referred to contextual teaching and learning (CTL), where students construct scientific knowledge through connecting relevant real-life experiences with conditions in their surrounding environment (Reddy & Revathy, 2024), through critical reflection on their existing knowledge to internalize values that foster awareness, thereby enabling them to apply their knowledge to undertake concrete conservation actions. In line with research (Wang & Yang, 2026), students' concerns regarding biodiversity issues in their local environment can foster a sense of responsibility, and such a sense of responsibility is what motivates them to take conservation action. The acquisition of adequate knowledge has been shown to foster positive attitudes, which can lead to the development of conservation behavior (Hsu et al., 2025). Consequently, pedagogical

interventions through biology education perform an important role as a preventative measure in addressing the biodiversity crisis through the transformation of knowledge, the internalization of awareness, and the reinforcement of conservation behavior among students. Therefore, the strengthening of SL among students remains crucial.

SL has been identified as a foundational step towards understanding the importance of conservation and addressing biodiversity loss (Melis et al., 2021; Wold et al., 2023). The concept of biodiversity literacy (BL) has been conceptualised as the foundation for the development of SL, encompassing understanding, attitudes and actions towards animal and plant species (Aminullah et al., 2025). Based on a literature review of the conceptualization of SL as proposed by Hooykaas et al. (2019), SL is defined as knowledge of facts, basic understanding, awareness, the ability to observe species, and the application of knowledge. The development of the SL framework still has gaps, as there is as yet no universal and established definition that is academically accepted within the field of biology education. Therefore, a redefinition of the conceptual framework of SL is required, as it should be integrated and systematic, as well as capable of accommodating competences in the cognitive, affective and psychomotor domains. This redefinition represents a transformative step in biodiversity education, where the aim should be to actualize students' knowledge, attitudes and skills in the practice of species conservation in practical life. These three domains are key pillars of science education (Cannady et al., 2019; Ornstein & Hunkins, 2018). According to research by Faruhana et al. (2022), the focus should not merely be on the transfer of knowledge, but there is a crucial need for affective stimulation to act as a bridge in fostering biodiversity conservation behavior.

Despite the conceptual framework, the dimensions of SL remain underrepresented in a holistic and multidimensional perspective. Based on a review of the literature, the dimensions of SL have been discussed separately and include species knowledge and species identification (Almeida et al., 2020; Barrutia et al., 2024; Jaun-Holderegger et al., 2022b), interest and attitudes towards species (Randler & Heil, 2021), and conservation behavior (Sigit et al., 2021). The dimensions of SL remain fragmented, where each dimension, such as species knowledge, species identification, interest, attitudes and behavior towards species, tends to be discussed separately and uni-dimensionally. The lack of a holistic theoretical framework to explain the interrelationships between the dimensions of SL causes a significant gap in the integration of SL within the biology education curriculum.

Therefore, the present study is considered important for conducting an SLR to formulate a conceptual framework for SL that encompasses knowledge, attitudes and skills. Furthermore, this study aimed to

map out a holistic and integrative framework for SL. These SLR findings are expected to serve as a new conceptual model that can advance future research, as well as the development of effective methodological practices in biology education to foster SL among students across various levels of education, either on a local or global scale. Therefore, this study emphasizes the importance of exploring SL in biology education as a strategic pedagogical approach to realizing quality education that supports the conservation and sustainability of global biodiversity.

METHODOLOGY

In this study, an SLR was conducted to answer clearly formulated research questions (RQs). This study followed a systematic and explicit process consisting of identification, selection, critical evaluation, analysis, and synthesis of relevant studies. The research framework followed the preferred reporting items for systematic reviews and meta-analyses (PRISMA) protocol. PRISMA serves as a reporting guideline that ensures the transparency and completeness of the systematic review process. The stages executed consisted of:

- (1) the process of inclusion and exclusion of articles based on predetermined eligibility criteria, such as methodological quality and topic relevance,
- (2) critical assessment of the quality of selected articles, and
- (3) synthesis of findings from selected articles to provide comprehensive answers on the RQs (Moher et al., 2010; Zawacki-Richter et al., 2020).

Research Question

The RQs guiding this study are as follows:

- (1) How is the concept of SL defined and theoretically grounded in the literature?
- (2) What are the dimensions that constitute SL?

Article Search Strategy

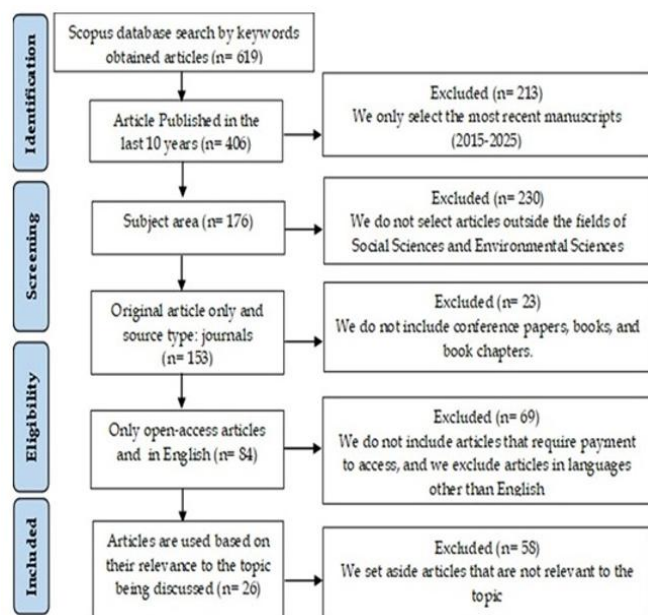
In this systematic review, the literature search phase began with keyword identification. These keywords were expanded by exploring synonyms and related concepts from authoritative reference sources. All collected terms were identified to formulate a Boolean query, which was entered into the Scopus database. The keyword search strategy is ("Species Literacy") AND ("Species Knowledge" OR "Species Identification Skills" OR "Interest in Species" OR "Attitude Towards Species" OR "Awareness of Species").

Selection Criteria

The article selection was performed using inclusion and exclusion criteria. This process aimed to ensure that the selected articles met methodological quality and

Table 1. Inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Database	Scopus	Other than Scopus
Subject area	Social science and environmental science	Other than social science and environmental science
Literature type	Journal (article)	Conference papers, book, book chapter
Timeline	2015-2025	Publications before 2015
Language	English	Other than English
Access	Open access	Non-open access

**Figure 1.** Flowchart PRISMA (the authors' own elaboration)

substantive relevance standards. These inclusion and exclusion criteria used for this selection stage are summarized in **Table 1**.

Article selection process

The article selection process was conducted according to the PRISMA framework (**Figure 1**). All articles were retrieved from the Scopus database, which offers a broader range of published articles covering multidisciplinary research, thus making it a suitable source for discussing this research topic. The initial search in the Scopus database using keywords relevant to the research topic yielded 619 articles. When applying the criteria for publication for the years 2015-2025, 406 articles were included, excluding 213 articles. Then, selecting based on the subject areas of social science and environmental science yielded 176 articles that met the criteria. At the same time, 230 were excluded because their subject areas were not relevant to this study. The selection based on document type yielded 153 articles that met the criteria, while 23 were excluded because they were not journal articles.

Moreover, regarding the criteria of open access and English writing, 84 articles fulfilled the criteria, while 69 articles were excluded. The English writing requirement was applied to ensure full readability and avoid misinterpretation. In the next stage, the 84 articles were

reviewed thoroughly based on the relevance of the topic, article title, research objectives, methods, and research findings. From this process, 58 articles were considered irrelevant for discussion in this SLR. As a result, 26 articles fulfilled the criteria for synthesis in this research.

Quality Assessment

Assessment of article eligibility was based on a critical evaluation of the methodological quality and completeness of the article. This process was conducted independently by the main researcher and two external reviewers. Consensus on quality assessment was reached through collaborative discussions focused on the suitability of the topic, methods, and the significance of the article's main findings in addressing the RQs. Then, the article coding process was conducted, including the author's identity, journal name, publisher, year of publication, and journal quartile (Arif et al., 2025; Hardianto et al., 2024; Maghfiroh et al., 2023). The instrument used to assess the quality and completeness of the articles was a standard checklist for systematic reviews, based on the guidelines recommended by Jahan et al. (2022) and JBI (2017).

Data Analysis

The collected article data were stored in RIS format. To eliminate data duplication, the Mendeley software was used for synchronization. The next process involved systematically identifying and classifying each article using Microsoft Excel (Husamah et al., 2023). The data analysis was conducted in a critical, systematic, and transparent manner to ensure the validity and relevance of the findings to the latest global research issues and trends. This approach aimed to produce a strong and scientifically accountable literature synthesis.

RESULTS

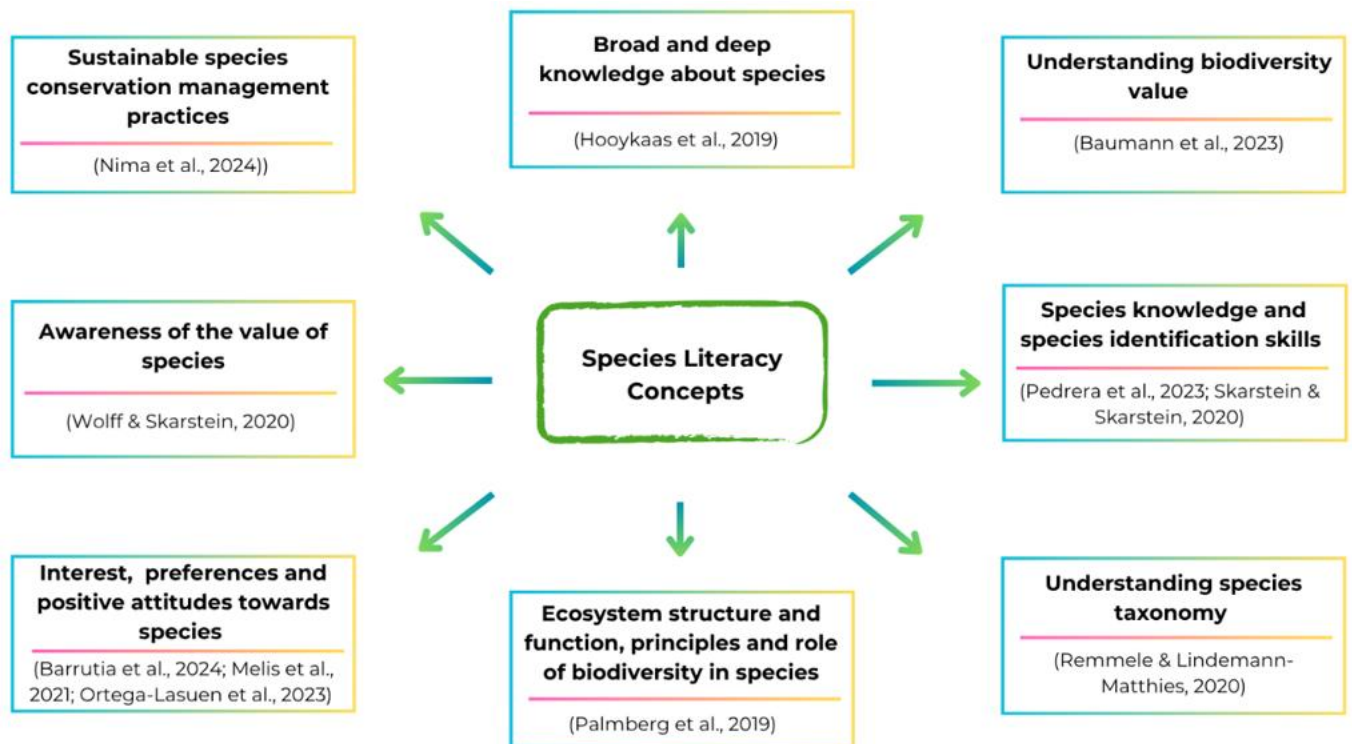
Out of the total of 26 articles analyzed in this SLR, 11 articles contributed significantly to conceptualization of SL, whereas the other 15 articles contributed to the identification of the dimensions of SL.

Concept of species literacy

Out of the 26 articles analyzed in this SLR, we gathered key information regarding the definition of SL (**Table 2**). From this information, we mapped key terms that served specific keywords for conceptualizing SL.

Table 2. Mapping of SL concepts

References	Key information provided in the article
Hooykaas et al. (2019)	SL encompasses broad and deep knowledge about species, such as their names, habitats, life cycles, roles in the food chain, feeding patterns, and behavior within ecosystems
Baumann et al. (2023)	Species knowledge becomes the most essential part of understanding biodiversity value
Pedrerera et al. (2023), Skarstein and Skarstein (2020)	Species knowledge and species identification skills are important for understanding our relationship with nature and biodiversity
Remmele and Lindemann-Matthies (2020)	Understanding species taxonomy well is the first step to determining appropriate conservation management
Palmberg et al. (2019)	Species knowledge and species identification skills enable an understanding of ecosystem structure and function, as well as the principles and role of sustainable biodiversity
Barrutia et al. (2024)	Interest and preferences towards species in nature can encourage and determine conservation goals
Melis et al. (2021), Ortega-Lasuen et al. (2023)	Positive attitudes towards species cultivate a sense of responsibility for the conservation of biodiversity
Wolff and Skarstein (2020)	Awareness of the value of species within nature promotes the conservation of biodiversity
Nima et al. (2024)	Designing effective species conservation management policies and practices encourages sustainability

**Figure 2.** SL concepts (the authors' own elaboration)

From a comprehensive synthesis of the articles, we specifically identified three key words and phrases: "understanding the taxonomy and ecology of species", "having awareness", and "practicing real and sustainable species conservation" (see **Figure 2**). Through a critical synthesis of systematically reviewed literature, we formulate a working definition of SL. The conceptual framework of SL encompasses not only knowledge but also extends to attitudes and skill. Within this framework, we define SL as "multidimensional competency that include scientific understanding of species taxonomy and ecology, awareness, and commitment to

actualize knowledge into real and sustainable species conservation actions".

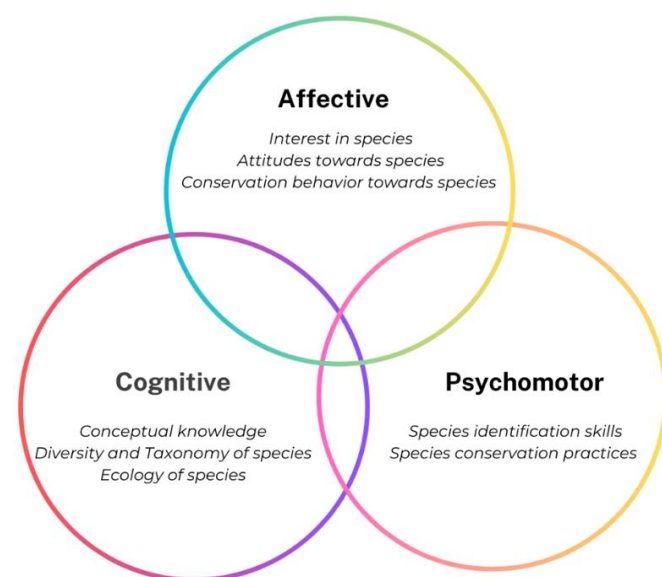
Dimensions of species literacy

After conceptualizing SL definitions, we also attempted to map the dimensions that construct SL from various synthesized articles from previous research (**Table 3**).

In this article, we identified eight dimensions of SL: conceptual knowledge, species diversity and taxonomy, ecology of species, species interest, attitudes towards species, conservation behavior towards species, species

Table 3. Mapping of SL dimensions

References	Key information provided in the article	Dimension
Wold et al. (2023)	Understanding biodiversity concepts related to plant and animal species	Conceptual knowledge
Barrutia et al. (2022)	The ability to recognize diversity through recognizing names, understanding species characteristics, and classifying taxonomy	Diversity and taxonomy of species
Ahlers (2019)	Understanding the ecological principles of species within ecosystems	Ecology of species
Callahan et al. (2019)	Perceptions of species ecology within ecosystems	
Mittermeier et al. (2021)	The interest in species strengthens conservation activities	Interest in species
Marcos-Walias et al. (2023)	The interest in biodiversity depends on a preference for species in nature	
Toth and Rubino (2025)	Attitudes towards species contribute to responsibility, attention, and awareness of endangered species	Attitude towards species
Coşkunserçe (2024)	Understanding species diversity in nature encourages the strengthening of biodiversity conservation behavior	Conservation behavior towards species
Xu and Jiang (2022)	Willingness to conserve species correlates directly with knowledge about the species, preference for the species, and frequency of contact with the species in the wild	
Jaun-Holderegger et al. (2022a), Lindemann-Matthies et al. (2024)	Possess field observation skills in species identification, such as recognizing species names and observing morphological characteristics	Species identification skills
Pernat et al. (2023)	Demonstrate proficiency in species identification skills using field guides and scientific literature	
de Melo et al. (2021)	Demonstrate performance in conceptualizing and identifying endemic (local) and invasive species in conservation practice	Species conservation practices
Aryanti et al. (2025), Barrutia et al. (2025)	Integrated interaction with species directly in nature through the use of technology	

**Figure 3.** Dimensions of SL (the authors' own elaboration)

identification skills, and species conservation practices. These eight dimensions of SL were integrated into three domains, namely cognitive, affective, and psychomotor, which are presented in **Figure 3**.

After mapping out the dimensions that constitute SL, we also identified instruments for assessing SL (**Table 4**).

In this article, we identified SL assessments in the cognitive domain using instruments such as species list completion tasks, multiple-choice tests, short-answer

essay tests, questionnaires and interviews. Assessment of the affective domain largely utilized open-ended or closed-ended questionnaires with a Likert scale. Meanwhile, assessment of identification skills utilized identification tests, questionnaires, interviews and digital identification applications. There were no assessments in the psychomotor domain that emphasized practical species identification skills in the field. Assessments using identification tests that contained two-dimensional images and multiple-choice questions were very limited, as they only covered the cognitive domain, which includes remembering, recognizing and naming species based on visual characteristics stored in students' knowledge memory. Questionnaires and interviews lack accuracy in measuring practical species identification skills, as these instruments emphasize students' confidence in their ability to identify species rather than their actual competence when identifying real species in the field. Measuring species identification skills using digital identification tools becomes effective if these instruments are used in a two-stage assessment process: assessing species identification performance via a dichotomous key and then validating the identification results through a digital application. As the essence of identification skills involves procedural abilities that encompass complex scientific processes such as observation, identification, analysis and interpretation of results. Therefore, instruments for measuring

Table 4. Instruments for assessing SL

References	Instruments	Assessments
Hooykaas et al. (2019), Marcos-Walias et al. (2023), Ortega-Lasuen et al. (2023), Palmberg et al. (2019), Wolff and Skarstein (2020)	Species identification test	Assessing the ability to identify animal and plant species
Barrutia et al. (2025)	Task of listing species	Assessing knowledge of animal species
Aryanti et al. (2025), Callahan et al. (2019), Nima et al. (2024)	Multiple-choice test	Assessing knowledge of animal species diversity, conservation status, diet and habitat
Ahlers (2019)	Short essay test	Assessing basic identification skills
Coşkunserçe (2024), de Melo et al. (2021), Pedrera et al. (2023), Skarstein and Skarstein (2020), Xu and Jiang (2022)	Questionnaire	Assessing knowledge of biodiversity concepts, knowledge of nature, knowledge of plant and animal species in the local environment, and knowledge of invasive species
Barrutia et al. (2022, 2024)	Questionnaire	Assessing the ability to identify animal and plant species
Lindemann-Matthies et al. (2024), Melis et al. (2021), Remmele and Lindemann-Matthies (2020), Toth and Rubino (2025)	Questionnaire	Assessing attitudes towards animal and plant species, assessing activities relating to animals, assessing interest in species, and assessing perceptions of species
Jaun-Holderegger et al. (2022a), Wold et al. (2023)	Interview	Measuring species recognition, knowledge of species' characteristics and habitats, and measuring the ability to identify species
Mittermeier et al. (2021), Pernat et al. (2023)	Digital identification tools	Measuring the accuracy of plant species identification

psychomotor domains in which species identification skills are assessed in students need to be developed into authentic performance-based assessments, such as a rubric for assessing species identification skills.

DISCUSSION

A conceptual redefinition of SL was formulated through the integration of the cognitive, affective and psychomotor domains into a systematic framework, which was derived from the identification of key aspects in the articles reviewed. The first aspect highlights species knowledge which acts as a fundamental foundation that is not merely memorized but fully understood in order to develop species identification skills (Baumann et al., 2023; Hooykaas et al., 2019; Palmberg et al., 2019; Pedrera et al., 2023; Remmele & Lindemann-Matthies, 2020; Skarstein & Skarstein, 2020). The second aspect emphasizes interest, preferences and positive attitudes towards species (Barrutia et al., 2024; Melis et al., 2021; Ortega-Lasuen et al., 2023), as well as an awareness of the value of species (Wolff & Skarstein, 2020). The third aspect focuses on effective species conservation practices as a prerequisite for achieving sustainability (Nima et al., 2024).

Students' knowledge could be passive if not supported with an internal encouragement to care about species conservation. Therefore, attitudes become mediators that link students' knowledge to the practical development of species conservation skills. Accordingly, the concept of SL is understood as an integrated, multidimensional competence that builds knowledge, fosters awareness, and equips students with the skills to take concrete action in species conservation efforts. This

concept provides a relevant framework for the biology curriculum, which is expected to contribute to preventing a biodiversity crisis in the future. According to Oai and Hoi (2019) and Robles-Moral et al. (2022). Education should be positioned as a tool that serves as a foundational pillar for the success of biodiversity conservation. Teaching should be based on an integrated and interdisciplinary approach to enhance students' learning experiences and to increase their practical involvement in conservation efforts (Oliveira et al., 2025).

There are eight dimensions of SL that have been comprehensively mapped in this article. These dimensions become an integrated holistic whole, grouped into three domains, including: *cognitive* which encompasses three dimensions such as conceptual knowledge, species diversity and taxonomy, and ecology of species. These three dimensions are integrated, where conceptual knowledge provides the most fundamental foundation that strengthens understanding of diversity, taxonomy and ecology of species. Taxonomy and ecology have been key pillars of biology, particularly for the study of species and the conservation of biodiversity (Kirti & Kaur, 2022; Sharma et al., 2024). These concepts are reflected when naming species through the identification of their morphological and ecological characteristics (Bevilacqua et al., 2022; Mooney et al., 2021). Meanwhile, diversity of species considered as a fundamental component of biodiversity requires an understanding of taxonomy and the quantification of species numbers and abundance (Lewinsohn & Jorge, 2023). In the context of biology education, fostering scientific conceptual understanding in students should be a crucial objective, as it facilitates

the integration of their currently fragmented knowledge. Students who are able to synthesize scientific concepts thoroughly and profoundly will have that knowledge firmly embedded within their cognitive structures (Kiviluoma et al., 2024; Thorn et al., 2016). Therefore, students' cognitive understanding of species acts as a critical foundation for them to think more systematic, analyze information, and make decisions according to scientific knowledge and evidence when responding to conservation issues in their local environment.

Affective, encompasses three dimensions: interest in the species, attitude towards the species, and conservation behavior towards the species. The affective dimension within this framework focuses on emotional responses formed through interactions between students and specific animal or plant species, rather than at broader taxonomic levels, such as genus or family. In line with this, evidence from a study (Oražem & Tomažič, 2025), reported that increased knowledge contributes to the formation of positive attitudes towards the Eurasian lynx (*Lynx lynx*), as reflected in students' interest in learning and their willingness to support conservation efforts for this species. In a study conducted by Billing et al. (2025), it was reported that students in Italy and Pakistan demonstrated positive attitudes towards the conservation of deer, such as the reindeer (*Rangifer tarandus*) and the roe deer (*Capreolus capreolus*), whereas Norwegian students showed a negative attitude towards the conservation of the red deer (*Cervus elaphus*), one of the contributing factors being the social environment, which is characterized by a deeply rooted hunting tradition within the community. These three affective dimensions are integrated, with interest serving as the initial psychological trigger that initiates an attraction to the species. These attractions develop into positive attitudes, reflected in increased attention and awareness of the species' existence. Furthermore, a positive attitude serves as a significant predictor of the emergence of species conservation behavior. The internalization of these three dimensions contributes to the development of awareness regarding species conservation. According to Fajri et al. (2025), fostering awareness and commitment to biodiversity conservation efforts should be a strategic step in education. Increasing students' awareness of species are necessary components of conservation activities (Fukano et al., 2021; Kamil et al., 2020), as this awareness directly encourages their involvement in biodiversity conservation actions (Qudrat-Ullah, 2025). Furthermore, the integration of cognitive and affective dimensions can strengthen the development of SL among students. According to Enzensberger et al. (2022) and Hartel et al. (2023), an understanding of species and their ecological roles forms the rational basis for the cultivation of awareness regarding the protection of biodiversity. Consequently, the knowledge and attitudes cultivated in

the minds of students play a key role in the future of species conservation (Billing et al., 2025).

Psychomotor, encompasses two dimensions: species identification skills and species conservation practices. Species identification becomes an important part of biology, specifically applied in species conservation management (Hallman & Robinson, 2015; Oliver et al., 2024). Meanwhile, species conservation practice requires the sustainable planning, management and monitoring of biodiversity (Zemanova, 2021). Species identification skills can be used to analyze species diversity and identify endangered species in the wild (Chac & Thinh, 2023). Species identification skills represent a competence that students need to master and which must be reinforced through training and experience in learning activities (Palmborg et al., 2019; Waldchen et al., 2018). This dimension represents the practical manifestation of SL, where conceptual knowledge and awareness are transformed into tangible engagement in species conservation. We assert that psychomotor skill constitute an integral dimension of SL, namely scientific competence whereby students possess the basic skills to identify species, acquired through formal education and structured experiences in biodiversity learning activities, in order to equip students with the ability to identify species accurately as a foundation for their future involvement in biodiversity conservation. As explained by Alshboul and Hamadneh (2025) and Özyurt et al. (2025), knowledge and awareness are oriented towards practical skills, which encourage engagement in practical actions for the conservation of biodiversity.

In the current digital age, the use of digital identification tools and AI allow for the identification of animal or plant species with high accuracy and speed, as well as being effective and practical (Cheng & Hsieh, 2026; Siddhartha & Akurathi, 2026). However, regarding species identification, there is a challenge in the use of AI in biology education, where students' critical thinking skills could be weakened as they receive information or data that might be incorrect or inaccurate, thus making them unable to verify the accuracy of such scientific data (Cotton & Cotton, 2026). In the long term, these conditions have the potential to produce a future generation lacking competence with taxonomy, as they will be unable to independently verify the results of species identification. Therefore, students, as the future generation of experts, need to be provided with an understanding of the basic concepts of taxonomy and trained thoroughly in species identification skills, so they have the ability to test the validity of scientific data (Hackel et al., 2026). Identification skills using conventional dichotomous keys are fundamental to preparing students' ability to verify data obtained through digital identification tools (Bebber et al., 2026). In line with the findings of the study by Finger et al. (2022), the appropriate teaching strategy for enhancing species identification skills involves integrating learning

through dichotomous keys and digital identification tools. Using this strategy, learning through dichotomous keys takes place at the start of the lesson to build students' scientific skills in the species identification process, and then students use digital identification tools to obtain comprehensive information on species.

On the other hand, the process of learning about biodiversity currently still faces fundamental challenges, particularly as the species identification practices that are applied remain limited to morphological observation and the compilation of scientific nomenclature. Based on the relevant studies analyzed, the focus of species identification skills tends to be on local and iconic species, without addressing deeper taxonomic complexities such as the existence of 'cryptic species'. However, in the scientific community, especially among biologists and conservationists, cryptic species have become a central topic, as they appear morphologically identical and are classified as a single species, even though they exhibit significant genetic differences (Monro & Mayo, 2022). The identification of cryptic species cannot be achieved solely through morphological observation of the species, rather it requires modern genetic and molecular analysis (Hending, 2025). The neglect of the topic of cryptic species in biology education represents a serious shortcoming, as an understanding of cryptic species can be key to the effectiveness of conservation strategies, such as for endangered endemic species (Ahmed et al., 2024). Therefore, there is a growing need for students to practice identifying cryptic species using a molecular approach based on DNA sequencing, so that they are provided with the relevant scientific competencies to address species conservation challenges (Elwess et al., 2018; Wright et al., 2024). Overall, these eight dimensions constitute the conceptual pillars of SL, which function as a pedagogical foundation in biology education. These frameworks can be operationalized through classroom teaching methodologies to address concrete needs in tackling the biodiversity crisis in local and global contexts.

To achieve learning objectives, three key domains should be considered: the cognitive, affective and psychomotor domains. Unfortunately, there is a disparity arising from the fact that the achievement of learning objectives in the cognitive learning domain, which is used as a benchmark for learning success, has overshadowed the psychomotor domain, which is a fundamental component required to develop well-rounded student competencies. However, the development of psychomotor competencies faces numerous challenges in educational practice. In the case of Indonesia, the development of students' skills remains incomplete, due to the complexity of psychomotor assessment tools, which makes it difficult for teachers when conducting classroom assessments (Bali & Musrifah, 2020). In Malaysia, the development of

students' skills in biology practicals remains limited, due to teachers' inadequate scientific skills (Fadzil & Saat, 2020). Meanwhile, in India, the development of practical skills in science laboratories has not been accompanied and supported by an assessment system, which means it is not considered as part of the measurement of students' academic achievement (Pareek, 2019). Meanwhile, in South Africa, students' skills in biology practicals encounter obstacles due to high student-to-teacher ratios, which limits the availability of resources and consequently hinders their implementation (Mlangeni et al., 2026). Inadequate performance in laboratory or field practicals could pose a major challenge to students' skill development (Tilling, 2018). The fact that learning oriented towards practical performance is a crucial component of biology education, which requires procedural skills in practice (Kervinen et al., 2020). The aim of developing psychomotor competencies enables students to acquire technical skills, think critically, communicate effectively and make decisions, as required by the scientific community (Assem et al., 2024). Therefore, learning based on laboratory or field practice is essential, as it is through direct experience that students can practice procedural skills, such as species identification in biology lessons, which would be impossible to develop adequately through theory alone. This is because the essence of psychomotor competence relies on sensorimotor experiences, which can only be acquired through hands-on practice in the real world.

The comparative analysis revealed a strong correlation between the proposed concept of SL and scientific literacy. According to Hallman (2017) and Holbrook and Rannikmae (2009), science literacy refers to the application of scientific knowledge, the formulation of critical questions, an understanding of the scientific method, and the drawing of conclusions based on evidence to solve problems, make decisions and improve the quality of life in a sustained manner. Thus, SL should not be viewed as a separate concept but rather as a specific contextualization of scientific literacy. Scientific literacy emphasizes scientific understanding, critical questioning, the scientific method and making evidence-based conclusions. These principles are directly reflected in SL, which requires an understanding of the taxonomy and species ecology grounded in valid scientific understanding. In other words, SL is the application of scientific understanding to a concrete object of knowledge, such as species. SL encompasses scientific knowledge, conservation awareness and a commitment to translating this knowledge into tangible and sustainable species conservation actions. These principles reflect the commitment to safeguarding biodiversity for the balance of ecosystems on Earth and human well-being in the future. Hence, SL is closely aligned with the objectives of scientific literacy in solving problems, taking decisions and improving the quality of life in a sustainable manner.

According to Smith et al. (2015), the conceptual framework of SL comprehensively addresses the four main constructs of science literacy: *Firstly*, 'science content' is represented as conceptual knowledge regarding biodiversity, which provides a profound understanding of species diversity, taxonomy and species ecology. *Secondly*, 'scientific reasoning skills' which are implicated in the process of applying existing knowledge to analyze, evaluating and solving problems based on local contextual issues found in the surrounding environment. *Thirdly*, 'interest and attitude' which are reflected in conservation awareness, acting as a bridge between knowledge and skills. *Fourthly*, 'active participation' which involves the actualization of acquired skills in actively participating in sustainable species conservation.

Science literacy consists of five dimensions, including mastery of scientific knowledge, the application of scientific knowledge in everyday life, positive attitudes towards science, the role of science in a social context, and collective engagement with scientific issues (Oikonomou, 2019). Although the dimensions of SL generally align with those of science literacy, analysis reveals that the dimensions of SL remain limited when compared to those of science literacy. The dimensions within the cognitive domain have been found to be at a moderate level in terms of procedural and epistemic content knowledge. In contrast, the scientific knowledge dimension in science literacy includes high-level epistemic knowledge, which is the expert ability to construct, evaluate information and validate knowledge based on scientific developments, as well as the ability to solve related problems. According to research from Zetterqvist and Bach (2023), science education tends to focus more on content and procedural knowledge than on epistemological knowledge. In fact, reinforcing epistemological knowledge in the learning process might actually improve science education outcomes (Vazquez-Alonso & Mas, 2018).

The affective dimension of science literacy refers to aspects intrinsic to the individual, such as interests, attitudes and behaviors towards more specific objects, such as plant and animal species. However, there is a distinction from the dimensions of positive attitudes towards science and the social context of science within science literacy, which encompass a broader scope, including socio-scientific issues. The inclusion of socio-scientific issues within the learning context contributes significantly to fostering students' self-efficacy and interest in science (Smit et al., 2025; Turk & Cam, 2025). Meanwhile, the psychomotor dimension was limited to the skills of identification and active individual participation in conservation activities. These are distinct from the dimension of collective engagement in scientific issues, which involves collective and participatory engagement of individuals to act alongside the community in conservation practice, such as public

discussions addressing conservation conflicts or priorities, analyzing government policies, and citizen science. According to Ayong (2024), participatory engagement in addressing conservation issues within the community provides direct experience in linking theoretical knowledge with practical application. Teaching that involves the community enriches students' experience in resolving environmental issues (Donahue et al., 2023).

To define advanced SL, it is necessary to develop all three aspects: knowledge, attitudes and skills. The knowledge development prioritizes the profound integration of content, procedural and epistemic knowledge at level 6 (high). According to the PISA scale at level 6 (OECD, 2017), students are able to think systemically, evaluate and validate knowledge based on scientific developments, and solve problems in everyday life. In addition, the future development of species conservation awareness needs to broaden its scope to include socio-scientific contexts. A socio-scientific approach to science education encourages intrinsic motivation in students by facilitating more meaningful learning through the connection of scientific content to real-life contexts (Buma, 2018). Moreover, future skills development should be directed towards building the capacity to collaborate with the community in addressing complex species conservation issues. Teaching practices that involve citizen science could have a positive impact on students' awareness, broaden their knowledge and provide them with valuable experience (Howe et al., 2025).

Implications of the Study

The main implication of this research highlights the importance of a holistic approach to SL in biology education as a multidimensional competence developed through the integration of knowledge, attitudes and skills. These competencies include critical knowledge, building awareness, and participating in problem-solving, making scientific decisions, and taking part in concrete and sustainable conservation actions. SL competencies contribute to shaping a generation that has scientific knowledge, ecological wisdom and the ability and willingness to take concrete action for the conservation of biodiversity.

The practical implications of this research consisted of two main parts. *Firstly*, the curriculum development for biology education through the redesign of learning objectives for biodiversity that integrate the domains of knowledge, attitudes and skills to a balanced proportion. The learning objectives in the knowledge domain focused on the acquisition of critical concepts, which is the ability to analyze, evaluate and critique. In the attitude domain, the learning objectives emphasize the internalizations of awareness values, such as appreciation, commitment and internalization. In the

psychomotor domain, the learning objectives focus on participatory skills, which are designing, performing, and resolving problems. *Secondly*, the improvement of biology teaching methodology through the design of instructional approaches that are oriented towards students' active engagement in acquiring scientific knowledge, building awareness, and practicing skills through fieldwork. Several learning models considered to have the greatest potential for implementation include CTL, IBL, PBL, and PjBL.

Limitation of the Study

While this study provides valuable insights, the researchers acknowledge certain limitations. *Firstly*, the scope of the literature sources used was restricted to the Scopus database. As an SLR, dependence on a single database could potentially exclude relevant articles on SL in biology education, which might not be included in that database. *Secondly*, these study findings were limited based on several criteria, including publications from 2015 to 2025, document types restricted to articles in scientific journals, language limited to English, articles limited to open access, and a limited focus on the fields of social sciences and environmental sciences. These criteria were applied to ensure the quality and consistency of the data obtained. However, these criteria also could potentially exclude important articles that fall outside the established criteria. *Thirdly*, this study relied heavily on a theoretical synthesis of the content of the articles identified in the literature. Therefore, this study merely provides conceptual recommendations regarding the definition and dimensions of SL within the context of biodiversity in biology education.

For future research, we suggest several research stages. *Firstly*, conducting empirical testing of the concepts and dimensions of SL through a quantitative approach using confirmatory factor analysis. The purpose of this analysis would be to confirm whether the identified dimensions of literacy have indeed formed a valid and acceptable construct. The results of this stage would produce a conceptual model of SL that is robust in theory and empirically. *Secondly*, developing standardized and validated psychometric assessment instruments for SL. The instruments developed can be categorized into two types:

- (1) test instruments, which include multiple-choice questions and essays to measure knowledge and
- (2) non-test instruments, such as questionnaires that measure attitudes and performance assessment rubrics to measure skills.

Thirdly, the effectiveness of various learning models in fostering SL among students should be investigated using quasi-experimental and mixed-methods research designs to gain a comprehensive understanding of the dynamics of SL development in students during the learning process.

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