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The strategic role of conservation education in efforts to improve biodiversity literacy: a systematic review

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ABSTRACT
Biodiversity literacy is becoming increasingly important in the era of globalisation to understand and conserve various forms of life on Earth. Education plays a crucial role in improving biodiversity literacy, but this aspect is often underemphasized in formal and non-formal education. This study aims to analyse the strategic role of conservation education in improving biodiversity literacy through a systematic review of 25 relevant articles, selected using the PRISMA framework. These articles were sourced from reputable international journals indexed in Scopus and Google Scholar. The findings indicate that biodiversity literacy can be enhanced through various innovative learning models that integrate technology, such as virtual reality and mobile applications, to improve learning experiences, motivation, and student engagement. However, the study lacks direct empirical measurements of this improvement, highlighting the need for further research to quantify its impact. Additionally, direct learning approaches that incorporate nature-based experiences have been effective in fostering environmental awareness, though this finding is primarily drawn from the literature review rather than new empirical evidence. Integrating biodiversity literacy into curricula through multidisciplinary approaches and local knowledge is also beneficial for promoting students' understanding and conservation behavior. However, challenges such as the lack of appropriate teaching methods and the need for curriculum adjustments persist. To address these issues, a holistic and integrated educational approach is recommended, incorporating technology, hands-on experiences, and local knowledge. By implementing these strategies, conservation education can not only enhance biodiversity literacy but also cultivate a generation that is more environmentally conscious and committed to conservation efforts.

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Introduction

In the modern era of globalization, fostering biodiversity literacy is essential for comprehending and safeguarding Earth's diverse ecosystems. Education serves as a key driver in enhancing awareness of biodiversity conservation. However, its significance is frequently overlooked in both formal and informal learning settings. This neglect results in limited public engagement and insufficient conservation efforts. To bridge this gap, education must incorporate interdisciplinary approaches, hands-on experiences, and technological innovations to cultivate deeper ecological awareness. Strengthening biodiversity literacy will empower individuals to take informed actions, ensuring the sustainability of natural resources and promoting a more environmentally conscious society for future generations. Biodiversity literacy is not just a basic understanding of biodiversity, but more broadly includes the ability to use this knowledge to solve environmental problems and form a sensitive and responsive attitude to environmental issues (Utari et al., 2021). This knowledge is an important foundation in shaping effective conservation policies and practices, showing the link between scientific understanding and practical applications in daily life.

Knowledge and awareness about biodiversity gained through education are needed to shape pro-environmental behaviour and strengthen community involvement in nature conservation. Schneiderhan-Opel & Bogner (2020) emphasize that biodiversity education is an essential tool for sustainable development, providing a basis for individuals to make environmentally responsible decisions. According to Durmuş & Kinaci (2021), effective environmental education can improve environmental literacy and result in behaviour changes that support long-term sustainability. Nevertheless, challenges persist in implementing biodiversity education effectively, including inadequate integration into curricula, limited teaching resources, and a lack of innovative approaches.

The integration of biodiversity literacy into the educational curriculum is a strategic step to strengthen understanding and appreciation of biodiversity. Through a well-designed curriculum, school learners are taught not only about species and ecosystems but also about the impact of human intervention on the environment and ways to reduce the ecological footprint of humans. Masemene & Msezane (2021) describe how science education and curriculum-based activities can promote sustainable behaviour and deeper ecological awareness.

There are several learning models or strategies that have been applied in biodiversity learning, including the use of environmental literacy instruments which has proven to be effective in increasing public awareness and knowledge about the environment(Miterianifa, 2024). The integration of local wisdom in biodiversity learning not only enriches learning materials but also contributes to the development of pupils' character, such as reading and writing literacy (Joyo, 2018). The application of technologies such as augmented reality (AR) and digital learning platforms has revolutionised the way we teach and learn about biodiversity. According to Merino et al., (2022), the use of AR in education helps learners visualise and understand the concept of biodiversity more deeply, which allows for richer interactions with the subject matter. This approach not only increases their engagement but also strengthens their understanding of complex environmental issues.

Recent research shows the importance of innovative approaches in education to increase understanding and engagement in biodiversity issues. (Wolff, 2023) emphasises the role of biodiversity education in fostering concern and concern for the environment. Education about organisms in the surrounding environment is important to instil a sense of responsibility for biodiversity (Lindemann-Matthies & Bose, 2008). Adolescents' perception of biodiversity has a significant effect on their attitudes and behaviours towards environmental conservation (Schneiderhan-Opel & Bogner, 2019). There has been a surge in global interest in biodiversity and conservation efforts, with research assessing the level of awareness of various groups, both professional and non-professional, regarding the concept of biodiversity (Akindele et al., 2021; Caetano et al., 2023). Promoting reflectivity and encouraging involvement in biodiversity protection is crucial to addressing knowledge gaps and encouraging proactive conservation behaviours (Quarshie et al., 2019). Local land-use planning is recognised as a key strategy for biodiversity conservation,

emphasizing the importance of education programs in raising awareness and supporting conservation efforts (Stokes et al., 2010).

This review utilizes the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework to conduct a structured and systematic analysis of biodiversity education's role in enhancing biodiversity literacy. While the study primarily synthesizes findings from existing literature, it also critically evaluates the effectiveness of various educational approaches. A true systematic review requires rigorous methodological criteria, including data extraction, quality assessment, and synthesis of empirical evidence. Therefore, this study aims not only to provide an overview but also to highlight gaps in current research, offering insights into how biodiversity education can be more effectively integrated into learning environments.Articles included in the review were selected based on explicit inclusion and exclusion criteria: (1) studies published in the last 10 years, (2) articles indexed in reputable databases such as Scopus and Google Scholar, (3) studies focusing on biodiversity literacy, conservation education, and innovative learning models.

To guide this systematic review, the following research question is posed: "What are the effective educational strategies and curriculum integration approaches that enhance biodiversity literacy and conservation behaviour among learners?"

By systematically examining the existing literature, this review aims to the growing body of knowledge on biodiversity education by exploring innovative methods and their integration into formal and non-formal educational systems. the study is to analyse and discuss the strategic role of biodiversity education in improving biodiversity literacy.

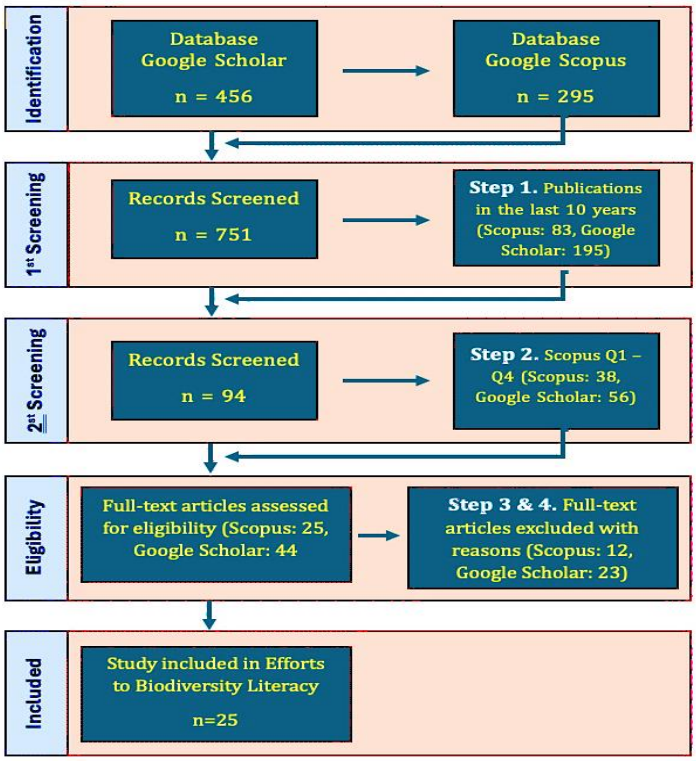
Methods

This study uses the PRISMA (Preferred Reporting Items for Systematic Review and Meta-analyses) framework to conduct a systematic review and meta-analysis (Zarate et al., 2022) of articles related to biodiversity literacy, conservation education and biodiversity learning from reputable international journals and proceeding indexed in Scopus. The PRISMA framework is a widely known tool for evaluating systematic reviews and meta-analyses consisting of 4 steps (Liberati et al., 2009; Moher et al., 2009): 1) Identification of journals to be included in the meta-analysis; 2) Screening, screening or selection of data; 3) Eligibility, determining the article to be used as material for literature assessment; and 4) Inclusion, combining and reporting results. The selection of articles uses the *Publish or Perish* application using databases from Scopus and Google Scholar.

The following is an illustration of the analysis from PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) based on articles relevant to the research study can be seen in Figure 1 below. Based on Figure 1, The PRISMA diagram shown illustrates the systematic selection process for biodiversity literature studies. The process began with an identification stage, where an initial search was conducted using two databases, Google Scholar and Scopus, yielding a total of 751 publications (456 from Google Scholar and 295 from Scopus). The first screening stage restricted publications to those published in the last 10 years, reducing the number of publications to 278 (195 from Google Scholar and 83 from Scopus). The second screening further refined publications based on journal quality, with only journals indexed in the Q1 to Q4 quartiles of Scopus being considered. From this process, 94 publications remained for consideration (56 from Google Scholar and 38 from Scopus).

Figure 1

Mapping the selection of relevant articles for systematic review



Note. Adoption from (Zarate et al., 2022)

In the eligibility stage, 69 articles were evaluated based on their full text to determine their suitability to the study criteria. Of these, 25 articles from Scopus and 44 from Google Scholar were further assessed. However, some articles were excluded for specific reasons, such as relevance, methodology, or quality, resulting in the exclusion of 35 articles (12 from Scopus and 23 from Google Scholar). After the selection and exclusion process, 25 articles that met all the selection criteria were finally included in this study.

This process demonstrates a systematic and rigorous approach to ensure that only quality and relevant studies are included, increasing the validity and reliability of findings related to biodiversity literacy. In this way, research can produce more accurate and reliable insights in efforts to improve understanding and awareness of biodiversity. The following are the results of the analysis from PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) in Table 1 below.

Table 1

Article selection results

No	Author	Journal	Index-Journal
1	De Oliveira et al., 2020	Journal of Ethnobiology and Ethnomedicine	Scopus Q1
2	Hooykaas et al., 2019	Biological Conservation	Scopus Q1
3	Paradise & Bartkovich, 2021	Citizen Science: Theory and Practice	Scopus Q1
4	Grúňová et al., 2017	Applied Environmental Education and Communication	Scopus Q2
5	Ardoin et al., 2020	Biological Conservation	Scopus Q1

No	Author	Journal	Index-Journal
6	Thomas et al., 2019	Environmental Education Research	Scopus Q1
7	Lo & Tsai, 2022	Sensors	Scopus Q1
8	Kamaludin et al., 2022	Applied Environmental Education and Communication	Scopus Q2
9	Babou, 2023	International Journal of Educational Methodology	Scopus Q3
10	Zedda, 2023	Lichenologist	Scopus Q2
11	Akwetey, 2023	Limnology and Oceanography Bulletin	Scopus Q3
12	Børresen et al., 2023	Environmental Education Research	Scopus Q1
13	Audrin & Audrin, 2022	Environmental Education Research	Scopus Q1
14	Yli-Panula, 2018	Sustainability	Scopus Q1
15	Leksono et al., 2015	Educational Horizons	Scopus Q3
16	Coşkunserçe, 2024	Ecology and Evolution	Scopus Q1
17	Soddu Pirellas et al., 2024	Environments - MDPI	Scopus Q1
18	Babou et al., 2023	Education Sciences	Scopus Q2
19	Moss et al., 2014	Nature	Scopus Q1
20	Picanço et al., 2021	Environmental Conservation	Scopus Q1
21	Zukmadini et al., 2024	Indonesian Journal of Science and Technology	Scopus Q1
22	Janžekovič, 2022	The American Biology Teacher	Scopus Q3
23	Bermudez et al., 2022	International Journal of Education in Mathematics, Science and Technology	Scopus Q4
24	Aznar-Díaz et al., 2019	International Journal of Environmental Research and Public Health	Scopus Q2
25	Skupien et al., 2016	Human Dimensions of Wildlife	Scopus Q1

Findings

Biodiversity Learning Model

In this study, researchers identified and compared various learning models that are effective in increasing biodiversity literacy. Therefore, from the 25 articles reviewed, 7 articles were obtained that mentioned a learning model that was able to increase learners' biodiversity literacy. Details can be described in Table 2 below.

Table 2

Biodiversity learning model

No	Author	Learning Model	Synthesis
1	Lo & Tsai, 2022	3D virtual reality architecture in the metaverse (VRAM)	In the learning process of water resources education, it was stated that participants who were given learning and received instruction by involving VRAM had a significant increase in learning experience, learning motivation, learning interaction, self-efficacy, and attendance in learning the concept of environmental conservation.
2	Yli-Panula et al., 2018; Zedda, 2023	Hands-on learning, hands-on instruction, experiential learning, roleplay, and service learning	Effective direct learning must support hands-on experience in nature, interdisciplinary knowledge transfer, active participation, cooperation, the use of digital media in the learning process and increased environmental awareness. But unable to improve high-level thinking skills
3	Coşkunserçe, 2024	Mobile PlantNet	By implementing Mobile PlantNet, behaviour related to biodiversity conservation can be improved. Students can also identify more plant species in their environment than ever before. In particular, the number of plant species that students can recognise increases significantly after using the app. In addition, this research was able to overcome the problem of recognizing plant species that exist around them as "plant blindness". The use of these apps can also increase their interest and knowledge about biodiversity.
4	Aznar-Díaz et al., 2019	Environmental care attitude instrument	Through the implementation of environmental attitude test instruments, primary school teachers have highly positive environmental attitudes. This is important to teach the next generation.
5	Skupien et al., 2016	Classroom-based conservation education programmes and field trips.	The growing population of *Alligator mississippiensis* in a human-dominated landscape presents challenges for wildlife managers. Therefore, managers conducted an evaluation using two classroom-based conservation education programs and field trips. The results showed that respondents had more positive attitudes toward alligators and believed they could coexist.
6	Grúňová et al., 2017	Conservation education programmes	The results of the evaluation of the impact of environmental education programmes on children's short-term and long-term environmental knowledge in West Africa showed a significant increase in knowledge after the programme. Furthermore, the knowledge gained was proven to be long-lasting and contributed to increased awareness of the importance of conservation. However, increased knowledge alone is not enough to drive behavioral change. More targeted awareness campaigns are needed to encourage individuals to take real action in conserving the environment. With a more comprehensive approach, environmental education programs can have a more sustainable impact on conservation behavior.

Curriculum Integration

Ways to integrate biodiversity literacy can be carried out in the educational curriculum, both formal and non-formal education. Based on the 25 articles reviewed, 8 ways or strategies have been carried out in integrating biodiversity into the learning process. The strategy can be detailed in Table 3 of the synthesis results of How to Integrate Biodiversity in Learning below.

Table 3

How to integrate biodiversity in learning

No	Author	How to Integrate Biodiversity in Learning	Synthesis
1	Ardoin et al., 2020; Paradise & Bartkovich, 2021	Integrating local knowledge	Through a new approach to the learning process, it can enrich the learning experience, and actively involve them in seeking knowledge of biodiversity conservation in residents, as well as being able to increase their understanding and literacy of biodiversity
2	Kamaludin et al., 2022	Providing Mangrove Ecosystem Conservation Education	This study assessed the effectiveness of conservation education in improving students' understanding of the mangrove ecosystem in Setiu Wetlands. With 74 students participating in the survey and workshop, the results showed that the benefits of cultural services were less recognized, while regulatory, provision, and support services were considered important. Further analysis showed no significant difference in the improvement of understanding between male and female students, suggesting a need for a more comprehensive educational approach.
3	Babou et al., 2023	Providing Biodiversity Knowledge	The study involved 202 a grade level of 2nd year Baccalaureate. The results showed that only 2% of the students, were able to provide a complete definition of biodiversity that includes three dimensions: species, ecosystems, and genetic diversity. The study found that there was a low to moderate correlation between their representations and the knowledge they acquired related to the biodiversity concepts discussed in the school program.
4	Audrin, 2023; Zukmadini et al., 2024	Textbook	By integrating biodiversity education into compulsory textbooks in the French-speaking region of Switzerland in natural sciences, humanities and social sciences at all levels of education. The results show that it can improve biodiversity literacy, the ability to deal with environmental issues and manage natural resources.
5	Akwetey, 2023	Integrating water resources and biodiversity learning	The activity involved 50 student and 5 teachers. The results showed that participants gained a better understanding of aquatic life forms and their ecological functions as well as the impact of human activities on organisms living in lagoons. and fostering a sense of responsibility to maintain cleanliness and environmental sustainability.
6	Leksono et al., 2015	Conservation Based on Local Wisdom (BKBKL)	Lectures by integrating BKBKL can affect the improvement of biodiversity literacy. This is because BKBKL lectures involve learners' ability to investigate, develop biodiversity process skills and the ability to master concepts so that they can act to appreciate biodiversity.
7	Bermudez et al., 2022	Integrate knowledge about biodiversity education using a holistic approach	Learners have a diverse understanding of biodiversity, with a primary focus on species diversity. However, an understanding of the broader components and attributes of biodiversity is often neglected. The research also found that conceptions of biodiversity among students from ethnic and rural communities were stronger than among students from urban contexts, indicating a link between local knowledge and understanding of biodiversity.

No	Author	How to Integrate Biodiversity in Learning	Synthesis
8	De Oliveira et al., 2020	Integrating biodiversity knowledge	Exploring the biology education approach to teaching wildlife and conservation in urban and rural schools in a semi-arid region of Brazil. The study involved 990 students, with 528 urban and 462 rural students, who were interviewed using a questionnaire. The results showed that students had a high level of knowledge regarding the richness and diversity of birds and mammals among other fauna. Only about 70% said that their educational process discussed wildlife conservation, while almost 50% in both urban and rural contexts showed no conceptual understanding of nature conservation.

The Role of Biodiversity Literacy and Conservation Education

Biodiversity literacy and conservation education play an important role in promoting pro-environmental awareness and action among the public. Evaluation of conservation programs should be more rigorous and based on local cultural contexts for greater effectiveness, while active participation of local communities and integration into formal education curricula are also needed. The following articles can explain this in Table 4 below.

Table 4

The role of biodiversity literacy and conservation education

No	Author	Synthesis
1	Hooykaas et al., 2020	Biodiversity literacy is essential for conservation, yet a gap exists between experts and the public. Professionals have higher species literacy, emphasizing the need for broader education. Conservation education can bridge this gap by promoting inclusive learning and increasing species awareness. By integrating biodiversity literacy into education, society can develop a stronger connection to nature and actively participate in sustainable conservation efforts.
2	S. Thomas, 2016	Conservation Education (CE) approaches are essential in biodiversity conservation. However, challenges remain in evaluating the effectiveness of CE programs. More rigorous, longitudinal, and contextual evaluation methods that consider cognitive, behavioral, social, and ecological aspects are needed. Thus, through a collaborative and culturally integrated assessment approach can increase the effectiveness of CE, ensuring long-term engagement and impactful biodiversity conservation efforts.
3	Børresen, 2023	Education plays an important role in increasing awareness and knowledge of ecosystem services and biodiversity. Through education, students can demonstrate positive attitudes towards environmental conservation, understand the negative impacts of climate change, and the importance of ecosystem services. Education that incorporates conservation materials into school curricula, especially in areas near conservation areas, can increase participation and awareness of local communities.
4	Moss, 2017; Moss et al., 2014a	Visiting a zoo can increase visitors' understanding of biodiversity. While raising awareness, there is a need to ensure that zoos also encourage significant behavioural change to support conservation efforts.
5	Picanço et al., 2021	Teachers' perspectives in the Azores found that although teachers are aware of the importance of conservation, the use of the internet as a tool for teaching about biodiversity has not been maximized. Most teachers focus more on the species level than on the ecosystem or genetic level. This suggests the need for further training for teachers to integrate biodiversity knowledge into the curriculum in a more holistic way.
6	Janžekovič, 2022b	Biodiversity loss is a global challenge that can only be addressed through behaviour influenced by education. Biodiversity literacy must be promoted through educational approaches that reconnect people with nature, recognizing the importance of nature for children's well-being and cognitive development.

Discussion

Theories and Concepts of Conservation Education to Improve Biodiversity Literacy

Conservation education is essential for fostering awareness, knowledge, and behaviors that support biodiversity protection and natural resource sustainability (Leksono et al., 2023). By equipping individuals with the necessary skills and attitudes, these programs encourage active participation in conservation efforts. Research highlights that knowledge gained through conservation education significantly influences conservation beliefs and behaviors (Oražem et al., 2022; Thomas, 2016). Institutions such as zoos and aquariums play a key role in this process by integrating conservation education into their missions, providing hands-on experiences that promote ecological awareness (Mellish et al., 2018).

To ensure the effectiveness of conservation education, a structured evaluation framework is required to assess learning outcomes and behavioral changes (Thomas, 2016). Effective programs employ multidisciplinary approaches that incorporate iterative monitoring and participatory learning, enhancing long-term engagement in conservation efforts (Lukas et al., 2017). However, many programs rely on a top-down pedagogical approach delivered by biologists rather than trained educators, which may limit educational effectiveness (Fernanda Bernárdez-Rodríguez et al., 2021). Addressing this gap by integrating formal education strategies can enhance program impact.

Furthermore, conservation education plays a critical role in raising public awareness about the sustainable management of natural resources, such as water conservation (Valenzuela-Morales et al., 2022). Studies show that well-designed educational practices positively influence public perceptions and attitudes toward conservation (Mormul et al., 2017). To maximize impact, conservation education must incorporate evidence-based strategies that translate knowledge into actionable conservation behaviors, ensuring long-term environmental sustainability (Sakurai & Uehara, 2020).

To achieve sustainable conservation goals, conservation education must continue to be developed and implemented with a holistic and measurable approach. It involves collaboration between different disciplines and stakeholders to ensure that such educational programs not only increase knowledge but also encourage real action in conservation efforts. Through effective conservation education, future generations can be equipped with the knowledge and skills necessary to safeguard and preserve our environment. Conservation education plays a strategic role in addressing global challenges related to biodiversity conservation and environmental sustainability. In an era where pressure on natural resources and biodiversity is constantly increasing, it is important to develop a deep understanding of these issues among the wider community. One effective way to achieve this is through increasing biodiversity literacy, which not only increases knowledge but also fosters concern and responsibility for the environment (Kusumaningrum, 2017; Nugraha et al., 2021)

Biodiversity literacy plays a crucial role in understanding biodiversity concepts as well as promoting conservation efforts. As explained by (Aslan Efe & Efe, 2022), a deep understanding of biodiversity helps individuals and communities realize the importance of preserving biodiversity in their surrounding environment. To introduce biodiversity literacy in the classroom, several techniques have been developed by several previous researchers such as integrating biodiversity education in learning textbooks (Nuraeni et al., 2022) and learning models (Katili & Rahmat, 2020; Rijal et al., 2018). Through biodiversity learning, not only biodiversity literacy increases but also conservation behaviours both through direct and indirect actions. This starts from the surrounding environment first (Ardoin et al., 2020; R. E. W. Thomas et al., 2019)

Improving biodiversity literacy through conservation education is crucial, as has been highlighted in various literature. Stokes et al., (2010) emphasise the importance of educating the public about local conservation, increasing ecological literacy, and promoting collaboration for biodiversity conservation in local land use planning. (Jiménez (2015); and Jiménez et al., 2014) also emphasize the significance of conservation education and counseling programs in fostering public understanding vation. Birdsall & Kelly (2022) propose that effective conservation education occurs

when students engage with local nature and take action to increase biodiversity in their communities. Thus, through targeted conservation education efforts, biodiversity literacy can be improved, which in turn will strengthen conservation behaviour in the community. This approach not only has an impact on local environmental conservation but also contributes to global conservation efforts.

In addition, Fischer et al., (2020) highlight the positive correlation between knowledge about biodiversity and attitudes towards biodiversity-friendly green space management, emphasizing the need to provide environmental information and education about the role of biodiversity in urban areas. Caetano et al., (2023) recommend increased extension and education efforts, especially in areas with economic disparities and weak education systems, to promote biodiversity conservation. Education is emerging as an important element in the success of biodiversity conservation, as noted by Daan et al., (2020), which emphasizes the need for educational initiatives. Faruhana et al., (2022) highlight the important role of educators and policymakers in instilling the positive traits of biodiversity conservation in children through hands-on experience. Coracero (2021) Suggests reviewing the college curriculum to ensure environmental education in all courses of study, with an emphasis on biodiversity conservation. Furthermore, Merino et al., (2022) rewords an interdisciplinary approach to improve students' knowledge and literacy about biodiversity and its conservation. Integrating citizen science, as proposed by Paradise & Bartkovich (2021), can equip students with the knowledge and motivation to contribute effectively to biodiversity conservation. Efe & Efe (2022) showed that biodiversity literacy is included in environmental literacy, emphasizing its importance in science education.

Based on the literature above, the steps that need to be taken to increase biodiversity literacy through conservation education can be concluded including:

1. Community and Student Education: Provide easily accessible and relevant information on the importance of biodiversity and ways to protect it, both through formal schools and community outreach programs.
2. Hands-on Experience: Facilitate hands-on experiences with nature for students, such as outdoor learning programs and local conservation projects, to enhance their engagement and understanding.
3. Collaboration and Public Participation: Encourage active community participation in conservation efforts through citizen science programs and community initiatives, which can increase conservation awareness and action.
4. Multidisciplinary Education: Integrating biodiversity conservation materials in various disciplines and courses in colleges and universities to ensure that all students have a basic understanding of the importance of biodiversity conservation.
5. Inclusive Approach: Addressing economic and educational disparities by providing additional resources and support to underprivileged areas, to ensure that all levels of society receive adequate conservation education.

By implementing these strategies, it is hoped that biodiversity literacy can be significantly improved, which will ultimately support more effective and sustainable biodiversity conservation efforts.

Biodiversity Learning Model

Based on Table 2, states that various innovative learning models have shown effectiveness in improving environmental conservation understanding, attitudes, and behaviour among students. For example, the use of 3D virtual reality architecture in the metaverse (VRAM) by Lo & Tsai (2022) has been shown to improve learning experiences, motivation, interaction, self-efficacy, and participant attendance in learning environmental conservation concepts. This model offers an immersive learning experience that can replace the limitations of direct experience in the real world. The application of various innovative learning models shows great potential in improving environmental and conservation education. The use of technologies, such as 3D virtual reality architecture in the

metaverse (VRAM) and the Mobile PlantNet application, presents new opportunities to make learning more interactive, engaging, and relevant to today's digital generation. VRAM provides an immersive experience that allows students to deeply understand environmental concepts, while Mobile PlantNet helps overcome "plant blindness" and enrich students' knowledge of biodiversity. These technologies not only increase students' motivation and learning experience but also foster interest and caring attitudes towards the environment.

Zedda (2023) emphasizes the importance of direct, hands-on learning in nature, cross-disciplinary knowledge transfer, active participation, and digital media use to enhance students' environmental awareness. Breaking this down, hands-on learning models allow students to engage directly with natural processes, reinforcing conceptual understanding and fostering a deeper awareness of environmental issues. Additionally, these activities promote collaboration and active participation. These skills are particularly crucial in 21st-century learning, as they equip students with problem-solving abilities, critical thinking, and teamwork—competencies essential for addressing complex global challenges in an increasingly interconnected world (Dewi & Rahayu, 2024).

Coşkunserçe (2024) demonstrates that the Mobile PlantNet application effectively enhances biodiversity conservation behavior by addressing "plant blindness" and increasing students' engagement with biodiversity. This effectiveness is evidenced by measurable improvements in students' ability to identify plant species, increased participation in conservation activities, and higher self-reported interest in biodiversity topics. Similarly, Aznar-Díaz et al., (2019) found that teachers with positive environmental attitudes, as measured by standardized environmental attitude instruments, play a crucial role in fostering conservation values among students. Skupien et al., (2016) further reported that a classroom-based conservation education program, combined with field trips, led to a statistically significant increase in students' positive perceptions of species such as Alligator mississippiensis and their willingness to support conservation efforts. Overall, integrating technology, experiential learning, and attitude-focused approaches in conservation education proves to be highly effective in fostering long-term pro-environmental awareness and actions across different educational levels. The implementation of various innovative learning models has proven effective in improving environmental and conservation education. Technologies such as 3D virtual reality (VRAM) and mobile applications such as PlantNet provide more interactive and engaging learning experiences, which can increase students' knowledge, motivation, and engagement in environmental issues. In addition, direct or hands-on learning models that involve real-world experiences provide opportunities for students to be actively involved, which ultimately increases their understanding and awareness of conservation issues.

Instruments to measure environmental attitudes are also important in ensuring that conservation values are taught effectively, starting from teachers to students. The positive attitudes held by teachers towards the environment can have a direct impact on how they teach these values to the younger generation. In addition, conservation education programs that combine classroom-based learning with field experiences have shown success in changing students' perceptions and attitudes towards wildlife, emphasizing the importance of coexisting with other living things.

Overall, the combination of technology, direct experience, and attitude-based approaches in environmental education provides a strong foundation for creating a more environmentally aware and caring young generation. This approach not only increases environmental awareness but also equips students with the critical thinking, problem-solving, and collaboration skills needed to face future ecological challenges. Thus, the integration of this innovative learning method is an important step in supporting environmental sustainability and conservation in the future.

Curriculum Integration

Based on the synthesis results in Table 3, the integration of biodiversity in learning through specific approaches—such as utilizing local potential, applying a multidisciplinary approach, and incorporating hands-on experiences—has been shown to enhance students' knowledge, skills, and

environmental conservation behaviors. These approaches improve learning outcomes by fostering direct engagement with ecosystems, encouraging critical thinking, and connecting theoretical knowledge with real-world applications. However, challenges remain in delivering conservation materials effectively. Studies by Kamaludin et al., (2022) and Babou (2023) highlight difficulties such as the lack of teacher training, limited educational resources, and insufficient curriculum alignment. Addressing these issues requires improved instructional strategies, better resource allocation, and curriculum reforms to ensure a more impactful biodiversity education.

The following is a summary of the results of the article review:

a) Integration of Local Knowledge in the Learning Process

Paradise & Bartkovich (2021) emphasize the importance of integrating local knowledge into the learning process to enhance students' learning experiences. They point out that this approach not only enriches students' knowledge about biodiversity conservation but also actively engages them in seeking this knowledge through direct interaction with the local community. For example, by inviting students to participate in conservation projects involving local communities, students can learn firsthand about traditional ways of preserving their environment. This not only improves their understanding and literacy of biodiversity but also forms a positive attitude towards environmental conservation. Additionally, Dewi et al., (2021) this approach, students can understand the importance of maintaining biodiversity in the context of their daily lives, which in turn can influence their behaviour to support environmental sustainability and make learning more relevant and engaging for students.

b) Mangrove Ecosystem Conservation Education

A study by Kamaludin et al. (2022) highlights the importance of mangrove ecosystem conservation education, which can provide important insights into this often-under-appreciated ecosystem. In this study, 74 students were involved in learning about mangrove ecosystem conservation. However, most respondents were not familiar with the learning material. These findings suggest the need for increased efforts to introduce the topic of mangrove ecosystem conservation to students, both through formal curricula and extracurricular activities. Education about mangroves is important because this ecosystem plays an important role in maintaining ecological balance, including as a habitat for various species, protecting the coast from erosion, and absorbing carbon. Through a comprehensive educational approach, students can better understand the importance of preserving mangrove ecosystems and their role in preserving nature.

c) Increasing Knowledge of Biodiversity

Babou et al. (2023) identified that students' understanding of biodiversity is still limited, with only 1.82% of students being able to provide a complete definition of biodiversity that includes three dimensions: species, ecosystems, and genetic diversity. This study showed a low to moderate correlation between students' representations and the knowledge they gained from the school curriculum regarding the concept of biodiversity. These results underscore the need for a more comprehensive approach to environmental education, which does not only focus on one aspect, such as species but also includes ecosystems and genetic diversity. This holistic approach will enable students to understand the interrelationships between ecosystem components and how various factors affect the survival of species and the balance of the ecosystem.

d) The Importance of Interdisciplinary Integration in Environmental Education

Audrina (2023) suggests that integrating multiple disciplines in environmental education, as is done in the environmental education curriculum in the French-speaking region of Switzerland, can provide a more comprehensive understanding of environmental issues. In compiling textbooks, it is important to combine perspectives from multiple disciplines such as biology, geography, economics, and social sciences. This not only helps students understand environmental issues from multiple perspectives but also enriches their ability to solve environmental problems. With this interdisciplinary approach, students can develop broader knowledge and better skills in responding to complex environmental challenges.

e) Water Resources and Biodiversity Education

A study by Akwetey (2023) highlighted the importance of integrating learning about water resources and biodiversity to improve students' understanding of aquatic ecosystems and their ecological functions. In an activity involving 50 students and 5 teachers, the results showed that participants gained a better understanding of aquatic life and its ecological functions as well as the impact of human activities on organisms living in the lagoon. In addition, this activity succeeded in fostering a sense of responsibility for maintaining environmental cleanliness and sustainability. This study shows that learning that focuses on aquatic ecosystems can be an effective means of educating students about the importance of maintaining ecosystem balance and their active role in conservation efforts.

f)Integration of Nature Conservation in the School Curriculum

Oai (2019) highlighted the importance of integrating conservation content into routine lessons such as biology and geography, as well as through activities such as field trips and environmental clubs. The results of this approach showed that students not only gained better knowledge and skills about nature and biodiversity conservation but also developed positive attitudes and behaviours towards the environment. By involving students in hands-on activities such as field trips, they can observe firsthand the impacts of human activities on the environment and the importance of conservation efforts. This approach can also increase students' active participation in environmental conservation efforts, both at school and in their communities.

g) Local Wisdom-Based Conservation

Leksono et al. (2015) discuss the benefits of using local wisdom-based conservation in lectures to improve students' biodiversity literacy. By integrating BKBKL in lectures, students can engage in investigative activities that allow them to develop process skills in biodiversity and the ability to master important concepts. This approach also encourages students to appreciate biodiversity and understand the importance of conservation from a local perspective, which is often more relevant and understandable to students than a more abstract global approach. The use of local wisdom as a learning resource can also increase students' awareness of the cultural and ecological values in their environment, which ultimately supports sustainable environmental conservation. The application of a learning model based on local wisdom through the reconstruction of original knowledge can significantly improve students' conservationist character and their investigative abilities (Khusniati et al., 2017; Parmin et al., 2016).

h) Holistic Approach to Biodiversity Education

Bermudez et al. (2022) emphasized the importance of a holistic approach in biodiversity education, which recognizes students' diverse understandings of biodiversity. This study found that understanding the concept of biodiversity often focuses on species diversity, while broader components and attributes are often overlooked. In addition, the concept of biodiversity among students from ethnic and rural communities was stronger than that of students from urban contexts, indicating a relationship between local knowledge and understanding of biodiversity. This suggests that integrating local knowledge and cultural perspectives in biodiversity education can provide students with deeper and more relevant understandings. With a holistic approach that considers local context and cultural diversity, biodiversity education can be more effective in fostering broad understanding and positive attitudes towards environmental conservation.

The integration of local knowledge, interdisciplinary approaches, and contextualized educational strategies are key to improving biodiversity literacy among students. The results of various studies indicate that by combining local knowledge and innovative educational approaches, students can develop a more comprehensive understanding of biodiversity and form attitudes and behaviours that support environmental conservation. Therefore, it is important for educators and educationpolicymakerss to adopt learning strategies that involve local knowledge, practical activities, and holistic approaches in environmental education curricula. Thus, biodiversity education not only enhances students' knowledge but also prepares them to become responsible and proactive citizens in environmental conservation efforts.

Conclusion

The following are the conclusions based on the three main topics of discussion:

1. Biodiversity Literacy Theory and Concept: Biodiversity literacy is the ability to understand and use knowledge about biodiversity to solve environmental problems. This literacy is more than just a basic understanding of species and ecosystems; it includes the ability to contribute to environmental conservation and the formation of responsive attitudes towards environmental issues. Through conservation education, individuals can develop a deeper understanding of the importance of biodiversity, which in turn can encourage pro-environmental behaviour.
2. Biodiversity Learning Models: Various learning models have been developed to improve biodiversity literacy. For example, the use of technology such as 3D virtual reality and mobile applications can increase student interaction and motivation to learn, as well as their understanding of environmental conservation concepts. In addition, direct and attitude-based learning approaches, such as conservation education programs combined with field trips, are effective in increasing students' positive attitudes towards species and environmental conservation.
3. Curriculum Integration of Biodiversity Literacy: Integration of biodiversity literacy into formal and non-formal education curricula can be done through various strategies, including the use of local knowledge, multidisciplinary approaches, and direct experiences. This integration not only improves students' knowledge and skills about environmental conservation but also forms attitudes and behaviours that support environmental sustainability. Challenges in this implementation include the need for more effective teaching methods and curriculum adjustments to achieve better results.

Recommendations

To strengthen biodiversity literacy, this research suggests specific actionable recommendations for educators and policymakers:

1. Educators: Incorporate hands-on, technology-enabled learning activities in the classroom to engage students actively and enhance their understanding of biodiversity.
2. Policymakers: Develop and implement policies that prioritize the integration of biodiversity education within national curricula and support professional development for educators in this area.
3. Community Engagement: Encourage collaboration between schools and local communities to promote knowledge sharing and participation in biodiversity conservation efforts.

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