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Enhancing Student Sustainability Awareness in Science Education: A Systematic Literature Review

M. Andriansyah✉, Indri Yani, Sandi Budiana, Didit Ardianto, Indarini Dwi Pursitasari

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Universitas Pakuan, Indonesia

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Abstract

Sustainability awareness in secondary school students is an important element in modern education that aims to address global challenges such as climate change and environmental degradation. This study used a systematic literature review (SLR) approach to evaluate the level of sustainability awareness, the effectiveness of learning media, and the challenges of implementing sustainability-based learning. The analysis was conducted on 10 articles selected based on strict inclusion and exclusion criteria, using the PRISMA method and NVivo software. Results show that students' emotional awareness is at the highest level, followed by sustainability knowledge, while behavioral awareness is still low. Education for Sustainable Development (ESD)-based learning media proved most effective, followed by web-based applications and learning modules. Key challenges include teacher readiness, time constraints, and learning resources. The study concludes that there is a need for the integration of sustainability values in the curriculum, intensive training for teachers, and the use of innovative learning media to improve the success of sustainability education.

How to Cite

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✉ Correspondence Author:
E-mail: mandriansyah11@gmail.com

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INTRODUCTION

Sustainability has become an increasingly pressing global issue due to complex environmental, social, and economic challenges. Recent data shows that climate change, environmental degradation, and social injustice require urgent attention through a holistic approach (Yuzbasioglu, 2023). Education is crucial in responding to these challenges by instilling sustainability awareness, especially in younger generation. High school students are in a significant cognitive and moral development phase, making them a strategic target for sustainability learning (Yuzbasioglu, 2023).

Science education plays an important role in fostering students' awareness of sustainability. Through science learning, students can understand scientific concepts relevant to sustainability issues, such as climate change, energy conservation, and natural resource management (Nowotny et al., 2018). Scientific literacy also equips students with the critical thinking skills to analyze and solve complex environmental problems (Suastrawan et al., 2021). This approach enhances students' conceptual understanding and motivates them to take concrete actions sustainability.

Various studies have shown that sustainability-based education can enhance students' understanding of global issues, but secondary school students' sustainability awareness level still varies significantly. Previous studies have shown that despite the increasing access to information about sustainability, students' in-depth understanding and application of sustainability values in their daily lives are still relatively low (Nations, 2020). In addition, implementing sustainability education faces major challenges, such as a lack of curriculum integration, limited resources, and minimal teacher training (Akins et al., 2019; Janse van Rensburg & Oguttu, 2022).

The Digital technology, project-based approaches, and interactive learning materials can enhance student engagement in sustainability education (Bringle & Clayton, 2020; Islam & Faisal Ali Khan, 2024; Tomas et al., 2015). However, most studies remain fragmented, and systematic reviews comprehensively assessing the effectiveness of these strategies for secondary school students are still limited. Furthermore, while secondary school students are often identified as particularly vulnerable to social and environmental changes, research specifically addressing their needs in context of sustainability remains scarce.

This study aims to examine the level of sustainability awareness among secondary school students, identify effective learning interventions to support their sustainability awareness and explore challenges faced by implementing sustainability education at this level. Employing a systematic literature review methodology and utilizing NVivo analytical tools, this research provides an innovative approach to uncovering patterns and themes relevant to current challenges in sustainability education. By synthesizing recent literature, study contributes theoretically and practically by offering insights to improve effectiveness of sustainability education in secondary schools.

METHOD

This study employs a Systematic Literature Review (SLR) approach to identify, evaluate, and synthesize literature related to sustainability awareness among secondary school students. Article searches were conducted using Publish or Perish software, with Scopus and Google Scholar as primary databases. The combination of keywords used for this purpose is presented in Table 1.

Table 1. Keyword String Each Research Question

Research Question	Keyword String
What is the level of sustainability awareness among secondary school students?	"Sustainability awareness" AND "middle school students".
What learning interventions are effective in supporting sustainability awareness?	"Sustainability awareness" AND "effective media" OR "learning resources" AND "students"
What challenges are encountered in implementing sustainability education in secondary schools?	"Sustainability awareness" AND "teachers' challenges" AND "middle school"

Boolean Operators (AND, OR) were used to ensure broad coverage while maintaining relevance to the research focus. Searching the Scopus database yielded 593 articles, while Google Scholar produced 993, resulting in 1.586 articles. These were then screened based on inclusion and exclusion criteria. Table 2 outlines inclusion and exclusion criteria used as guidelines to filter articles to address the research questions effectively.

Table 2. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Articles published between 2020–2024	Articles published outside the 2020–2024 timeframe
Articles written in English	Articles not written in English
Articles from international journals indexed by Scopus, ERIC, Copernicus, or national journals indexed at least Sinta 2	Articles not indexed by Scopus, ERIC, Copernicus, or below Sinta 2

Inclusion Criteria	Exclusion Criteria
Empirical research articles	Non-empirical research articles
Participants are secondary school students	Participants not in secondary school, such as university students or teachers
Articles focused on science and its teaching	Articles unrelated to science or its teaching
Articles aligned study focus and research questions	Articles irrelevant study focus/research questions

The article screening and selection process used the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology. The PRISMA diagram visually represents the selection stages, including removing duplicates, title and abstract screening, and full-text assessment. This process ensures that only articles meeting the inclusion and exclusion criteria are analyzed, guaranteeing high relevance and quality. The PRISMA diagram detailing the article selection flow is presented in Figure 1.

The quality of studies was assessed using a rubric adapted from Mullet et al., (2017). This rubric includes seven key aspects: research objectives and problems, literature review, conceptual framework, population description, sampling procedures, data collection methods and tools, results and conclusions, and research significance. Each aspect was rated on a 4-point scale, with 1 = Does not meet standards, 2 = Partially meets standards, 3 = Meets standards, and 4 = Exceeds standards. The maximum score an article could achieve was 28, with a minimum threshold of 19 required for inclusion in further analysis. Articles scoring below 19 were deemed not to meet established quality standards and were excluded. This approach ensures that only high-quality, relevant articles are used to address research questions.

Data from the selected 10 articles were extracted using a systematic worksheet to identify research aims and questions, methodologies, including design, sample, and analysis techniques, and key findings on sustainability awareness, effective learning media or resources, and challenges in implementing sustainability education. Data analysis was conducted thematically using NVivo software, facilitating data organization, pattern identification, and theme determination relevant to the research questions (Doris M. & Brennan, 2018). This process addressed the three primary research questions and provided insights into trends and research gaps.

Thematic coding focused on three main categories: students' sustainability awareness, effective learning media or resources, and challenges in implementing sustainability education. Subcodes for each category were developed to group information in greater detail. These grouped data provide initial insights into key aspects for further analysis. Subsequently, findings from these categories and subcodes will be narrated in-depth and visualized through tables, diagrams, or other graphical representations to understand the research outcomes comprehensively.

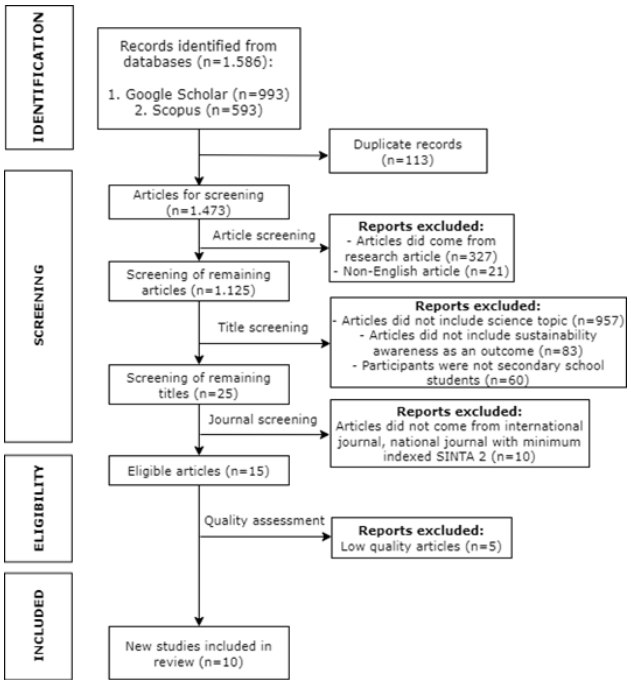

Figure 1. PRISMA Diagram of Selection Article

RESULT AND DISCUSSION

A total of 10 articles were selected for analysis after rigorous screening based on the inclusion criteria. These articles were published between 2020 and 2024, written in English, and derived from international or national journals indexed by at least Sinta 2. The studies focused on science education involving secondary school students and employed empirical approaches. The following table summarizes the key information from each article, including the authors, year of publication, research titles, methodologies used, and main findings.

Table 3. Summary of Articles Selected based on Inclusion Criteria

Author(s) (Years)	Title	Finding
Setiawan et al. (2023)	Sustainability Awareness, Engagement, and Perception of Indonesian High School Students during Sustainability Project Based Learning Implementation in Biology Education	The ESD project in Biology lessons increased students' awareness and engagement with sustainability issues, as evidenced by changes in mindset and tangible actions, such as creating campaign videos. The PjBL model effectively stimulated student engagement with popular activities like designing clothing from waste, though challenges such as time limitations and low self-regulation remained.
Sobari et al. (2022)	Critical Thinking Skills and Sustainability Consciousness of Students for the Implementation Education for Sustainable Development	The results show that students' critical thinking skills fall into the moderate category with an average score of 74.4%, highest in basic skills (78.1%), and lowest in concluding (64.8%). Meanwhile, students' sustainability awareness is in a suitable category, with an average score of 79.8%, covering knowledge (82.1%), attitude (79.5%), and sustainability behavior (77.8%).
Ekamilasari et al. (2021)	Critical thinking skills and sustainability awareness for the implementation of education for sustainable development	The study found that students' sustainability awareness was at a moderate level (average score 3.65), with the highest emotional awareness (86.92%), followed by behavioral and attitudinal awareness (70.63%), and low practical sustainability awareness (37.95%). Students' critical thinking skills were categorized as weak, with an average score of only 28.68%.
Putri et al. (2024)	Developing Global Warming Module Based on Education for Sustainable Development to Increase Middle School Students' Understanding and Sustainability Awareness	The ESD-based module demonstrated excellent validity in terms of media and content. N-Gain test results showed a moderate improvement in the experimental class and a low improvement in the control class. Effect size tests indicated a high criterion for the experimental class and a moderate one for the control class.
Annisa et al. 2024	STEM ESD-Based Learning with "Arduino Uno-Based Trash Can" to Improve Students' Critical Thinking Skills and Sustainable Awareness in Learning Environmental Pollution	STEM ESD-based learning with the "Arduino UNO-Based Trash Can" project improved students' critical thinking skills with an N-Gain score of 0.202, although the effect was not uniform. However, this learning method had limited significance in enhancing sustainability awareness, with an N-Gain score of only 0.040.
Irawan et al. (2024)	Profile Analysis of Creative Thinking Skills and Sustainability Awareness of Senior High School	The findings show that students' creative thinking skills are categorized as moderate for fluency (65%), elaboration (67%), originality (67%), and creativity for flexibility (74%). Students' sustain-

Author(s) (Years)	Title	Finding
	Students in Polewali Mandar Regency	ability awareness is categorized as moderate for behavioral and attitudinal awareness (68%) and practical awareness (59%), and high for emotional awareness (78%).
Zulkarnaen et al. (2023)	Analysis of Students' Sustainability Awareness of the Environment	The study examined the sustainability awareness of SMAN 1 Ciasem students concerning environmental pollution topics. Results showed an average sustainability awareness score of 3.14 for positive statements and 1.89 for negative statements, falling into the high category. A gender-based difference in awareness was found, with 77.19% of male students and 78.86% of female students showing positive awareness.
Utami et al. (2023)	Development of Global Warming E -Module Based on Socio Scientific Issues (SSI) to Improve Students' Critical Thinking Skills and Sustainability Awareness	EThe SSI-based global warming e-module showed high validity, with media (91%), content (97%), and CVI (0.99) scores. Its implementation enhanced students' critical thinking skills with an N-Gain of 0.78 (high category) and sustainability awareness with an N-Gain of 0.45 (moderate category). Student responses to the e-module were very positive, with an average score of 91%.
Mylonas et al. (2022)	Playful interventions for sustainability awareness in educational environments: A longitudinal, large-scale study in three countries	The study evaluates the use of the GAIA Challenge web application to enhance children's awareness of sustainability and energy across more than 25 schools in three countries. Of the 3,762 registered users, around 20% completed all content, particularly with the support of community competitions. Results showed an increase in children's awareness of sustainability issues.
Setiawan et al. (2023)	Gender differences and the correlation of environmental knowledge with sustainability awareness after ESD-PjBL implementation	The study found that Indonesian students had high environmental knowledge but a low understanding of global warming. Students' sustainability awareness, including the frequency of sustainability practices, was also high. Female students showed higher knowledge, awareness, and sustainability behaviors than male students. Environmental knowledge had a moderate positive correlation with sustainability practices but a weak correlation with sustainability awareness. Sustainability practices had a low correlation with sustainability awareness.

RQ1: Level of Sustainability Awareness in Secondary School Students

The level of sustainability awareness in secondary school students shows that emotional awareness and awareness of sustainable practices are the most dominant aspects, each accounting for 30.77 percent. This reflects the high emotional sensitivity of students to sustainability issues and their tendency to engage in practical actions like recycling. Sustainability knowledge ranks third with a percentage of 23.08 percent, indicating a developing theoretical understanding, though still in need of strengthening. On the other hand, behavioral awareness and attitudes only reach 15.38 percent, suggesting that consistent real actions based on sustainability understanding remain a challenge. This data highlights the need for a holistic approach in sustainability education that emphasizes emotional aspects and strengthens students' knowledge and practical application.

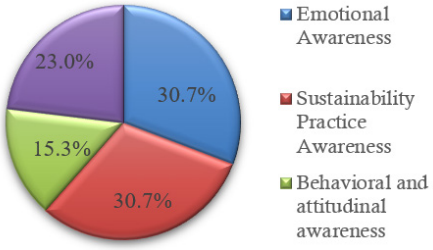

Figure 2. Level sustainability awareness

Sustainability Practice Awareness

As shown in Figure 2, despite being at a fairly good level, sustainability practice awareness is still lower than emotional awareness. Irawan et al., (2024) state that sustainability practice indicators of students are only in moderate category, with an average score of 59%, indicating that sustainability practices are only moderately implemented. This finding is supported by Zulkarnaen et al. (2023), who found that sustainability practice awareness is the second-highest indicator after emotional awareness. However, Mylonas et al. (2023) noted an increase in sustainability practice awareness in students after receiving game-based interventions, showing the potential for improvement through innovative approaches.

Emotional Awareness

The analysis reveals that emotional awareness ranks highest compared to other aspects of sustainability awareness. Several articles indicate that students have a good emotional sensitivity to sustainability issues. For example, Ekimalasari et al. (2021) reported that students achieved high scores on emotional awareness indicators, with a percentage of 86.92%, showing concern and care for the environment. However, practical sustainability actions were still minimal. Irawan et al. (2024) also revealed that the average score for the emotional awareness indicator was 78%, reflecting that students often feel concern, sadness, and motivation regarding environmental issues. Similarly, Zulkarnaen et al. (2023), reported an average percentage of 82.30%, placing emotional awareness as the highest sub-code in students' sustainability awareness.

This study aligns with previous research showing that emotional awareness is fundamental to building students' sustainability awareness. Ienna et al. (2022) state emotional aspects, such as empathy and environmental concern, significantly motivate students to engage in sustainability actions. This is reinforced by Steg et al. (2017) who found that emotional responses to environmental issues, such as worry about climate change impacts, are more effective in driving sustainable actions than theoretical knowledge alone.

Research by Altassan (2023) shows that implementing long-term interventions integrated into school curriculum effectively raises students' awareness of sustainability practices. This is consistent with findings by Mylonas et al. (2023), who noted that innovative interventions, such as cross-cultural learning programs, enriched students' experiences and increased sustainability awareness both emotionally and practically.

Sustainability Awareness Knowledge

Regarding sustainability awareness knowledge, Sobari et al. (2022) report that the knowledge construction of sustainability has the highest percentage at 82.1 percent in the sustainability awareness profile of students. This indicates that many students have a good theoretical understanding of sustainability issues. However, Mylonas et al. (2023) noted that only 57.1 percent of students believed they had learned something interesting about energy from an educational challenge. This finding shows that although theoretical understanding of sustainability is quite high, direct experience and engaging learning could be improved to maximize its impact.

RQ2: What Learning Interventions Are Effective in Supporting Sustainability Awareness?

As shown in Figure 3, learning interventions based on ESD (Education for Sustainable Development) occupy the highest position with a percentage of 58.33%, indicating that this approach is highly effective in supporting sustainability learning by integrating environmental values into students' learning processes. The second most commonly used learning intervention is web-based applications, with a percentage of 25%, offering interactivity and flexibility in accessing learning materials. Learning modules rank third with a percentage of 16.67%, emphasizing that conventional media remains relevant to reinforce students' theoretical understanding. These findings highlight the importance of combining ESD-based approaches, digital technology, and conventional materials to provide a holistic and effective learning experience in enhancing students' sustainability awareness.

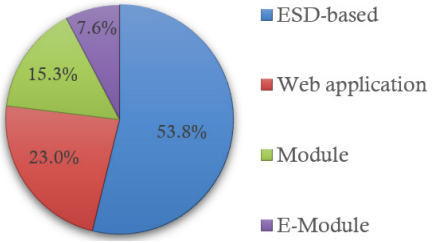

Figure 3. Learning Interventions

Learning Interventions Based on ESD

Learning interventions based on ESD (Education for Sustainable Development) have proven to be highly effective in increasing students' sustainability awareness, with the main subcategories being ESD PJBL (Project-Based Learning) and ESD STEM. Setiawan et al. (2023) showed that ESD PJBL integrated into biology learning changed students' mindsets from less concerned to more aware of sustainability. Students understood sustainability values and applied them through practical activities such as making campaign videos and reflective journals. This result is consistent with Wals et al. (2014) who stated that project-based learning effectively builds student engagement with environmental issues and enhances critical thinking skills. Additionally, Tilbury et al. (2015) research emphasized the importance of project-based approaches in strengthening students' understanding of sustainability values.

ESD STEM introduces innovation through technology implementation, although its impact on students' sustainability behavior tends to be moderate. Puspha Annisa et al. (2024) revealed that STEM-based learning, such as the use of "Arduino Uno-Based Trash Can," was effective in increasing students' understanding of sustainability (sustainable knowingness). However, changes in sustainability behavior were not yet significant. This finding is supported by Orr et al. (2020), who showed that technology-based learning helps students understand the environmental impact of technological innovations. Leicht et al. (2018) , in a UNESCO report, also highlighted success of STEM approach in providing cross-disciplinary learning experiences relevant to sustainability issues. Sterling et al. (2017) added that integrating sustainability values into technology-based media can strengthen long-term impact of sustainability education. Thus, ESD PJBL provides more holistic results in building students' sustainability awareness, while ESD STEM offers additional potential through attractive and relevant technological innovations for modern era.

Web Applications

Web applications are one of the effective learning media for enhancing students' sustainability awareness, as seen in the research by Mylonas et al. (2023) through GAIA Challenge platform. This application uses simple gamification mechanisms, such as inter-group competitions, to increase student engagement in class and outside formal learning times. These findings align with Hamari et al., (2019) who stated gamification in digital applications can enhance students' intrinsic motivation to learn about environmental issues. Chen & Chiu (2016) affirmed that competition-based designs raise awareness and encourage students to take real action. Thus, applications like GAIA Challenge combine technology, gamification, and sustainability education to create engaging and effective learning experiences.

Module

The ESD-based learning module is an effective medium for enhancing students' theoretical understanding of sustainability. Sobari et al. (2022) report that ESD-based modules are designed with easily accessible materials that can be used independently, providing flexibility in learning and helping students systematically internalize sustainability concepts. This finding aligns with Fatemi & Islam, (2016), who assert that sustainability-based modules bridge theory and practice, and Tilbury et al. (2015), who emphasize that contextual modules strengthen students' awareness of environmental impacts. Sterling et al. (2017) also found that modules incorporating explicit sustainability values can enhance students' understanding. Thus, ESD-based modules serve as a relevant medium in building a profound and contextual foundation for students' understanding of sustainability.

E-Module

E-modules based on Socio-Scientific Issues (SSI) have proven effective in enhancing students' sustainability awareness through a digital approach supports critical learning about environmental issues. Utami et al. (2023) report that SSI-based e-modules led to an average N-Gain score increase of 0.78, indicating students could deeply understand sustainability issues in both social and scientific contexts. This finding is in line with Seruni et al. (2020), who found that problem-based e-modules improve students' critical thinking abilities, and Suastrawan et al. (2021) who stated that SSI-based e-modules can enhance students' critical thinking skills. Additionally, van Valkengoed & Steg (2019) note that e-modules containing real-world case studies can motivate students to adopt sustainable actions. Zarkasih et al. (2023) further emphasize SSI-based e-modules encourage students think reflectively and creatively in addressing global sustainability challenges. Therefore, SSI-based e-modules are relevant medium for building sustainability awareness through flexible, context-based digital approach.

RQ3: Challenges in Implementing Sustainability Education

Curriculum Relevance

The national curriculum plays a pivotal role

in shaping how sustainability education is implemented in schools. In Indonesia, although the Merdeka Curriculum (Kurikulum Merdeka) and prior revisions have included themes related to environmental education and global citizenship, the integration of sustainability concepts remains fragmented and often lacks explicit pedagogical guidance. Studies reviewed in this research (e.g., Setiawan et al., 2023; Sobari et al., 2022) indicate that the absence of clear curriculum standards and sustainability learning outcomes contributes to inconsistent implementation across schools.

Furthermore, the curriculum often emphasizes cognitive achievement over affective and behavioral aspects of sustainability awareness, which limits holistic development in students. Teachers are frequently left without concrete frameworks or structured materials that align with national standards while promoting sustainability competencies. This gap reinforces the need for curriculum developers to embed Education for Sustainable Development (ESD) more explicitly and systematically across subjects, supported by teacher training and resource development.

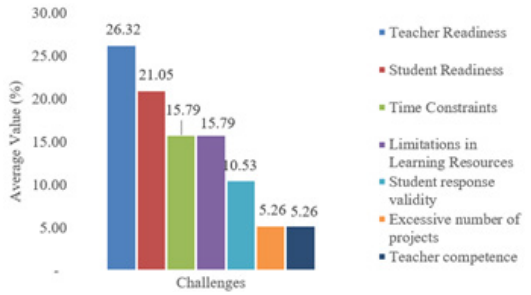

Figure 4. Graph of challenges in implementation

As depicted in Figure 4, teacher readiness is the primary challenge in implementing sustainability education at the secondary school level, accounting for the highest proportion at 26.32%. Teachers often face difficulties delivering sustainability content due to limited understanding or a lack of relevant training. The second major challenge is student readiness, accounting for 21.05%, indicating that many students do not fully comprehend or are not motivated to engage in sustainability education. Moreover, time constraints and limited learning resources contribute 15.79%, suggesting that logistical factors and access to quality materials still pose significant barriers. Student response validity is also a concern, at 10.53%, highlighting that some students may provide inadequate responses during the learning process. Lastly, challenges such as an excessive number of projects and teacher competence each represent 5.26%, indicating that, although these factors have a smaller contribution, they still play a role in influencing the success of sustainability education.

Teacher Readiness

Teacher readiness remains a critical challenge in implementing sustainability education, as emphasized by Setiawan et al. (2023), who underscore the importance of teachers in monitoring student progress. However, Ekimalasari et al. (2021) note that a lack of teacher efforts to encourage sustainability practices among students constitutes a significant barrier, while Puspha Annisa et al. (2024) demonstrate that unclear technical instructions from teachers often result in students neglecting sustainability tasks. Mylonas et al. (2023) add that teachers' limited technical competence can affect the success of application-based learning. Sobari et al. (2022) emphasize the lack of initiative from teachers in motivating students to practice sustainability. These findings are supported by Andersson & Palm (2017) who state that intensive teacher training enhances the capacity to integrate sustainability, and Birdsall (2014) who notes the importance of teachers' understanding of sustainability values. Additionally, Backman et al. (2019) highlight the significance of experience-based training and curriculum development based on sustainability, while López et al. (2024) emphasize that collaboration among teachers can enhance creativity and innovation in sustainability education. Overall, teacher readiness is key to the success of sustainability education, with an urgent need for training, technical guidance, and institutional support.

Student Readiness

Student readiness presents a significant challenge in the implementation of sustainability education. Setiawan et al. (2023) report that students frequently encounter time constraints in completing projects. Mylonas et al. (2023) found that students' motivation tends to be extrinsic, often driven by teacher encouragement, with a noticeable decline in student interest after enrollment. However, simple quiz-based interventions have proven effective in enhancing student engagement with sustainability issues. This finding aligns with Valerio (2012) who emphasizes the importance of intrinsic motivation. Salinas-Navarro et al. (2022) also highlight that experiential learning can foster student interest in sustainability, Gifford et al. (2018) note that psychological barriers such as environmental apathy can be overcome through engaging pedagogical approaches. Evans et al. (2021) stress the importance of designing relevant materials, and Brundiers & Wiek, (2017) suggest that time management skill development can assist students in effectively completing sustainability projects. Therefore, stu-

dent readiness can be enhanced through intrinsic motivation, relevant content, and strategically designed interactive approaches.

Time Constraints

Time constraints are a significant challenge in implementing sustainability education. Puspha Annisa et al. (2024) note that raising sustainability awareness is not a one-off process, but rather requires a long-term commitment with consistent time and effort. In addition, the time needed to deliver sustainability messages depends on the audience, the media used and delivery method.

This finding is in line with Aldabbus (2018), who highlighted that project-based learning requires sufficient time allocation to maximize student understanding. (Gregersen-Hermans, 2021) observed that integrating sustainability values into learning requires additional time to ensure student internalization. Furthermore, McGarry et al. (2015) argue that flexibility in curriculum scheduling can provide sufficient space for deeper sustainability learning.

Other Challenges

Other challenges identified in the literature include limitations in learning resources, excessive projects, validity of student responses, and teacher competence, all of which require attention for successful sustainability education implementation. Limited learning resources remain a key challenge, as highlighted by Puspha Annisa et al. (2024), who noted that the absence of contextual materials often hampers students' understanding. However, digital resources and collaborative efforts with environmental organizations, as suggested by Sarva & Purina-bieza, (2023) and Suwanprapha et al. (2022), offer potential solutions to address this limitation.

Excessive projects can overwhelm students, with Setiawan et al. (2023) recommending consolidation into fewer, larger projects for better focus. Similarly, Mylonas et al. (2023) emphasize the importance of balanced student engagement during projects. Validity of student responses is another minor issue, where clear survey guidelines, as noted by Marsh & Roche (2018), could improve accuracy. Teacher competence, while less significant, still poses challenges. Mohammed et al. (2020) highlighted disparities in outcomes due to uneven training. Addressing this through consistent teacher development programs can help bridge the gap.

CONCLUSION

This study reveals that the level of sustainability awareness among secondary school students falls within the moderate to high category, with emotional awareness showing the most notable results compared to practical and behavioral awareness. ESD-based learning media are the most effective in supporting and enhancing students' sustainability awareness, followed by web-based applications that offer interactivity and flexibility. Conventional learning modules also contribute significantly, particularly in reinforcing students' theoretical understanding. However, implementing sustainability education faces several challenges, including time constraints, teacher and student readiness, and limitations in learning resources. Therefore, an integrated, innovative, and technology-based pedagogical approach is necessary to overcome these challenges and ensure the success of sustainability education in secondary schools. Some limitations still exist even though this study used a strict selection procedure to guarantee the inclusion of relevant, high-quality literature. The conclusions are based only on secondary data, therefore interpretations rely on the context and data reporting methods used in each original study. NVivo's theme coding assisted in identifying useful trends, but the findings are still limited by the breadth and depth of the original publications' approaches. This study could be strengthened by future research that uses meta-analytic methods to quantify the impact of different sustainability education initiatives. Furthermore, empirical research that directly contrasts various instructional approaches for example, ESD-PJBL against ESD-STEM would be helpful in determining the most effective tactics for raising awareness of sustainability. Examining alternative educational levels or regional variations could potentially yield more comprehensive understandings of the efficacy of sustainability education in various settings.

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