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A Systematic Literature Review on Practical Work in Sustainability

Ulku Seher Budak [1], Hakan Akcay [2] *

[1] Department of Mathematics and Science Education, Bogazici University, Istanbul, Türkiye, 0000-0002-4047-9920
[2] Department of Mathematics and Science Education, Bogazici University, Istanbul, Türkiye, 0000-0003-0307-661X
* Corresponding author: Hakan Akcay (hakan.akcay@bogazici.edu.tr)

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Abstract

This review examined research trends in practical works on sustainability in peer-reviewed, empirical studies indexed in the Web of Science database from the first mention through the first half of 2025. This qualitative study used a content analysis approach to identify trends in the practical work in sustainability by using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guideline. The result revealed that there is a fluctuating publication trend with periodic increases and decreases in research over the years, mainly from the United States and Germany. Although instructional interventions were used extensively in the studies, extracurricular and pedagogical development program interventions were rarely used. Most studies used hands-on laboratory activities, while virtual and remote laboratories were underused. While most participants were university students, K-12 students, academics, and the public were the least represented. This study provides empirical evidence of current research gaps and the need for multiple stakeholders.

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Introduction

There are many interconnected global problems, such as climate change, hunger, and water crises. These problems are becoming increasingly complex. Therefore, the need to address sustainability issues is growing every day. Sustainability is the concept that individuals are responsible for their awareness of and behavior toward nature for the benefit of present and future generations (Baumgärtner & Quaas, 2010). Sustainable development is defined by the World Commission on Environment and Development (1987) as "the development that meets the needs of the present without comprising the abilities of future generations to meet their own needs" (Rieckmann, 2017). At the heart of the UNESCO 2030 agenda are the 17 Sustainable Development Goals (SDGs), which are universal and transformational goals aimed at ensuring a sustainable and prosperous life on Earth for all. The SDGs address major global sustainability issues, such as hunger, inequality, and systemic barriers to progress. In order to achieve these interconnected goals, all countries need to develop policies and take urgent action (Rieckmann, 2017).

Practical work is an essential part of implementing, adopting, and promoting sustainability. Therefore, practical work needs to be integrated into sustainability efforts (Ferk Savec & Mlinarec, 2021). According to Millar (2010), practical work is defined as "*any science teaching and learning activity in which the students, working individually or in small groups, observe and/or manipulate the objects or materials they are studying*" (p. 109).

Practical work includes laboratory work, hands-on work, experiments, science practices, and science inquiry. In the UK, the term "practical work" is often used, while in the US, the term "laboratory work" is often used (Gericke et al., 2023). For this reason, the authors of this study prefer to use the term "practical work" throughout the article. Practical work helps individuals actively participate in sustainability, raise their awareness of it, and encourage behavioral changes. It also increases social awareness and sensitivity (Uzorka et al., 2024). Therefore, it is of great importance to review and research the gaps in practical works on sustainability.

As a result of the literature review conducted by the researchers in this study, practical work reviews teaching and using of virtual reality (Altay & Balım, 2024; Amarulloh & Aswie, 2024); Lopes et al., 2024), emerging trends of virtual laboratories (Ajizah et al, 2024) laboratory safety (Emiroğlu & Yılmaz, 2024), hands-on laboratories (Hidayat et al., 2024; Khoirunnisa et al., 2024), and both virtual and remote laboratory (Heradio et al., 2016). However, these studies addressed specific types of practical work but did not address sustainability specifically. To the best of the authors' knowledge, no review or bibliometric analysis focusing on sustainability-related practical work has been identified. Therefore, this study aims to address this gap by conducting a review of practical work on sustainability.

This review examined research trends in practical works on sustainability in peer-reviewed, empirical studies indexed in the Web of Science (WoS) database from elementary to higher education, from the first mention through the first half of 2025. The current research addresses the following research question: "How is practical work on sustainability addressed in the WoS database from elementary through higher education from its first mention through the first half of 2025?"

Methods

Research Method

This study used a qualitative research method to gain a deep understanding of a specific phenomenon (Creswell & Plano Clark, 2018). Specifically, content analysis, a qualitative research method, was employed. Content analysis is a rigorous method that describes the nature of a document's content through systematic coding and categorization. It is used to analyze trends, patterns, and frequencies of terms used in texts and their relationships (Vaismoradi et al., 2013). The content analysis method was chosen because it can reveal changes and developmental trends in a research area in detail (Chang et al., 2010). Unlike hermeneutic phenomenology, content analysis is a reliable method that allows minimal interpretation (Vaismoradi et al., 2013).

Data Source

In this study, the Web of Science (WoS) database was purposively selected as the data source. The WoS database was chosen because it is the oldest and most reputable database, is selective in terms of journal coverage, and has reliable scientometrics indicators. Additionally, WoS has extensive citation and bibliographic data coverage (Chadegani et al., 2013; Singh et al., 2021).

Data Collection Procedure

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guideline was used to identify and analyze studies on practical work on sustainability in the Web of Science (WoS) database. The PRISMA guideline provides a rigorous framework for transparent and complete reporting of the results of review studies and for ensuring that the research is reproducible by other researchers. The PRISMA guideline provides systematic and precise guidelines for the selection of articles for review based on a specific set of criteria, such as inclusion and exclusion criteria (Moher et al., 2009). The PRISMA guideline also provides a standardized methodology for ensuring the reliability of review studies, which is an essential step in the research process (Liberati et al., 2009).

A systematic literature review was conducted to examine in-depth studies of practical work on sustainability. The aim was to identify research trends in studies with participants from elementary through higher education. To this end, the researchers searched the WoS database's abstract section using the following keywords:

> ((“sustain*”) AND (“practical work” OR “laborator*” OR “hands on” OR “hands-on” OR “experiment*” OR “science practices” OR “science inquiry”) AND (“elementary school” OR “primary school” OR “middle school” OR “secondary school” OR “high school” OR “higher education” OR “college” OR “university”))

The intention behind choosing the keyword sustain* was to make it as inclusive as possible of work in the field of sustainability. All combinations of educational levels, from elementary education to higher education, were entered to search the database comprehensively. This study did not impose a year limitation, and articles related to sustainability were included from the first mention until the first half of 2025.

Figure 1 shows the PRISMA flow diagram for article selection process on practical work on sustainability. As shown in Figure 1, the WoS database was searched by the researchers' using keywords and 4,882 articles were listed. Articles in the Education & Educational Research (E&ER) category were filtered, and this screening process resulted in 743 articles. Since one of the eligibility criteria for this study was to analyze studies with first-hand empirical data, the article type was filtered as article and 435 articles were found. As another eligibility criterion, articles in English language were filtered and the number of articles was reduced to 385. The researchers determined the inclusion criteria for the articles to be included in the review. The following criteria were considered for screening.

Inclusion criteria:

1. Sustainability studies should be empirical in nature and directly address sustainability.
2. Studies should be conducted in educational settings ranging from elementary to higher education.
3. Studies should include practical work related to sustainability.

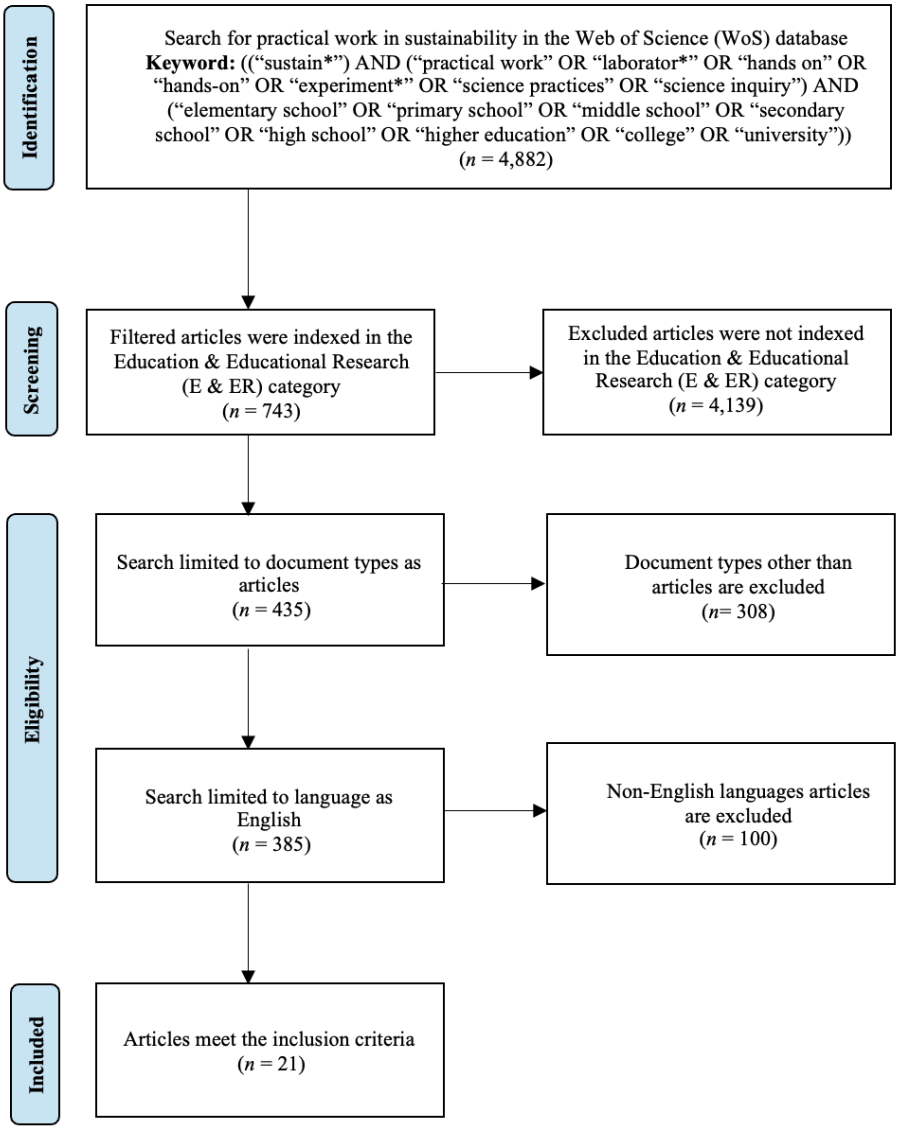

Figure 1. PRISMA Flow Diagram for Article Selection Process (Moher et al., 2009)

This screening was conducted to align with the goal of the study, which is to examine empirical and peer-reviewed sustainability studies using practical work in settings ranging from elementary to higher education. According to these inclusion criteria, 21 of the 385 articles were found to be eligible for inclusion. All review processes were completed on May 21, 2025. The appropriateness of the selected studies was confirmed by consulting a field expert.

Data Analysis

In this systematic review, 21 studies were selected and analyzed using content analysis according to the authors' predetermined criteria. The studies were coded and categorized consistently so that other researchers could easily apply them (Vaismoradi et al., 2013). The 21 reviewed articles were transferred to an Excel file in Google Drive and hyperlinked to enable collaboration among researchers. All selected articles were coded under the following criteria: author names, year of publication, abstract, purpose, research country, discipline (domain-general), sustainability topic (domain-specific), laboratory type, learning environment, sustainability dimension emphasized, SDG(s) emphasized, research methodology, research design, teaching model, intervention type, participant type, school type and/or grade (if participant type student), undergraduate/graduate students faculty (if any), data sources, and findings. After each article was coded according to the authors' predetermined criteria, frequencies were calculated, and research trends were identified. The results are visualized in various tables and figures, and critical explanations and implications are presented.

Findings

Research Trends by Years

The trends in the number of articles on practical work on sustainability analyzed in this review, a total of 21, published from the first mention in the WoS database until the first half of 2025, are shown in Figure 2.

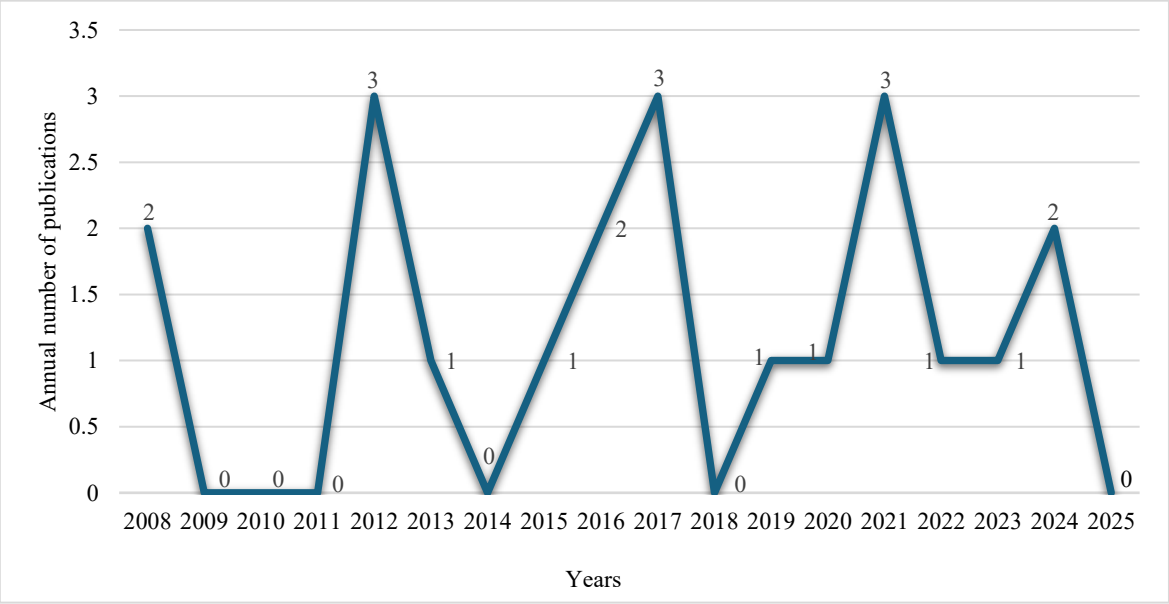

Figure 2. The Number of Practical Work on Sustainability Studies

As shown in Figure 2, the first study on practical sustainability work was found in the WoS database in 2008. No studies were found in 2009, 2010, 2011, 2014, 2018, or during the first half of 2025 (until 21 May). The highest number of publications (three each) was reached in 2012, 2017, and 2021. Although we acknowledged that studies on practical sustainability work are scarce, Figure 2 shows a fluctuating trend with periodic increases and decreases in research over the years.

Research Trends by Country of Origins

As shown in Figure 3, the 14 articles analyzed in this review on practical work in sustainability studies presented data from 14 different countries. Of the 14 articles analyzed, the United States and Germany contributed the most, with three articles each (13.04%). These two countries were followed by Australia, Brazil, Malaysia, and Mexico with two articles each (8.70%). The remaining seven countries in Figure 3 each contributed one article (4.35%). Only two papers presented data from two different countries. One paper presented data from Germany and Finland (Affeldt et al., 2017), and the other presented data from Germany and Morocco (Nourredine et al., 2023).

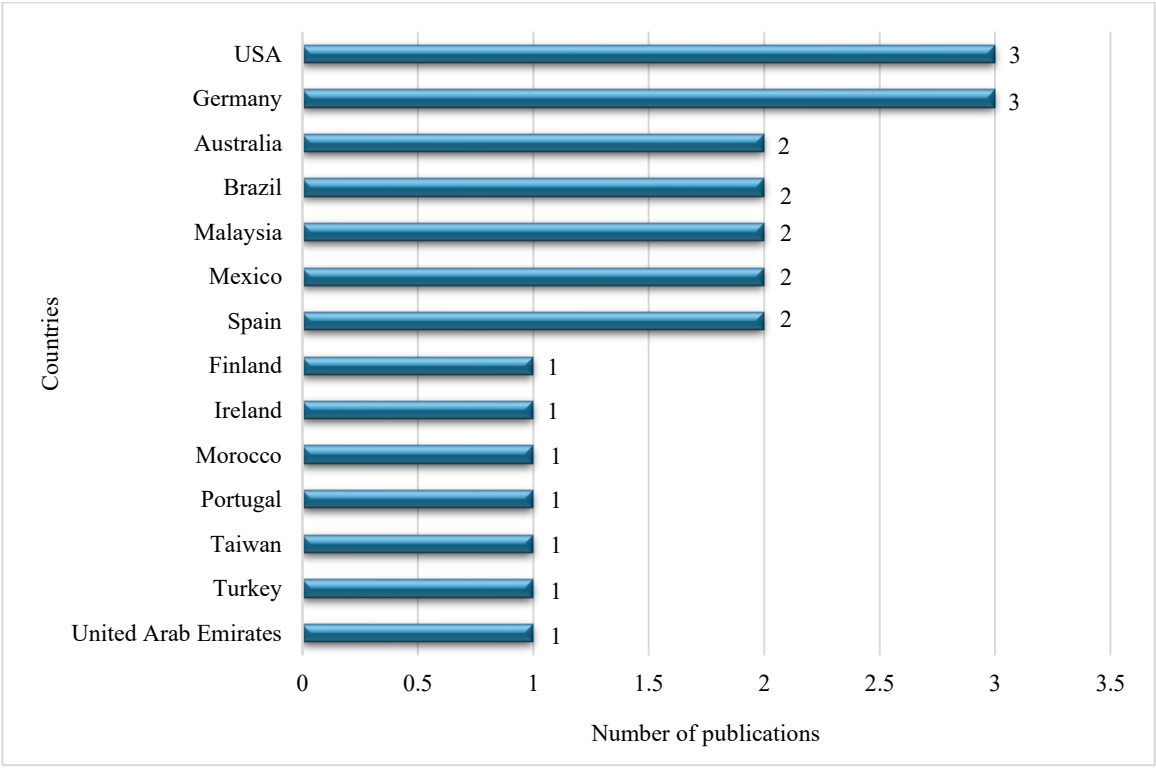

Figure 3. Research Trends by Country of Origin

Study Domain by Trend

When a total of 21 articles were categorized according to their domains-general, it was found that 10 of the studies were from the domain of environmental education (47.62%), which revealed that almost half of the studies were from this domain. Environmental education was followed by chemistry education with seven studies (33.33%). Limited contributions were made by three articles from science education (14.29%) and one article from

engineering education (4.76%). It is noteworthy that mathematics education, physics education, biology education and STEM education did not contribute any practical work on sustainability.

Table 1 lists articles that focus on practical work on sustainability. Most of the studies addressed green and sustainable chemistry (33.33%) and sustainable development (23.81%). These are followed by studies with a focus on environmental values (14.29%) and sustainable energy literacy and practices (9.52%). Notably, very few studies were conducted on the specific topics of green building literacy, water management, climate change, and campus sustainability (4.76% each).

Table 1. Articles Referring to Domain-specific Focus on Practical Work on Sustainability

Domain-specific focus of sustainability	Number of studies	References
Green and sustainable chemistry	7	Affeldt et al., 2017; Ashraf et al., 2012; de Oliveira et al., 2021; Galgano et al., 2012; Gunter et al., 2017; Karpudewan et al., 2012; Rojas-Fernandez et al., 2017
Sustainable development	5	Doran, 2016; Gomez Zermeno & Aleman de la Garza, 2021; Malone et al., 2024; Mateus et al., 2020; Miguez-Alvarez et al., 2022
Environmental values	3	Lewis et al., 2008; Raab & Bogner, 2021; Tomas et al., 2015
Sustainable energy literacy and practices	2	Karpudewan et al., 2016; Lee et al., 2013
Green building literacy	1	Cole et al., 2019
Water management	1	Nourredine et al., 2023
Climate change	1	Alvarez-Nieto et al., 2024
Campus sustainability	1	Savanick et al., 2008

Research Trends in Research Methods and Designs

Of the 21 studies included in this review, 11 studies used qualitative research methods (52.38%), 7 studies used quantitative research methods (33.33%), and 3 studies (14.29%) used mix research methods. The case study research design (61.91%) was the most commonly used design for investigating practical work in sustainability studies, appearing in 13 studies. Experimental research design (33.33%) was used in seven studies, which is less

preferred than case studies. The least used research design was action research (4.76%), which was used in only one study.

Research Trends in Data Sources

Figure 4 shows the frequency of data collection sources used in practical sustainability studies. The data collection tools used in a total of 21 studies were categorized under nine data collection sources. The most frequently used data collection source was questionnaires, which were used in three quarters of the studies (76%). Participant artifacts (38.01%) and interviews (23.81%) were also used as data collection sources. Observation (9.52%), autobiographical inquiry such as demographic data, documents such as school-based information and policy statements, field notes, journals, and reflections were used in limited numbers (4.76%each).

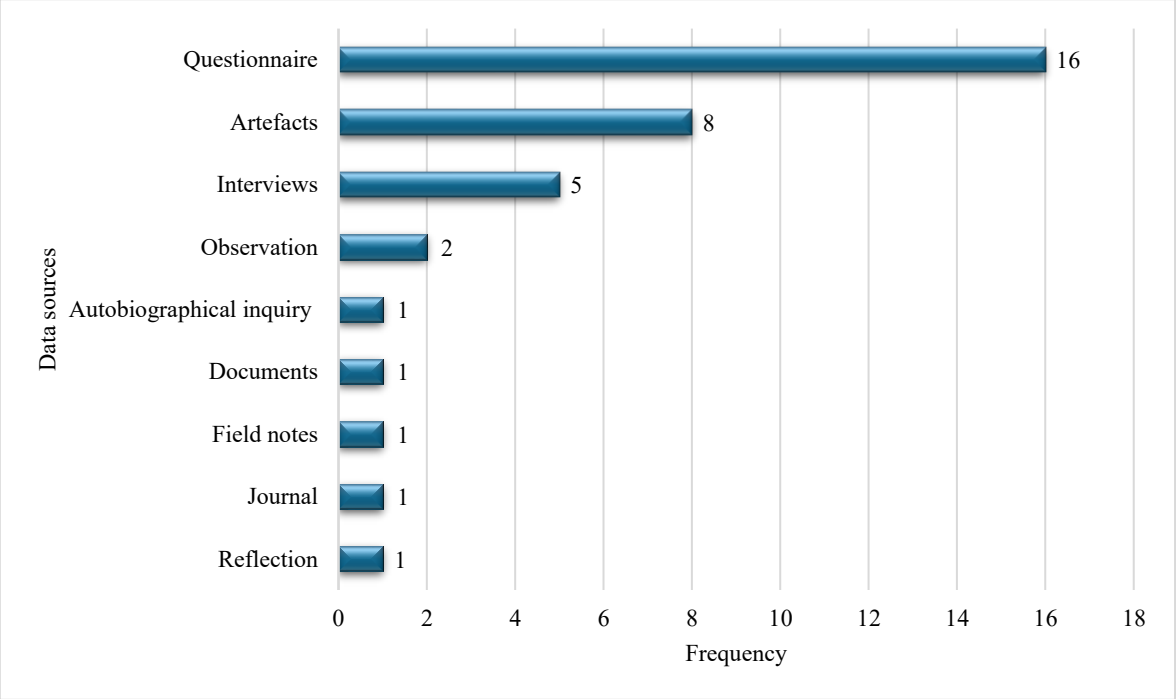

Figure 4. Frequency of Data Collection Sources used in Practical Work on Sustainability Studies

Research Trends on Intervention Types

A total of 21 studies were organized under three categories of intervention types: instructional interventions, extracurricular interventions and PD program. 19 of the 21 studies used instructional interventions (82.61%), which are planned, targeted, and systematic strategies designed to support participants' learning (e.g., de Oliveira et al., 2021; Nourredine et al., 2023). Three studies used extracurricular interventions (4.35%) (e.g., Affeldt et al., 2017; Savanick et al., 2008), which are activities carried out outside the formal learning environment. Only one study (Gomez Zermeno & Aleman de la Garza, 2021) used professional development (PD) (13.04%), defined as training to increase knowledge, skills, and competencies. Only two studies examined two different types of interventions within the same study. One study used an instructional intervention and a PD program (Gómez Zermeño & Alemán de la Garza, 2021), and the other study used an instructional intervention and extracurricular

activities (Raab & Bogner, 2021).

Research Trends in Laboratory Types and Learning Environments

A total of 21 studies were organized under three categories of laboratory types: hands-on lab activities, virtual labs and remote labs. Hands-on laboratory activities are laboratory activities in which applications are performed by working one-on-one with tools and equipment in a physical laboratory environment. In this study, 19 studies used the hands-on lab activity type (86.36%) and the majority of the studies were conducted in this lab type. A virtual laboratory is a type of laboratory that allows experiments to be performed in a virtual environment without physical devices through simulation or software such as virtual reality (VR), augmented reality (AR), and mixed reality (MR) (Elmoazen et al., 2023).

Remote laboratories, on the other hand, are laboratories where individuals are not physically present and do not touch the equipment, but can control it remotely in real time through technology. This study revealed that only two studies used virtual labs (9.10%) (Alvarez-Nieto et al., 2024; Doran, 2016), while one study used a remote lab (4.54%) (Miguez-Alvarez et al., 2022). Of the studies reviewed, only one used both hands-on lab activities and remote labs (Miguez-Alvarez et al., 2022).

This study coded learning environments under two categories: indoor learning and outdoor learning. Of the 21 studies analyzed, 17 studies were conducted only in an indoor learning environment (80.95%) (e.g., Malone et al., 2024), while one was conducted only in an outdoor learning environment (4.77%) (Lewis et al., 2008). Three of the studies (14.28%) took place in both indoor and outdoor learning environments (Mateus et al., 2020; Nourredine et al., 2023; Raab & Bogner, 2021).

Research Trends on Sustainability Dimensions and Emphasized SDG(s)

The dimensions of sustainability in the reviewed articles were coded as environmental, social, and economic. While we acknowledge that studies may emphasize more than one sustainability dimension, all of the studies included in this review emphasized the environmental dimension. Of the 21 studies, 11 studies (52.38%) addressed the economic dimension, and 7 studies (33.33%) addressed the social dimension. Notably, while only one article emphasizes both environmental and social dimensions (Affeldt et al., 2017), another article emphasizes both social and economic dimensions (Cole et al., 2019). Both the environmental and economic dimensions are emphasized in five studies (Alvarez-Nieto et al., 2024; Karpudewan et al., 2012; Lee et al., 2013; Savanick et al., 2008; Tomas et al., 2015). Very few articles address all three dimensions (Doran, 2016; Gomez Zermeno & Aleman de la Garza, 2021; Karpudewan et al., 2016; Malone et al., 2024; Nourredine et al., 2023).

Figure 5 shows trends in SDGs in practical works on sustainability studies. To ensure transparency, the SDGs focused on in each study were obtained from the Sustainable Development Goals subcategory in the Web of Science (WoS) database. Considering that studies may highlight more than one SDG, a total of 21 articles focused on 48 SDGs. The majority of studies addressed SDG 4 (31.25%). Very few studies addressed SDG 9 (6.25%),

SDG 3 (4.17%), SDG 6 (2.08%) while the remaining eight SDGs were not addressed by the studies included in this review.

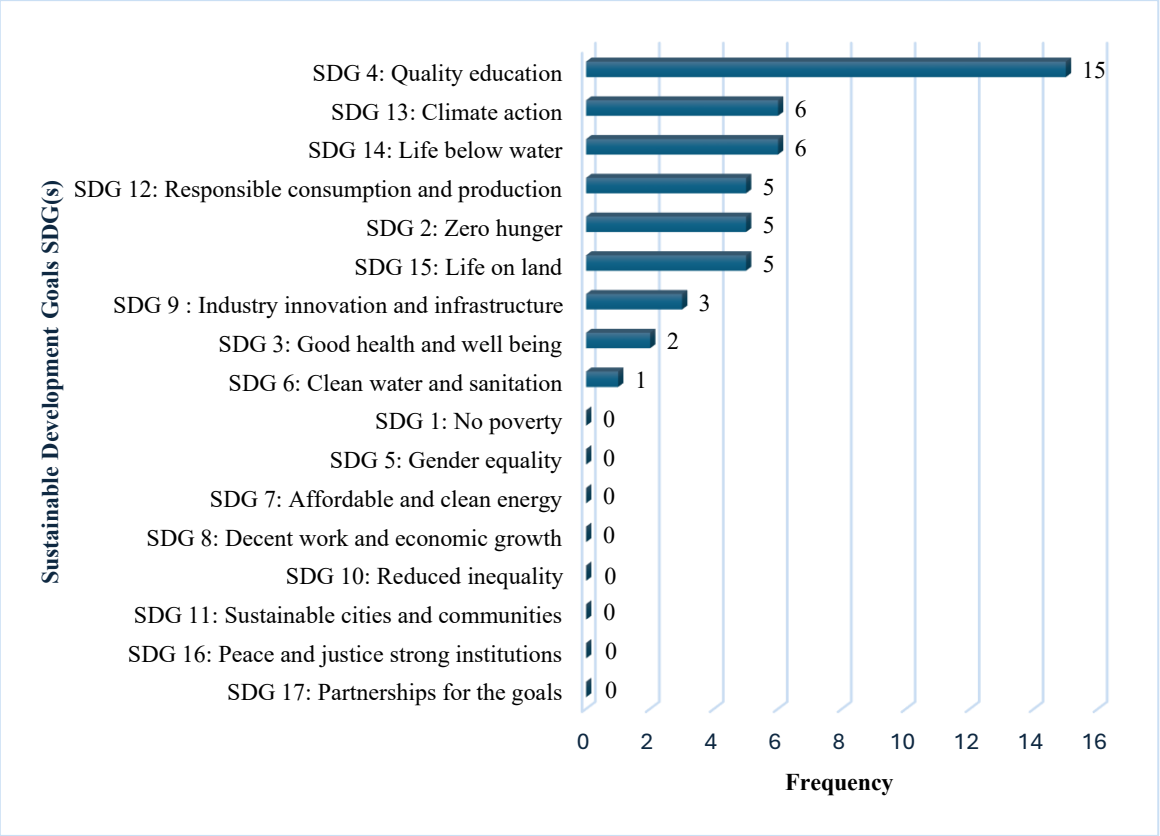

Figure 5. Trends in SDG(s) in Practical Works on Sustainability Studies

Research Trends in Teaching Strategies

In this review study, 13 teaching strategies used in practical work on sustainability were identified. Table 2 shows the list of articles that used teaching strategies. As shown in Table 2, we acknowledge that studies may use more than one teaching strategy. Experimental learning (20.00%), experiential learning (17.50%), and inquiry-based learning (15.00%) were most commonly used in the studies. These were followed by project-based learning (10.00%), problem-based learning, and collaborative learning (7.50% each). Very few studies used blended learning (5.00%), immersive learning, immersive learning, challenge-based learning, outreach learning, place-based learning, situated learning and scenario-based learning (2.50% each) as teaching strategies.

Table 2. List of Articles that used Teaching Strategies in Practical Work on Sustainability.

Teaching strategies	Number of studies	References
Experimental learning	8	Ashraf et al., 2012; de Oliveira et al., 2021; Galgano et al., 2012; Karpudewan et al., 2012; Lee et al., 2013, Mateus et al., 2020; Nourredine et al., 2023; Rojas-Fernandez et al., 2017;

Teaching strategies	Number of studies	References
Experiential learning	7	Affeldt et al., 2017; Cole et al., 2019; Doran, 2016; Lee et al., 2013; Malone et al., 2024; Mateus et al., 2020; Tomas et al., 2015
Inquiry-Based Learning (IBL)	6	Ashraf et al., 2012; Doran, 2016; Galgano et al., 2012; Gunter et al., 2017; Karpudewan et al., 2012; Lewis et al., 2008
Project-Based Learning (PBL)	4	Affeldt et al., 2017; Karpudewan et al., 2016; Lewis et al., 2008; Mateus et al., 2020
Problem-Based Learning	3	Galgano et al., 2012; Gunter et al., 2017; Savanick et al., 2008
Collaborative learning	3	Malone et al., 2024; Nourredine et al., 2023; Raab & Bogner, 2021
Blended learning	2	Miguez-Alvarez et al., 2022; Tomas et al., 2015
Immersive learning	1	Doran, 2016
Challenge-based learning	1	Gomez Zermeno & Aleman de la Garza, 2021
Outreach learning	1	Raab & Bogner, 2021
place-based learning	1	Malone et al., 2024
Situated learning	1	Alvarez-Nieto et al., 2024
Scenario-based learning	1	Alvarez-Nieto et al., 2024

Participant Trends Across Studies

In this review article, 4 different groups of participants were identified: K-12 students, university students, academics and public. The reviewed articles revealed that most of the participants were university students, accounting for 14 studies (58.33%). Eight of the studies were conducted with K-12 students (33.33%), one with the public (4.17%), and one with academics (4.17%). One study was conducted with both K-12 and university students (Karpudewan et al., 2012). Remarkably, only one study used more than one group of participants with

university students, the public, and academics (Gomez Zermeno & Aleman de la Garza, 2021).

In this review article, K-12 students were coded under the elementary, middle, and high school student categories. University students were coded under the undergraduate and graduate student categories. Figure 5 shows trends in all student types in practical works on sustainability studies. The elementary school student category included students in grades 1–5, while the secondary school student category included students in grades 6–8. The high school category referred to students in grades 9-12. Undergraduate students (41.66%) was the most frequently studied groups comprising the participant group in eleven articles (Alvarez-Nieto et al., 2024; Ashraf et al., 2012; de Oliveira et al., 2021; Galgano et al., 2012; Gomez Zermeno & Aleman de la Garza, 2021; Mateus et al., 2020; Karpudewan et al., 2012; Miguez-Alvarez et al., 2022; Savanick et al., 2008; Rojas-Fernandez et al., 2017; Tomas et al., 2015). In 5 articles, high school students (20.84%) were used as participants (Affeldt et al., 2017; Karpudewan et al., 2012; Karpudewan et al., 2016; Malone et al., 2024; Nourredine et al., 2023). The least frequently studied participant groups were graduate students (16.67%) with four articles (Affeldt et al., 2017; Doran, 2016; Malone et al., 2024; Nourredine et al., 2023), primary school students (12,50%), with only three article (Lee et al., 2013; Lewis et al., 2008; Raab & Bogner, 2021) and also middle school students (8.33%) with only two articles (Affeldt et al., 2017; Lewis et al., 2008). Notably, only four study used more than one group of participants. Two studies were conducted with both undergraduate and graduate students (Gomez Zermeno & Aleman de la Garza, 2021; Mateus et al., 2020). While one study included both elementary and middle school students (Lewis et al., 2008), the other included both middle and high school students (Affeldt et al., 2017).

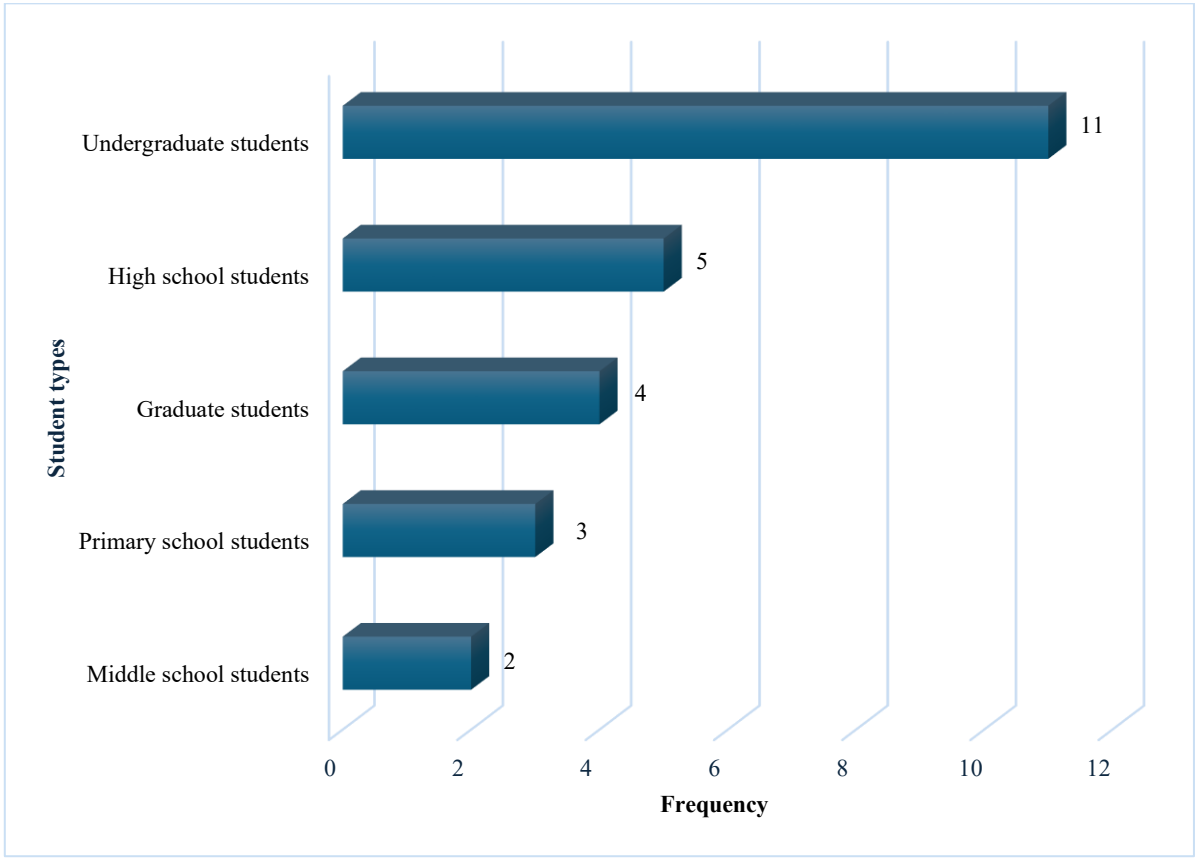

Figure 6. Trends in Student Types in Practical Works on Sustainability Studies

The faculties of the university students are shown in Figure 7, and a total of 7 faculties were identified. High numbers of studies were found in the Faculty of Arts and Sciences (26.67%) (Ashraf et al., 2012; de Oliveira et al., 2021; Galgano et al., 2012; Rojas-Fernandez et al., 2017), the Faculty of Education (20%) (Gunter et al., 2017; Karpudewan et al., 2012; Tomas et al., 2015) and the Faculty of Engineering (20%) (de Oliveira et al., 2021; Mateus et al., 2020; Miguez-Alvarez et al., 2022). A limited number of studies was found in the interdisciplinary programs (13.32%), which are open to all students regardless of their major (Gomez Zermeno & Aleman de la Garza, 2021; Savanick et al., 2008). There was only one study in each conducted with the Faculty of Architecture and Design (Cole et al., 2019), the Faculty of Health Sciences (Alvarez-Nieto et al., 2024) and the Faculty of Law (Doran, 2016) (6,67% each). Only one study included participants from both the Faculty of Arts and Sciences and the Faculty of Engineering (de Oliveira et al., 2021).

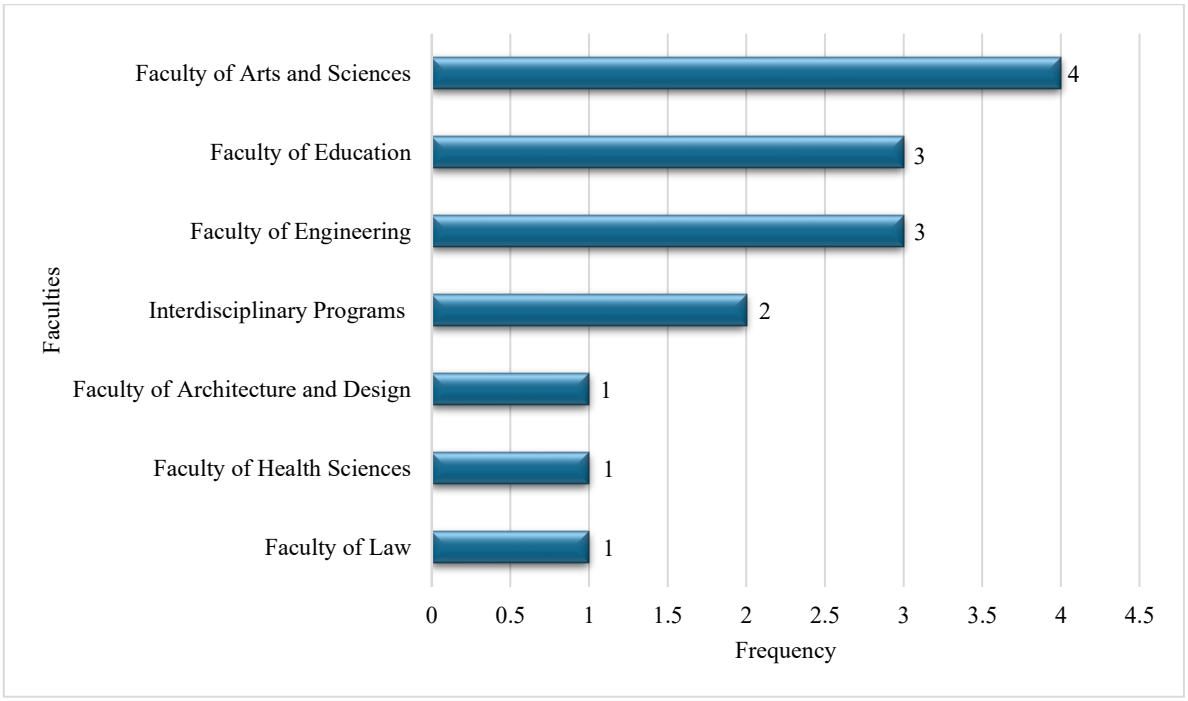

Figure 7. The Frequency of Faculty Types in Practical Work on Sustainability Studies

Discussion and Conclusion

This review examined research trends in practical works on sustainability in peer-reviewed, empirical studies indexed in the Web of Science (WoS) database from elementary to higher education, from the first mention through the first half of 2025. This article reviews 21 studies on practical sustainability work and reveals that the first study was published in 2008. While this finding indicates that theoretical studies on sustainability began much earlier, evidence suggests that practical work in this area started much later (e.g., Savanick et al., 2008). There are fluctuations in the number of articles published each year; however, no studies were found in 2009, 2010, 2011, 2014, 2018, and the first half of 2025. This is consistent with Geels et al.'s (2013) argument that sustainability was overlooked in the search for solutions to the 2008 global economic crisis, particularly during the initial and subsequent years of the crisis. Furthermore, the greatest number of studies occurred in 2012, 2017, and 2021. The authors of this paper argue that global policies, technological developments, and financial factors

can explain these fluctuations. Global politics can also shape the sustainability agenda.

Valuable initiatives such as the United Nations' Sustainable Development Goals, the 2015 Paris Agreement, and the Conference of the Parties (COP) have increased academic interest in sustainability and e-business models. Ahmad et al. (2025) revealed an increase in publications on sustainability and e-business models from 2016 to 2020. Furthermore, they indicated that technological developments, such as artificial intelligence, as well as a focus on environmental, social, and governance factors, have led to an increase in sustainability research. Financial crises and the impact of pandemics can be attributed to fluctuations in the amount of practical work on sustainability publications over the years. The onset of the pandemic forced researchers to halt face-to-face meetings and data collection due to social isolation, negatively affecting research productivity within their teams (Leal Filho et al., 2021). This study revealed that very little research has been conducted on practical work on sustainability. This finding highlights a significant gap in sustainability research, which limits the effectiveness and prevalence of practical work. These findings support the suggestion that concrete examples of practices are needed in the literature, as well as an understanding of the benefits and challenges of implementing sustainability approaches in practice (Lennox et al., 2020).

This study's findings reveal that practical work in sustainability studies provides data from 14 countries, most of which are from the United States and Germany. In general, most practical work on sustainability studies stems from OECD countries. There are many possible reasons for the high volume of practical sustainability studies in OECD countries. First, these countries provide research support for sustainable development and have introduced many innovation policy initiatives to promote sustainable development and achieve the SDGs (Borowiecki et al., 2019). As Eid et al. (2024) suggest, energy research and development (R&D) expenditures in OECD countries have a positive and significant impact on green growth, which may have improved attitudes and understanding of sustainability in these countries.

Funding sources also have an important role in research trends. Funding and equipment support for researchers should be provided to generate more projects, especially in applied areas of sustainability. The Horizon programs of the European Union and the National Science Foundation (NSF) of the USA are important types of incentives. However, we recommend increasing the number of publications from non-OECD countries as well, as providing literature from these countries will improve our understanding of the practical work of sustainability and go beyond the theoretical foundation to provide good practical examples.

Most of the studies were found to be from the domains of environmental education and chemistry education. Limited contributions were found from science education and engineering education. Notably, no studies were found from the mathematics, physics, biology, or STEM education domains. The authors of this paper attribute the concentration of practical work on sustainability in environmental sciences and chemistry to the differences in the nature of these disciplines and their application areas. Since environmental sciences and chemistry are directly related to sustainability through areas such as waste management and green chemistry, these fields focus heavily on improving quality of life (Gunbatar et al., 2025). Trott and Weinberg (2020) demonstrated that children's learning and action on climate change significantly improved their participation in science education as

well as their attitudes and perspectives. AlAli et al. (2023) demonstrated that STEM-based teaching can achieve sustainable development goals. However, the integration of sustainability issues in STEM programs remains limited. Because sustainability requires an interdisciplinary approach, it is crucial for different disciplines to integrate sustainability issues (Schoolman et al., 2012). Therefore, as sustainability issues remain conceptual and are applied only in environmental and chemistry education, we suggest increasing applications in STEM fields to improve our collective understanding.

While many studies have addressed green and sustainable chemistry (e.g., Affeldt et al., 2017) and sustainable development (e.g., Malone et al., 2024), few have focused on green building literacy (Cole et al., 2019), water management (Nourredine et al., 2023), climate change (Alvarez-Nieto et al., 2024), or campus sustainability (Savanick et al., 2008). Green and sustainable chemistry, as well as sustainable development, play an important role in developing strategic theoretical frameworks. The large number of studies in these areas provides a valuable approach for organizational policy development (Leal Filho et al., 2023). The limited focus on specific application areas highlights the need to explore these areas more deeply, offering best practices and revealing implementation challenges.

This review found that most studies used qualitative research methods, while fewer studies used quantitative methods, and only a few used mixed methods. In terms of research design, most studies used case studies. Limited use of experimental and action research designs was seen in one study. These findings suggest that practical work on sustainability is primarily contextualized, original, and qualitative. It also suggests that sustainability studies do not include enough practice-oriented, empirically-based action research. These findings highlight the need for more mixed methods and action-based studies in the literature.

This study found that most of the reviewed studies used instructional interventions, while extracurricular interventions and professional development programs were rarely used. Since extracurricular interventions, such as hands-on sustainability projects and activities, positively impact sustainability, we recommend increasing these interventions (e.g., Affeldt et al., 2017; Raab & Bogner, 2021; Savanick et al., 2008). To increase participation, we recommend expanding PD programs, particularly those focused on social community development. Providing professional development programs for stakeholders is crucial for enhancing social innovation and sustainable development (e.g., Gómez Zermeño & Alemán de la Garza, 2021).

Although almost all of the studies included in this review used hands-on laboratory activities as an intervention type, virtual and remote laboratories were used very rarely. This finding indicates that the field of sustainability, which is practice-based, still relies on traditional, face-to-face learning methods. Virtual and remote labs are less costly because traditional hands-on labs require equipment, space, and maintenance staff. Although virtual and remote labs are a viable alternative to hands-on lab activities, logistical and economic barriers hinder their implementation (Heradio et al., 2016). Teachers' lack of technological pedagogical content knowledge is also an important reason (Voogt et al., 2013). However, given the potential of technological tools, such as virtual and remote labs, to increase the accessibility, diversity, and resource efficiency of sustainability education, we recommend using these lab types (Heradio et al., 2016; Tüysüz, 2010). We recommend that universities develop

open-access, sustainable virtual and remote lab platforms for public and student use, and that all faculty programs utilize these labs.

While most of the studies included in this review took place in indoor learning environments (e.g., Tomas et al., 2015), only one study took place in an outdoor environment (Lewis et al., 2008). Outdoor learning environments are important for alternative pedagogies and fostering a love of rich sensory experiences. Although outdoor learning has positive effects, barriers to its use remain (Rickinson et al., 2004; Waite et al., 2010). These barriers include structural limitations in schools, time constraints, curriculum constraints, and the perception that indoor environments are safer (Beames et al., 2012).

All of the articles reviewed in this study focus on the environmental dimension of sustainability. Half of the studies focus on the economic dimension, but the social dimension receives limited attention. Very few studies emphasize all three pillars of sustainability (e.g., Malone et al., 2024; Nourredine et al., 2023). This disproportionate emphasis on sustainability dimensions is a common issue in sustainability literature (Kopnina & Meijers, 2014). Science and environmental education curricula have been criticized for prioritizing environmental sustainability at the expense of the other two pillars (Wals, 2011). However, we recommend that, rather than prioritizing environmental sustainability, education policies balance the three pillars of sustainability (environmental, economic, and social) in the curriculum.

Most studies addressed SDG 4, while very few addressed SDGs 3, 6, and 9. The remaining eight SDGs were not addressed by the included studies. One possible reason for this outcome is the direct relevance of SDGs to education, especially the central role of SDG4 (Rieckmann, 2017). We also suggest that organizations such as UNESCO, the World Bank, and the Global Partnership for Education (GPE) providing funding for SDG 4 goals may have led researchers to focus on SDG 4. The 17 SDGs are not separate work packages; they are all interrelated (Boeren, 2019). Therefore, it is important to integrate underrepresented and non-represented SDGs into education curricula using interdisciplinary approaches and to include them in teaching and research agendas.

Thirteen teaching strategies used in practical sustainability work were identified. Experimental, experiential, and inquiry-based learning were the most common strategies, while blended, immersive, challenge-based, outreach, place-based, situated, and scenario-based learning were the least common. The predominant teaching strategies used are experiential, experimental, and inquiry-based learning, which is attributed to the fact that sustainability education is inherently inquiry-based and encourages transformational learning approaches to gain experience in the process (Sterling & Org, 2001; Wiek et al., 2011). These instructional strategies are important for helping individuals develop skills in questioning, problem-solving, and critical thinking. One reason for the underutilization of blended, immersive, and challenge-based teaching strategies may be the lack of technological infrastructure, as these strategies require technological infrastructure and educators' technological competence (Tondeur et al., 2020). Additionally, strategies such as challenge-based, outreach, place-based, situated, and scenario-based learning require planning and may not have been preferred due to time constraints. However, we recommend increasing the integration of various teaching strategies into sustainability education in future studies because it will provide in-depth insights into the practical benefits and challenges of different strategies, thereby

increasing our collective understanding.

This review article identified K-12 and university students, as well as academics and public groups, as participants. The reviewed articles revealed that the majority of participants were university students. This finding suggests that the researchers selected university students due to access and logistical considerations. Furthermore, since universities are influential institutions with the power to transform society for a sustainable future, it is reasonable to use university students as the sample (Rosen, 2019). Studies conducted with K-12 students show that more studies have been conducted with high school students than with primary and middle school students. Therefore, to understand the challenges of practical work on sustainability, we recommend conducting studies with students at all K-12 levels, especially primary and middle school.

Studies have rarely included the public and academics as participants. Remarkably, only one study included more than one group of participants: university students, the public, and academics (Gomez Zermeno & Aleman de la Garza, 2021). The failure to adequately represent the community in research may be due to weaknesses in community engagement caused by structural challenges (Leal Filho et al., 2019). Additionally, institutional support and guidance are needed to improve academics' understanding of sustainability and integrate it into their teaching. Furthermore, there needs to be more empirical research on the opportunities and challenges faced by academics when practicing sustainability, and therefore, more studies with academics are needed (Cebrián et al., 2015). However, since sustainability requires social transformation and collective consciousness beyond the individual, it is crucial to include all segments of society in research. Therefore, we suggest that sustainability studies be carried out using multi-stakeholder approaches to build a sustainable future based on quality of life and lifelong learning.

Studies conducted with university students revealed that research was carried out in seven faculties. Majority of the studies were conducted in the Faculty of Arts and Sciences. Very few studies were conducted in interdisciplinary programs, which are open to all students regardless of their major, the Faculty of Architecture and Design (Cole et al., 2019), the Faculty of Health Sciences (Alvarez-Nieto et al., 2024) and the Faculty of Law (Doran, 2016). These findings provide empirical evidence that the distribution of sustainability-related practical work across faculties is imbalanced and that universities have not yet embraced the issue of sustainability holistically. Research needs to be increased, especially in faculties that are underrepresented or have not been studied at all (Mulà et al., 2017).

This study has important implications for curriculum makers, sustainability researchers, and policymakers. However, there are limitations that need to be considered, and the data should be evaluated in light of these limitations. First, only the WoS database was used in this study. Future studies could expand their databases to increase literature coverage. Second, the language of publication was restricted to English, which may have excluded context-specific studies in other languages. For this reason, we recommend that future studies include languages other than English by collaborating with authors who speak different languages or using artificial intelligence. These limitations will guide future systematic reviews and meta-analyses and suggest further research on topics underrepresented in this study.

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