KnE Social Sciences | The 7th International Conference on Education and Social Science Research | KNE Publishing

Research Article

ESD-Based Green Chemistry Teaching Materials in High School to Support Sustainability

Rina Widyawati*, Mega Novita, and Siti Patonah

PGRI Semarang University, 50125, Indonesia

ORCID
Rina Widyawati: https://orcid.org/0009-0008-3180-6927

Abstract.
Learning green chemistry in senior high school (SMA) is crucial to help students understand environmental issues and play a role in supporting sustainability. Although the concept of Education for Sustainable Development (ESD) has often been applied in many fields, its application, specifically in green chemistry teaching materials in high school, still receives less attention. Previous studies focus more on the concept of green chemistry in general, so there is still a void in the development of teaching materials specifically designed to support sustainability goals. This study reviews and analyzes various literatures on the development of ESD-based green chemistry teaching materials in high school, evaluating their impact on students' environmental understanding and critical thinking skills. The method used is Systematic Literature Review (SLR), by reviewing research that has been published between 2018 and 2024. Relevant literature was identified from the Google scholar academic journal database to get a comprehensive view of the implementation of this teaching material. The results of the study show that ESD-based green chemistry teaching materials can increase students' awareness of environmental issues, encourage them to take concrete actions that support sustainability, and hone their critical thinking skills in understanding the environmental impacts of various chemical processes. Nevertheless, there are challenges in its implementation, such as limited resources for teachers and the need for further training so that teachers are ready to implement this teaching material properly. Overall, this study concludes that ESD-based green chemistry teaching materials have great potential in supporting sustainable learning in high schools. However, further development and stronger support for teacher training and the provision of adequate resources are needed.

Keywords: teaching materials, green chemistry, ESD, high school, sustainability

Corresponding Author: Rina Widyawati; email: aurelliofaeyza@gmail.com

Published: 18 April 2025

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the ICESRE Conference Committee.

1. Introduction

Increasing global awareness of the current environmental crisis, such as climate change, pollution, and depletion of natural resources, demands efforts from various sectors, including education, to support sustainability. Education plays an important role in shaping the mindset of the younger generation to be more concerned about the environment and active in maintaining sustainability [1]. One approach considered relevant for this purpose is the application of the Education for Sustainable Development (ESD) concept, which aims to integrate sustainability principles into the education curriculum [2] [3].

In the context of education in Indonesia, the Merdeka curriculum is the main focus in an effort to increase the flexibility and relevance of education in Indonesia [4]. The integration of the Merdeka Curriculum with the concept of sustainability is an important step in preparing future generations to face environmental and social challenges [5]. Especially in chemistry education, green chemistry is one of the important focuses that can be integrated with ESD to support learning that is more oriented towards environmental solutions.

Although the application of ESD concepts has begun to be adopted in various aspects of education, its application specifically in green chemistry teaching materials at the senior high school level is still limited [6]. Several studies have shown that most green chemistry initiatives in schools only cover conceptual aspects without providing clear direction on how to connect it to sustainability and real action in everyday life [7]. This suggests an urgent need to develop teaching materials that can incorporate the principles of green chemistry and ESD in the chemistry curriculum in high school, so that students not only understand the concepts, but are also motivated to take concrete actions in protecting the environment.

Furthermore, the development of these teaching materials should also consider the importance of critical thinking skills and environmental literacy. According to several studies, students trained with ESD-based approaches show significant improvements in their critical thinking skills, especially in solving problems related to environmental issues [8] [9]. Using the Systematic Literature Review (SLR) method, this study is expected to provide a comprehensive overview of the state of the art in this field and identify research gaps for further development of ESD-based green chemistry teaching materials in high school [10].

2. Methods

This study used the systematic literature review (SLR) method. The SLR methodology is used to identify, review, evaluate and interpret all research articles. Systematic literature review (SLR) is a method of interpreting and evaluating previous research related to a clear and systematic phenomenon [11]. The SLR technique can be used to conduct systematic reviews and journal identification according to predetermined steps or protocols for each process [12]. The SLR method was chosen because of its ability to provide a comprehensive and structured synthesis of the existing literature [13] [14]. The steps of using SLR are shown in Figure 1.

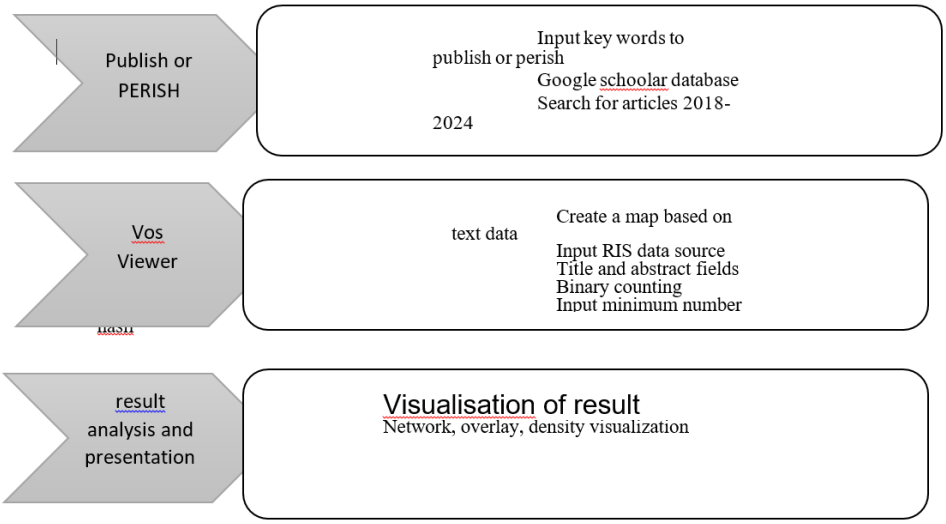

Figure 1: Steps of using SLR.

A systematic literature review (SLR) approach was used in this study to identify and analyse scientific articles relevant to ESD-oriented green chemistry teaching materials in high school chemistry learning. Inclusion and Exclusion Criteria. Inclusion and exclusion criteria were set following the updated PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [15]. These criteria ensured the relevance and quality of studies included in the review. Strategy The literature search was conducted using Publish or Perish (PoP) software by accessing the Google Scholar database, following the methodology outlined by [16]. The keyword combinations used included terms related to teaching materials, green chemistry, ESD, and upper secondary education. The search parameters in PoP were set as follows 2018-2024 with a maximum number of results of 500. The study selection process adopted a three-stage approach [17], including title and abstract screening, full-text review, and quality assessment using a checklist

adapted from CASP (Critical Appraisal Skills Programme). The data extraction process followed the protocol developed by [18] ensuring consistency and completeness of information collected from each article. Bibliometric analysis and visualisation, using VOSviewer software, enabled the identification of patterns and trends in the literature reviewed [19]. Data synthesis was conducted using a thematic analysis approach, this process enables the identification of key themes and patterns in the literature reviewed [20]. By following this SLR protocol, the study aimed to provide a comprehensive review and meaningful synthesis of the state of the art in the development of ESD-based green chemistry teaching materials at the high school level, as well as identify directions for future research in this area.

3. Results and Discussion

3.1. Research Results

Searching for articles with the title ESD-oriented green chemistry teaching materials in high schools to support sustainability, as well as the keywords 'green chemistry', 'teaching materials', 'ESD', 'high school', 'sustainability' in the Publish or Perish software. In Publish or Perish by determining the maximum number of results as many as 500 articles and determining the search year, namely the last 6 years (2018-2024), 433 articles were obtained. The source that researchers determine is the Google Scholar database. After the researcher obtained 433 articles, the researcher saved them in CSV format for Microsoft Excel and RIS format for VOSViewer software. The selection process was carried out using Publish or Perish (PoP) from 500 articles found with 5 keywords. The article data was then saved in RIS format and imported into Vosviewer, As presented in Figure 2.

3.2. Discussion

The selected articles were analysed using a thematic approach, to identify ESD-oriented green chemistry teaching materials in chemistry learning and the associated challenges and benefits. Based on the results of the analysis, the researchers found 433 articles. Next is to determine the visualisation that researchers found using VOSViewer software. The use of VOSViewer software provides an alternative way for researchers to conduct the latest research by reviewing the resulting spider web mapping results. Analysis

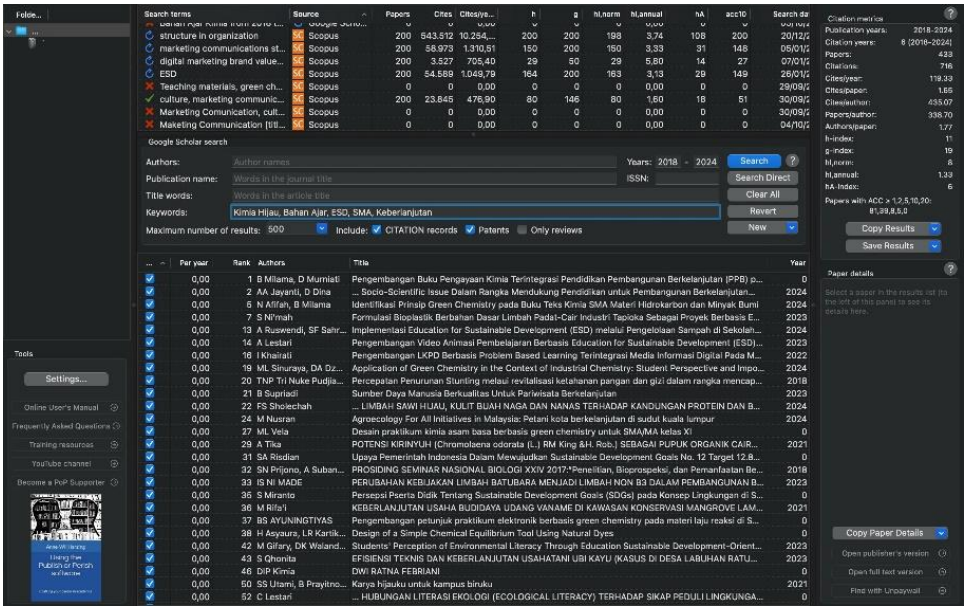

Figure 2: Article search results in PoP.

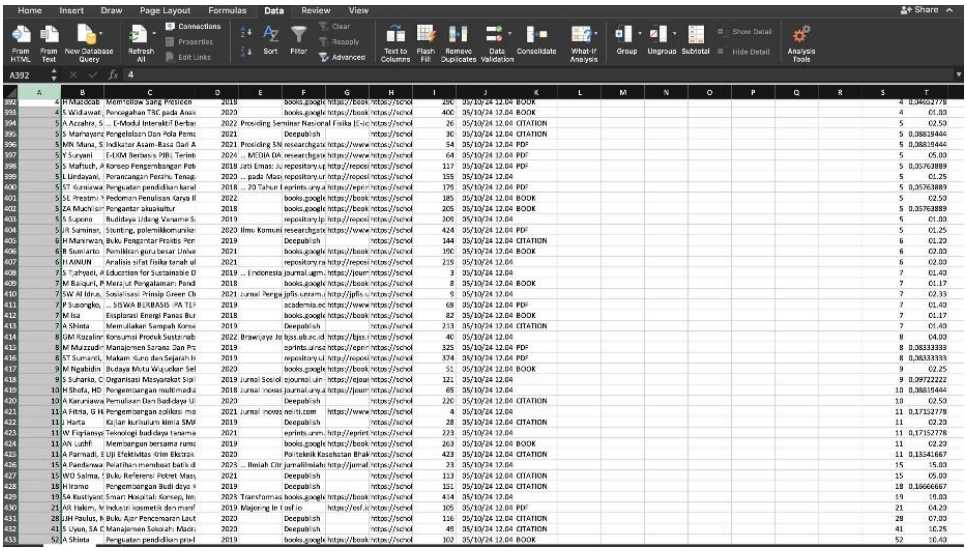

Figure 3: Data Filtering Results.

of ESD-based green chemistry teaching materials using the binary method, obtained 2830 words with a minimum limit of occurrence of each word set 2 times, then obtained 169 words. The bibliometric analysis using VOSviewer uncovered six distinct research clusters, each highlighting critical dimensions of integrating sustainability and chemistry education,

1. Environmental and sustainability focus, the red cluster emphasizes ecological aspects, underscoring the urgent need to contextualize chemistry learning within environmental challenges.

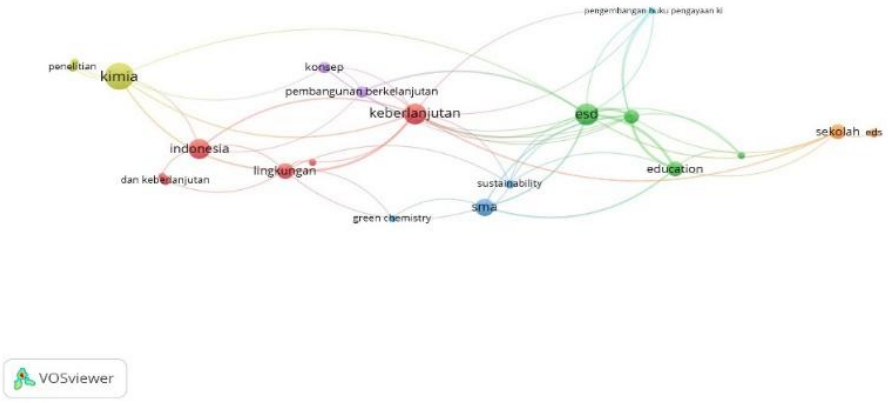

Figure 4: Relationship between keywords through VOS Viewer.

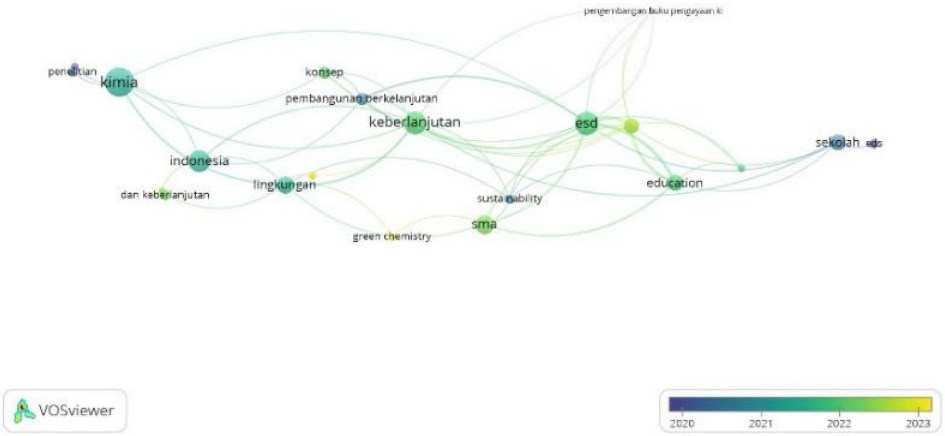

Figure 5: Shows the network of empirical studies examining the topic of green chemistry and sustainability from 2018 to 2024.

2. Educational integration, the green cluster demonstrates the increasing recognition of embedding sustainability concepts directly into curriculum design.

3. High school green chemistry application, the blue cluster specifically addresses the implementation of green chemistry principles at the secondary education level, a critical intervention point for developing environmental consciousness.

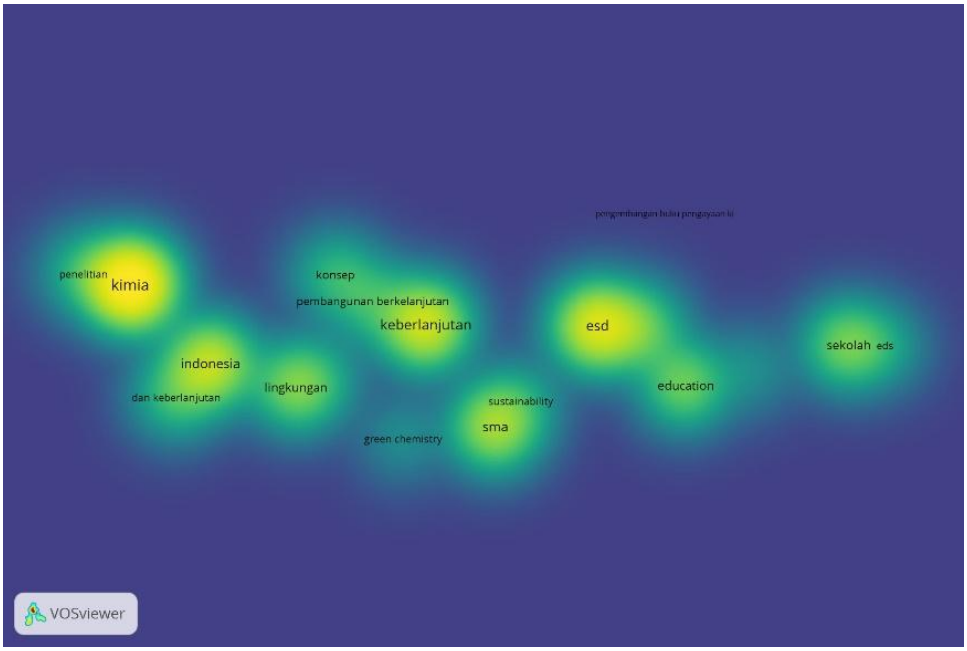

Figure 6: Density Visualisation of 169 Items with 6 clusters.

4. Practical implementation, the yellow cluster reveals the practical challenges and opportunities of introducing sustainability-oriented chemistry education.
5. Theoretical development, the purple cluster indicates ongoing theoretical refinement of teaching material frameworks.
6. Common themes, lights blue clusters that may connect various aspects of the other clusters.

The temporal analysis (Figure 5) shows the evolution of the research focus from 2018 to 2024. There is a shift from the basic concepts of green chemistry towards a more complex integration with ESD and its application in the high school curriculum. This reflects a growing understanding of the importance of linking green chemistry to the broader context of sustainability. Density visualization (Figure 6) reveals areas that have been extensively researched (dark colors) and areas that still require further exploration (light colors), based on Figure 6 there is still room for innovative research that combines aspects of chemistry, environment and sustainability in the context of specific teaching materials for high school. From the publication sources that have been collected for this study, there are 40 articles that will be the focus of the analysis. This distribution provides an interesting picture of the variation in literature sources.

The temporal analysis indicates a significant paradigm shift from isolated green chemistry concepts to a more holistic, interconnected approach to sustainability education.

This progression suggests a maturing understanding among educators and researchers about the transformative potential of integrated teaching materials. However, the density visualization reveals substantial gaps in current research, particularly in developing innovative, context-specific teaching strategies that can effectively bridge theoretical knowledge with practical environmental action. The analysis highlights that while there is growing interest in ESD-based green chemistry teaching materials, most existing approaches remain conceptually limited, often failing to provide clear pathways for students to translate environmental understanding into concrete sustainability practices. Critically, the research unveils significant implementation challenges that must be addressed to maximize the potential of ESD-based green chemistry teaching materials. These challenges include limited existing teaching resources, insufficient teacher training programs, and a lack of comprehensive curriculum design that goes beyond theoretical instruction. The findings suggest that successful implementation requires a holistic approach involving multiple stakeholders: curriculum developers must create more sophisticated, action-oriented materials; educational institutions need to invest in robust teacher professional development; and policymakers must develop supportive frameworks that facilitate ESD integration. Furthermore, the research indicates that the most effective teaching materials will not only impart knowledge but also cultivate critical thinking skills, environmental literacy, and a genuine commitment to sustainability among high school students, thereby preparing them to become proactive agents of environmental change.

The findings suggest that although there is an increasing interest in integrating green chemistry and ESD in high school learning, there is still a need for the development of more structured and contextualized teaching materials. Further research is needed to explore innovative methods of presenting green chemistry concepts that not only enhance students' theoretical understanding, but also encourage practical application and development of critical thinking skills in the context of sustainability.

4. Conclusion

Based on the results of a systematic analysis of the literature on ESD-based green chemistry teaching materials in high school, it can be concluded that there is a significant increase in research interest in the integration of green chemistry and ESD in the high school curriculum, which is reflected in the evolution of research focus during the 2018-2024 period. The systematic literature review of ESD-based green chemistry teaching

materials unveils a critical transformation in high school science education, representing a pivotal moment of pedagogical innovation and environmental consciousness. By integrating Education for Sustainable Development with green chemistry, the research transcends traditional disciplinary boundaries, positioning chemistry education as a dynamic mechanism for cultivating environmental stewardship. The findings reveal a significant paradigm shift from conventional, concept-driven instruction towards a holistic, action-oriented learning approach that empowers students to become critical thinkers and proactive environmental agents. This transformation is characterized by an emerging understanding that chemistry education can be a powerful tool for addressing global environmental challenges, bridging theoretical knowledge with practical sustainability skills.

The research exposes profound implementation challenges, including limited teaching resources, insufficient teacher training, and gaps in existing methodological approaches. These challenges underscore the urgent need for comprehensive curriculum development that goes beyond traditional scientific instruction. Strategic recommendations include creating interdisciplinary teaching materials that seamlessly integrate green chemistry principles with sustainability concepts, designing robust teacher training programs focused on experiential learning, and establishing collaborative ecosystems involving educators, researchers, and policymakers. The theoretical significance of this approach lies in its potential to reimagine science education as a transformative discipline that nurtures environmental literacy and cultivates a generation of scientifically informed, environmentally responsible citizens.

Looking forward, the research highlights critical future directions that demand scholarly attention. These include developing sophisticated assessment methodologies to measure the long-term impact of sustainability-oriented teaching materials, investigating cross-cultural implementations of green chemistry education, and creating longitudinal studies that track students' environmental attitudes and behaviors. The findings suggest that successful integration of ESD principles into chemistry education requires a holistic approach that simultaneously addresses pedagogical innovation, teacher professional development, and supportive policy frameworks. By positioning students as potential change agents and reframing chemistry as a solution-oriented discipline, this approach offers a compelling vision for education's role in addressing complex environmental challenges. Ultimately, the research presents a transformative model that extends far beyond traditional scientific education, offering a nuanced, comprehensive strategy for preparing future generations to navigate and mitigate global environmental challenges.

Acknowledgments

The first author has understood, examined, prepared the research topic and wrote the research, collected data, processed data, and drew conclusions. The second and third authors provided suggestions and feedback on the background used, discussion, improvement of writing structure, etc. The third author has contributed to the overall research. All three authors have contributed to the overall research. The authors express their gratitude to Allah SWT for His grace and guidance so that this research can be carried out well and smoothly. A big thank you to both parents and family for their prayers and support during the researcher's research.

References

[1] Althafullayya MR, Al-Qur'an Dan Tafsir I, Ushuluddin U, Islam N, Sultan S, Kasim R. Peran Pendidikan Karakter Untuk Generasi Muda Berdaya Tahan dalam Mendukung Ketahanan Nasional: Analisis Holistik [Internet]. Vol. 2, Journal Education Innovation E-ISSN. 2024. Available from: https://jurnal.ypkpasid.org/index.php/jei

[2] Amorós Molina Á, Helldén D, Alfvén T, Niemi M, Leander K, Nordenstedt H, et al. Integrating the United Nations sustainable development goals into higher education globally: a scoping review. Vol. 16, Global Health Action. Taylor and Francis Ltd.; 2023. https://doi.org/10.1080/16549716.2023.2190649.

[3] Vioreza N, Hilyati W, Lasminingsih M. Education for Sustainable Development: Bagaimana Urgensi dan Peluang Penerapannya pada Kurikulum Merdeka? PUSAKA: Journal of Educational Review [Internet]. 2023;1(1):34–48.

[4] Fahlevi MR. Upaya Pengembangan Number Sense Siswa Melalui Kurikulum Merdeka (2022). Sustainable Jurnal Kajian Mutu Pendidikan. 2022 Jun;5(1):11–27.

[5] Rosa E, Destian R, Agustian A, Wahyudin W. Inovasi Model dan Strategi Pembelajaran dalam Implementasi Kurikulum Merdeka. Vol. 5. J Educ Res. 2024;5(3):2608–17.

[6] Aulia R. Persepsi Mahasiswa Calon Guru Kimia tentang Pendidikan untuk Pembangunan Berkelanjutan. repository.uinjkt.ac.id [Internet]. Available from: https://repository.uinjkt.ac.id/dspace/handle/123456789/49987

[7] Zuin VG, Eilks I, Elschami M, Kümmerer K. Education in green chemistry and in sustainable chemistry: perspectives towards sustainability. Green Chem. 2021 Feb;23(4):1594–608.

[8] Almuhur E. Effective Teaching Strategies for Integrating ESD into STEM (Science, Technology, Engineering, and Math) in Jordanian Curricula. 2023;18:170–8. Available from: https://doi.org/https://doi.org/10.5281/zenodo.10049652#39.

[9] Permanasari A, Dwi Pursitasari I. Students' Critical Thinking Skills and Sustainability Awareness in Science Learning for Implementation Education for Sustainable Development. 2021; Available from: http://dx.doi.org/https://doi.org/10.17509/xxxx.vxix.

[10] Sulkipani Habibah SM. Pemberdayaan pendidikan indonesia tren, budaya, dan wawasan. Andriyanto Jusuf Blegur A, editor. LAKEISHA; 2024. 1–249 p.

[11] Priharsari D. SYSTEMATIC LITERATURE REVIEW DI BIDANG SISTEM INFORMASI DAN ILMU KOMPUTER. 2022;9(2):263–8.

[12] Triandini E, Jayanatha S, Indrawan A, Putra GW, Iswara B, Studi P, et al. Metode Systematic Literature Review untuk Identifikasi Platform dan Metode Pengembangan Sistem Informasi di Indonesia [Internet]. Vol. 1, Indonesian Journal of Information Systems (IJIS. Available from: https://www.google.com

[13] Okoli C. A Guide to Conducting a Standalone Systematic Literature Review Chitu Okoli. A Guide to Conducting a Standalone Systematic Literature Review [Internet]. Communications of the Association for Information Systems. 2015. Available from: https://hal.science/hal-01574600v1

[14] Xiao Y, Watson M. Guidance on Conducting a Systematic Literature Review. Vol. 39, Journal of Planning Education and Research. SAGE Publications Inc.; 2019. p. 93–112. https://doi.org/10.1177/0739456X17723971.

[15] Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. Vol. 372, The BMJ. BMJ Publishing Group; 2021.

[16] Martín-Martín A, Thelwall M, Orduna-Malea E, Delgado López-Cózar E. Google Scholar, Microsoft Academic, Scopus, Dimensions, Web of Science, and OpenCitations' COCI: a multidisciplinary comparison of coverage via citations. Scientometrics. 2021;126(1):871–906.

[17] Moher D, Shamseer L, Clarke M, Ghersi D, Liberati A, Petticrew M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Revista Espanola de Nutricion Humana y Dietetica. 2016;20(2):148–60.

[18] Snyder H. Literature review as a research methodology: an overview and guidelines. J Bus Res. 2019 Nov;104:333–9.

[19] van Eck NJ, Waltman L. Citation-based clustering of publications using CitNetExplorer and VOSviewer. Scientometrics. 2017;111(2):1053–70.

[20] Braun V, Clarke V. Can I use TA? Should I use TA? Should I not use TA? Comparing reflexive thematic analysis and other pattern-based qualitative analytic approaches. Couns Psychother Res. 2021 Mar;21(1):37–47.