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Review Article

The contributing of chemistry learning in supporting education for sustainable development: A systematic literature review

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Abstract

This study aimed to examine the contribution of chemistry learning in supporting Education for Sustainable Development (ESD) and the types of competencies that can be developed through ESD. The method used is Systematic Literature Review (SLR), which consists of five stages, namely question formulation, locating studies, study selection and evaluation, analysis and synthesis, reporting and using the results. Based on a study of 38 journal articles from International and National Journal, the contribution of chemistry learning in supporting ESD is manifested in the form of integrating ESD concepts into learning models, incorporating ESD concepts in a chemistry learning context, and developing ESD concepts through learning designs and teaching materials. Through the implementation of ESD in chemistry learning, competencies that can be developed are communication, collaboration, problem solving, creative thinking, systems thinking, critical thinking, scientific literacy, sustainable environmental literacy, understanding, motivation, environmental awareness, and sustainable awareness. Chemistry education and ESD have strong link in many aspects of life, so that competencies developed through the implementation of ESD in the learning process will be able to improve the quality of education and environment.

Introduction

On 25th September 2015 through a summit held in New York, the UN General Assembly adopted the 2030 Agenda for Sustainable Development which contained 17 Sustainable Development Goals (SDGs). The SDGs in an inclusive way describe development challenges for all world communities. The goal of the 17 SDGs is to ensure a sustainable, peaceful, prosperous and just life on earth for all people now and in the future (UNESCO, 2017). To create a more sustainable world and to engage with sustainability-related issues as described in the SDGs, individuals must become drivers of sustainability change. Young people need knowledge, skills, values and attitudes that empower them to contribute to sustainable development. Therefore, education is very important for achieving sustainable development. Education for Sustainable Development (ESD) is an approach that supports sustainable development that uses three pillars to guide students to take responsibility and make decisions related to social, economic and environmental issues (UNESCO, 2017).

ESD is explicitly recognized in the SDGs as part of SDGs Target 4.7 on education which reads, "By 2030, ensure that all students acquire the knowledge and skills to strengthen them, through education sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, public global population, respecting cultural diversity and its contribution to sustainable development". At the same time, it is also important to emphasize ESD for all the other 16 SDGs, with the aim of developing cross-sectoral sustainability competencies in learners (United Nations, 2015). ESD aims to develop skills that enable individuals to reflect on their own actions, taking into account current social impacts, their cultural, economic and environmental aspects in the present and future, from a local and global perspectives. Individuals must also be empowered to act in complex situations in a sustainable manner, which may require them to move in new directions; and to participate in socio-political processes, moving their societies towards sustainable development (UNESCO, 2012).

ESD is an important tool in supporting the achievement of the SDGs so that everyone can contribute to promoting sustainable development through economic, social and environmental changes. ESD can produce certain cognitive learning outcomes, skills and attitudes that enable each individual to face the global challenges of the sustainable development goals. That is, ESD enables each individual to contribute to achieving the SDGs by equipping them with the competencies they need, not only as a tool in understanding SDGs, but also to become smart and responsible citizens in overcoming the various

challenges in the future (UNESCO, 2017). ESD supports five basic kinds of learning to provide quality education, namely learning to know, learning to be, learning to live together, learning to do, and learning to transform oneself and society. ESD has the characteristics of creating an awareness, containing local and global visions, learning to be responsible, learning to change, participation, lifelong learning, critical thinking, emphasizing a systemic approach and complex understanding, decision making, interdisciplinary, problem solving, and satisfy the needs of the present without compromising future generations (UNESCO, 2009).

Education is the most strategic tool for promoting concepts, instilling and growing ESD values and producing a superior generation in environmentally sound development (Perkasa and Aznam, 2016). ESD requires a practice-oriented application and competency development to promote ESD so that it is not just a concept that is created but can produce competencies that are relevant to the lives of students. The global era requires students, especially prospective teacher students, to have 21st century competence and environmental insight in order to develop environmental knowledge and awareness. Universities must be at the forefront of sustainability projects to increase environmental awareness and create a sustainable future (Pike et al. 2003). So that ESD needs to become a core concept in education and competency development for prospective chemistry teacher students which is one of the important keys to success in cultivating ESD values (Wolff et al. 2017). Through this, prospective teacher students can also understand how to apply ESD values to students in the learning process at school.

Chemistry education should stand out in support of ESD because of the role played by chemistry and the chemical industry in everyday life (Burmeister et al. 2012). The contribution of chemistry learning to support ESD includes developing understanding of prospective chemistry teachers and their competence to apply ESD appropriately in teaching (Paristiowati et al. 2022). Chemistry education students are expected to be able to develop an understanding of the role of chemistry in society and be able to evaluate how chemistry can contribute to community sustainability and support natural resource management (Burmeister et al. 2012). For decades, teachers have been cited as key agents in the process of sustainability (UNESCO, 2005). So it is important for student teacher candidates to have competencies that can help overcome the challenges of various impacts from changing times. This competency cannot grow and develop naturally, but requires treatment in order to develop relevant competencies for student teacher candidates.

Method

Systematic literature review (SLR) method was used in this study to examine how academics innovate in implementing ESD in chemistry learning. SLR research is the process of identifying, evaluating and analyzing all information in the literature/references to discuss the parameters to be studied (Xiao and Watson, 2019). The data sources in this study were articles from various journals in the last 10 years regarding ESD in chemistry learning with the parameters identified which can be seen in Table 1.

Table 1. Parameters studied

Parameter	Description
Contribution of chemistry learning in supporting ESD	To see how chemistry learning contributes in support the implementation of ESD
Competencies that can be developed through ESD	To see what competencies can be developed through the application of ESD in the learning process

This SLR adopts the five-step guideline from Denyer and Tranfield (2009) (Fig.-1), which has also been reported to have been used by other authors such as Han et al. (2020) and Husamah et al. (2022).

Step 1: Question Formulation

This first step is to determine the scope for developing a clear research focus. This study proposes and attempts to answer questions based on the needs of the chosen topic, namely:

1. How does chemistry learning contribute to supporting ESD?
2. What competencies can be developed through the implementation of ESD in chemistry learning?

Step 2: Locating Studies

The second step of the SLR is finding, selecting, assessing, and listing the core contributions related to the review questions. The target of this research is the theme "Education for Sustainable Development in chemistry learning". These keywords are used to track related/appropriate articles published by national and international journals from 2012 to 2022. The search process uses the search menu on the Google Scholar platform (https://scholar.google.com) and the Scopus website (https://www.scopus.com) with the keyword "Education for Sustainable Development chemistry learning". Obtained articles are saved in PDF format which are then synchronized with Mendeley.

Step 3: Study Selection and Evaluation

This stage is carried out to ensure that the data obtained is suitable for use in SLR research or not. The study standards that meet the requirements are as follows: (i) the data used is from the year of publication 2012-2022; (ii) articles published in

English and Indonesian; (ii) the full article is accessible; (iv) related to the theme "Education for Sustainable Development in chemistry learning"; and (v) only types of research report articles. A search for publications using the keyword Education for Sustainable Development in chemistry learning resulted in 168 related publications. Selection of publications that are potential and relevant to the topic, namely those that examine the forms of ESD implementation in chemistry learning and the types of competencies that can be developed through ESD. As a result, 38 publication titles were obtained from the process. The systematic literature review scheme can be seen in Fig.-2.

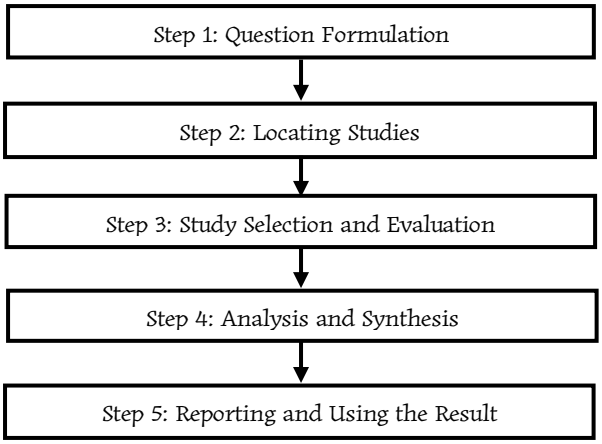

Fig.-1. Five Steps of systematic literature review (adapted from Denyer and Tranfield, 2009)

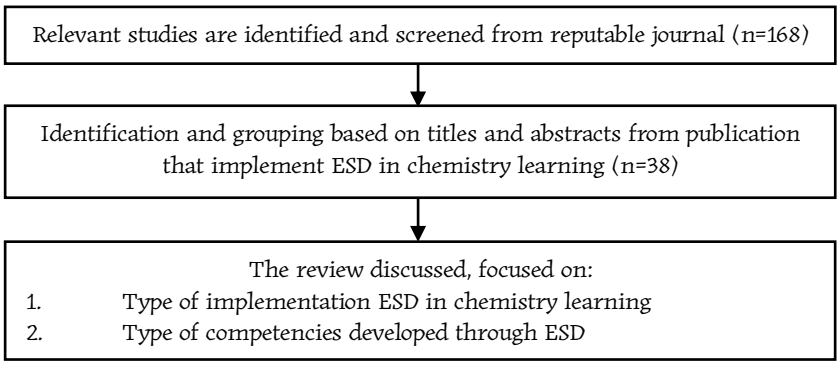

Fig.-2. The systematic literature review scheme

Step 4: Analysis and Synthesis

After selecting the articles, the next step is to synthesize data with the aim of analyzing and evaluating research results from various literatures according to the parameters to be discussed, namely the form of chemistry learning contribution in supporting ESD and the types of competencies that can be developed through ESD. The data synthesis carried out in this study is in the form of a narrative.

Step 5: Reporting and Using the Result

The reporting stage is the final stage in systematic literature review. This stage includes writing the results of a systematic literature review in written form according to a predetermined format.

Results and Discussion

This study aims to discuss in depth what ESD is, how chemistry learning contributes to supporting ESD, and the types of competencies that can be developed through ESD. Competence is the ability of each individual which includes knowledge, skills, and attitudes, and chemistry learning can contribute to supporting the development of these competencies through ESD. Research on ESD in Chemistry learning is still not widely carried out in Indonesia. This is known from the lack of articles or journal literature in Indonesia that discusses ESD in chemistry teaching. One of the contributing factors is the uneven distribution of information about ESD in Indonesia, particularly in the education sector. Therefore, through this research it is hoped that it can contribute to providing a complete explanation of ESD, especially in Chemistry learning.

The Contribution of Chemistry Learning in Supporting ESD

Chemistry learning is considered to have a central role in ESD (Bradley, 2005). It is based on the core role played by chemistry and the chemical industry in a sustainable way. Many products in our life are based on chemistry and the

chemical industry has great opportunities to focus on the environment, both in the manufacturing process and in the end product. Therefore, it has been asserted that chemistry learning should increase students' knowledge and ability to understand the role of chemistry in society, such as how chemistry can affect the future, contribute to a sustainable society and help manage of natural resources well (Burmeister and Eilks, 2012; Wheeler and Harvey, 2000).

The contribution of chemistry learning to support ESD includes developing the understanding of prospective chemistry teachers and their ability to understand ESD appropriately through the learning process. This is because student teacher candidates are the part that will be responsible for instilling sustainability values as early as possible in students (Paristiowati et al. 2022). ESD can be implemented through the implementation of chemistry learning in tertiary institutions (Mkumbachi et al. 2020) through the design of mature learning activities (Fauzi and Suryadi, 2020). The form of the contribution of chemistry learning in supporting ESD is realized through the implementation of ESD values in learning.

Various forms of ESD implementation in the chemistry learning process which are manifested through the implementation of ESD in chemistry learning in high schools and tertiary institutions. The forms of implementation include developing ESD implementation strategies, incorporating ESD values into a chemistry learning context, integrating them into learning models or approaches, and also developing them through learning designs and teaching materials. Burmeister and Eilks (2012) have presented four strategies for implementing sustainable development issues in formal chemistry education. They suggest that the following strategies should be implemented in the best combination by including ESD in chemistry learning, namely: (1) Application of green chemistry principles in practicum, (2) Addition of sustainability strategies as content in chemistry education, (3) Inclusion of socio-scientific issues and controversies in teaching, and (4) Use of chemistry education as part of ESD school development.

Based on the strategy developed by Burmeister and Eilks (2012) and Jegstad and Sinnes (2015) modified this strategy and produced a model that proposed how ESD could be realized in chemistry education, which later became known as the ESD elliptical model. The ESD Elliptical Model is a model that can assist teachers in planning chemistry lessons. This model provides a way to embody ESD in chemistry education without adding more content knowledge to the curriculum. The ESD Elliptical Model in chemistry education has been developed to assist teachers in their ESD implementation. This model covers five categories of ESD, all denoted by an ellipse. The three central ellipses of the model are closely related to the subject of chemistry, while the other two are of a more general educational nature. The 5 categories include Knowledge of chemical content, chemistry in context, peculiarities and methodological characteristics of chemistry, ESD competence, and ESD life.

The application of ESD in Chemistry learning can be supported by integrating it through learning approaches or models such as problem-based learning (PBL), project-based learning (PjBL), and inquiry-based learning. Through PBL students can apply the information and knowledge they have regarding sustainability issues such as the role of chemistry in industry and environment (UNESCO, 2018). The use of PBL in learning can support students to learn various forms of knowledge as a means of solving problems. The PjBL model is also a model that can be used as a platform for implementing ESD-laden chemistry learning. PjBL can train students to be active and creative in solving given problems. PjBL provides opportunities for students to be active in learning and produce a product based on the problems that have been discussed. The resulting product can be in the form of ideas or devices that can be a contribution of students in improving various aspects of the quality of life now and in the future (Permanasari, 2016).

Based on articles that have analyzed several forms of implementation, namely, Paristiowati et al. (2022) developed the competencies of Prospective Chemistry Teachers with continuing education through Project-Based Learning. Günter et al. (2017) understand 'green chemistry' and sustainability through problem-based learning (PBL). Hugerat (2020) incorporating Sustainability into Chemistry Education through Project-Based Learning. Juntunen and Aksela (2013) apply the context of the life cycle in Inquiry-Based Continuing Education to foster Student Chemical Literacy. Zowada (2018) integrates a socio-scientific issue related to sustainability into the chemistry undergraduate program. Nurfadilah and Siswanto (2020) apply the ESD-loaded STEAM approach to analyze creative thinking skills on polymer concepts.

Incorporating ESD values into a learning context is one of the most effective ways of implementing ESD, because through this students can directly think and apply the real context of chemistry in everyday life which can be collaborated with ESD values. Pernaa et al. (2022) developed a didactic design in the context of ionic liquid applications to introduce students to sustainable chemical properties. Hasibuan et al. (2021) integrated sustainability-based agro-industry development into chemistry learning to increase the competence of pre-service chemistry teachers. Koutalidi and Scoullos (2016) devised a didactic design to increase understanding of biogeochemical cycles that integrates ESD values. Zidny and Eilks (2022) developed a didactic design for using pesticides based on ethnoscience as a contribution to green and sustainable chemistry education. Holme (2020) introduces sustainable chemistry and systems thinking in basic chemistry through learning pharmaceutical chemistry.

Furthermore, the development of ESD-oriented design and teaching materials is manifested in the form of developing didactic designs such as in the research of Herranen et al. (2021) based didactic designs eco-reflexive in environmental chemistry oriented towards sustainable education. Burmeister and Eilks (2013) Developed modules on sustainability issues and Education for Sustainable Development in chemistry teacher education in Germany. Amyyana et al. (2017) developed a Learning Resource for plastic pyrolysis in the form of a book based on Education for Sustainable Development to support chemistry learning. Perkasa and Aznam (2016) developing a Subject Specific Pedagogy (SSP) for chemistry subjects based on continuity education to increase chemical literacy and environmental awareness. Fibonacci et al. (2020) developing

Chemsdro Mobile Learning based on Education for Sustainable Development on reaction rate material. In addition to the forms of implementation described above, other forms of ESD implementation in chemistry learning can be seen in Table 2.

Table 2. Implementation of ESD in chemistry learning from international journals

No	Type of Implementation	Author	Journal
1	Integrating green chemistry principles in chemistry learning as a tool to increase awareness of sustainability	(Loste et al. 2020)	Journal of Cleaner Production
2	Project-Based Learning for Environmental Sustainability Action	(Bramwell-Lalor et al. 2020)	Southern African Journal of Environmental Education
3	Instilling Sustainability Science Literacy through Chemistry Education in the Context of Climate Science	(Mahaffy et al. 2014)	ACS Sustainable Chemistry and Engineering
4	A series of core competencies are developed as a guide for implementing environmentally friendly and sustainable chemistry knowledge and skills into the curriculum	(MacKellar et al. 2020)	Journal of Chemical Education
5	Placing Sustainable Development in Secondary Chemistry Education through Systems Thinking	(Eaton et al. 2019)	Journal of Chemical Education
6	Using systems thinking, interdisciplinary research projects, and creative problem solving as the framework for a modern chemistry curriculum	(Blatti et al. 2019)	Journal of Chemical Education
7	Increasing environmental literacy and sustainability of learners in teaching chemistry by combining socio-scientific issues from life cycle thinking with inquiry-based learning approaches.	(Juntunen and Aksela, 2013)	Chemistry Education Research and Practice
8	Learning by integrating native and Western scientific perspectives to help broaden the chemistry of high school and college students.	(Zidny and Eilks, 2020)	Sustainable Chemistry and Pharmacy
9	Implementing learning designs for science education teachers and prospective teacher trainees to encourage and promote attention to the Sustainable Development Goals	(Chuliá-Jordán et al. 2022)	Sustainability
10	Integrating green chemistry concepts and sustainability in chemistry curriculum and teaching	(Zuin et al. 2021)	Green Chemistry
11	Assessing life cycle and system thinking skills to practice sustainable chemistry in learning	(Constable, 2021)	IScience
12	Integrating sustainability into chemistry education through systems thinking, and the Sustainable Development Goals framework	(Wissinger et al. 2021)	Journal of Chemical Education
13	Developing a systems thinking approach to educate students on the molecular basis of sustainability to help chemistry learning contribute meaningfully	(Mahaffy et al. 2019)	Journal of Chemical Education
14	Integrating sustainability into teaching using learning models	(Schultz, 2013)	Journal of Learning Design Embedding
15	Incorporating continuous topic into the teaching of chemistry on the topic of solar energy	(Pullen and Brinkert, 2014)	Journal of Chemical Education
16	Implementing laboratory courses and new green chemistry projects designed to promote sustainability thinking and reasoning	(Timmer et al. 2018)	Journal of Chemical Education
17	Using the concept of systems thinking and the Sustainable Development Goals (SDGs) to provide an overview some of the challenges facing chemistry in higher education.	(Michalopoulou et al. 2019)	Journal of Chemical Education
18	Applying an experiential learning approach based on sustainable practice within the industrial sphere	(Ginzburg et al. 2019)	Journal of Chemical Education

Competencies That Can Be Developed Through ESD

In the 21st century the development of science and technology is increasing and will continue to experience development over time. So that everyone must contribute in building a sustainable society. A sustainable society directs every individual to learn to understand the complex world in which they live, face various challenges, and the high speed of social change, and must be able to collaborate, communicate, and act positively towards changes in the world, so competence is needed to achieve this. The global era requires students to have 21st century skills and good environmental knowledge. Environmental awareness is very important to foster a sense of awareness of the environment. A concept that can be applied to develop environmental awareness is Education for Sustainable Development (ESD) (Svanström et al. 2008).

Education for Sustainable Development (ESD) aims to develop the competence of each individual to reflect on their own actions by considering current and future social, cultural, economic and environmental impacts locally and globally (UNESCO, 2018). Achieving the goals of sustainable development requires the awareness and ability of everyone, especially

the young millennial generation, to make a real contribution. ESD also allows students to play an active and responsible role in creating a sustainable society. ESD can develop competencies (knowledge, skills and attitudes) as capital for the younger generation to live a healthy life and be able to overcome various local and global challenges. Following are the results of the classification of articles based on competencies developed through the implementation of ESD in chemistry learning (Table 3).

Table 3. Competencies developed through the implementation of ESD

Competences Developed	References
Communication	(Paristiowati et al. 2022; Bramwell-Lalor et al. 2020)
Collaboration	(Paristiowati et al. 2022; Bramwell-Lalor et al. 2020; Hasibuan et al. 2021)
Creative Thinking	(Hasibuan et al. 2021; Blatti et al. 2019; Nurfadilah and Siswanto, 2020)
Problem Solving	(Hasibuan et al. 2021; Blatti et al. 2019)
Systems Thinking	(Eaton et al. 2019; Wissinger et al. 2021; Mahaffy et al. 2019; Holme, 2020)
Critical Thinking	(Blatti et al. 2019)
Scientific Literacy	((Pernaa et al. 2022; Dieni et al. 2020)
Environmental Literacy	(Juntunen and Aksela, 2013)
Chemical Literacy	(Perkasa and Aznam, 2016)
Comprehension	(Burmeister and Eilks, 2012; Günter et al. 2017; Juntunen and Aksela, 2013)
Environmental Awareness	(Paristiowati et al. 2022; Ekantini and Wilujeng, 2018; Perkasa et al. 2017; Günter et al. 2017; Zidny and Eilks, 2022; Koutalidi and Scoullos, 2016; Perkasa and Aznam, 2016)
Sustainability Awareness	(Loste et al. 2020; Hugerat, 2020; Chuliá-Jordán et al. 2022)

Based on Table 3 it is known that the implementation of ESD in chemistry learning can develop various competencies that can help overcome global challenges, such as communication skills, collaboration, and environmental awareness which are developed through the implementation of ESD using project-based learning (Paristiowati et al. 2022; Bramwell-Lalor et al. 2020). Communication and collaboration are two of the four skills of the 21st century. Communication skills are skills to convey new thoughts, ideas, ideas, knowledge and information to others through speech, writing, symbols, pictures, graphics or numbers. These skills include listening skills, obtaining information, and conveying ideas in front of many people (NEA, 2012). Collaborative skills are the ability to contribute actively, responsibly, and value in groups (Le et al. 2018).

Some of the abilities developed such as communication skills, collaboration, creative thinking, problem solving, systems thinking, and critical thinking are competencies which in the elliptical model developed by Jegstad and Sinnes (2015) are referred to as ESD competencies. There are nine main competencies that are considered important to support ESD, namely: 1) problem solving, 2) systems thinking, 3) critical thinking, 4) action competence, 5) creativity, 6) future thinking and beliefs, 7) normative competence, 8) collaboration, and 9) communication. These competencies are very important for sustainability. Each competency has its own qualities and areas of relevance. These competencies are interdependent on one another. That is the reason why integrated problem solving competencies are so important. In addition, basic competencies such as communication skills are very important to deal with sustainable development. Furthermore, these main sustainability competencies must be developed together with basic competencies (Brundiers et al. 2010).

Apart from the competencies mentioned in Jegstad and Sinnes (2015), other competencies can also be developed through the implementation of ESD in the learning process as can be seen in Table 2. Zidny and Eilks (2022) develop scientific literacy skills and environmental awareness through learning in the context of using pesticides based on Ethnoscience. Mahaffy et al. (2014) developed scientific literacy skills through learning chemistry in the context of climate science. Pernaa et al. (2022) Develop scientific literacy skills through learning chemistry in the context of sustainable ionic liquids. Perkasa and Aznam (2016) increase chemical literacy and environmental awareness through the development of Subject Specific Pedagogy (SSP) Chemistry Subjects Based on Continuing Education.

ESD is a competency-based approach to scientific literacy that emphasizes ethical competence, communicative competence, and other competencies that include socio-scientific decision-making skills (Jegstad and Sinnes, 2015). So that the nine ESD competencies are related to scientific literacy. Several studies on the implementation of ESD also aim to develop scientific literacy, this is because ESD competencies are aligned with scientific literacy. Scientific literacy includes scientific knowledge, scientific processes, and the development of scientific attitudes that will enable students to make decisions with their knowledge. Scientific literacy describes a person's ability to understand laws, theories, phenomena, and scientific matters (Aswirna and Ritonga, 2020). Scientific literacy is a combination of skills, values, attitudes, understanding, competencies, and scientific knowledge needed by individuals to develop research-investigations, problem-solving, skills and abilities to interpret data and facts scientifically and the ability to understand learning concepts (Klucevsek, 2017).

Based on the literature review that has been conducted on the contribution of chemistry learning in supporting ESD and the types of competencies that can be developed through ESD, it is found that there are many ways that can be done in disseminating sustainability values in the learning process, one of which is through integration into project-based learning models. This learning model has started to be implemented by incorporating the concept of ESD in it. Various competencies are also proven to be developed through the implementation of ESD in chemistry learning such as 21st century competencies, sustainability awareness, science literacy, etc. Among these competencies, science literacy is one of the good

competencies for students' self-development. However, there are still few articles that discuss the development of science literacy through the cultivation of sustainability values in chemistry learning. Therefore, there is a need for further research that can examine how to develop science literacy through the implementation of ESD in chemistry learning.

Conclusion

Chemistry learning has an important role in education for sustainable development to shape the current and future generations to live sustainably. Many academics study ESD, where the essence is that ESD requires a platform to disseminate it to students and chemistry learning is a contributor that can support ESD. The contribution of chemistry learning in supporting ESD is realized through the implementation of ESD in chemistry learning in schools and tertiary institutions. The forms of implementation include developing ESD implementation strategies, incorporating ESD values into a chemistry learning context, integrating them into learning models or approaches, and also developing ESD values through learning designs and teaching materials. One of the learning models that is suitable for developing ESD in learning is the PjBL model, where the PjBL model emphasizes project work based on real-life issues. The implementation of ESD in chemistry learning can develop various competencies that are relevant to the lives of students, including communication, collaboration, problem solving, creative thinking, systems thinking, critical thinking, science literacy, sustainable environmental literacy, understanding, motivation, environmental awareness, and sustainable awareness. These competencies are expected to help learners to overcome various global challenges and achieve the goals of the SDGs.

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Conflict of Interests

The author (s) declares that there is no conflict of interest in this research and manuscript.

References

Amyyana, A. H., Paristiowati, M., & Kurniadewi, F. (2017). Pirolisis sederhana limbah plastik dan implementasinya sebagai sumber belajar berbasis education for sustainable development (Esd) pada pembelajaran kimia. *Jurnal Riset Pendidikan Kimia*, 7(1), 38–51.

Aswirna, P., & Ritonga, A. M. (2020). Development of discovery learning - based e-book teaching based On KVISOFT flipbook maker on science liteartion in MAN 2 Padang Pariaman. *Hunafa: Jurnal Studia Islamika*, 17(2), 47–75.

Blatti, J. L., Garcia, J., Cave, D., Monge, F., Cuccinello, A., Portillo, J., Juarez, B., Chan, E., & Schwebel, F. (2019). Systems thinking in science education and outreach toward a sustainable future. *Journal of Chemical Education*, 96(12), 2852–2862. https://doi.org/10.1021/acs.jchemed.9b00318

Bramwell-Lalor, S., Kelly, K., Ferguson, T., Hordatt Gentles, C., & Roofe, C. (2020). Project-based learning for environmental sustainability action. *Southern African Journal of Environmental Education*, 36, 57–72. https://doi.org/10.4314/sajee.v36i1.10

Brundiers, K., Wiek, A., & Redman, C. L. (2010). Real-world learning opportunities in sustainability: From classroom into the real world. *International Journal of Sustainability in Higher Education*, 11(4), 308–324. https://doi.org/10.1108/14676371011077540

Burmeister, M., & Eilks, I. (2012). An example of learning about plastics and their evaluation as a contribution to Education for Sustainable Development in secondary school chemistry teaching. *Chemistry Education Research and Practice*, 13(2), 93–102. https://doi.org/10.1039/c1rp90067f

Burmeister, M., & Eilks, I. (2013). An understanding of sustainability and education for sustainable development among German student teachers and trainee teachers of chemistry. *Science Education International*, 24(2), 167–194.

Burmeister, M., Rauch, F., & Eilks, I. (2012). Education for sustainable development (ESD) and chemistry education. *Chemistry Education Research and Practice*, 13(2), 59–68. https://doi.org/10.1039/c1rp90060a

Chuliá-Jordán, R., Peña, A. V., & Llinares, M. C. (2022). The press as a resource for promoting sustainability competencies in teacher training: The case of SDG 7. *Sustainability (Switzerland)*, 14(2). https://doi.org/10.3390/su14020857

Constable, D. J. C. (2021). Green and sustainable chemistry – The case for a systems-based, interdisciplinary approach. *IScience*, 24(12), 103489. https://doi.org/10.1016/j.isci.2021.103489

Denyer, D., & Tranfield, D. (2009). *Producing a Systematic Review*. In The SAGE Handbook of Organizational Research Methods (pp. 671–689).

Dieni, W. E. F., Hernani, & Kaniawati, I. (2020). Applying the education for sustainable development approach to energy instruction design for encouraging scientific literacy of junior high school students. *E-Journal Ups*, 4, 1–11.

Eaton, A. C., Delaney, S., & Schultz, M. (2019). Situating sustainable development within secondary chemistry education via systems thinking: A depth study approach. *Journal of Chemical Education*, 96(12), 2968–2974. https://doi.org/10.1021/acs.jchemed.9b00266

Ekantini, A., & Wilujeng, I. (2018). The development of science student worksheet based on education for environmental sustainable development to enhance scientific literacy. *Universal Journal of Educational Research*, 6(6), 1339–1347. https://doi.org/10.13189/ujer.2018.060625

Fauzi, I., & Suryadi, D. (2020). The analysis of students' learning obstacles on the fraction addition material for five graders of elementary schools. Al Ibtida: *Jurnal Pendidikan Guru MI*, 7(1), 33. https://doi.org/10.24235/al.ibtida.snj.v7i1.6020

Fibonacci, A., Azizati, Z., & Wahyudi, T. (2020). Development of education for sustainable development (esd) based chemsdro mobile based learning for indonesian junior high school: Rate of reaction. *JTK (Jurnal Tadris Kimiya)*, 5(1), 26–34. https://doi.org/10.15575/jtk.v5i1.5908

Ginzburg, A. L., Check, C. E., Hovekamp, D. P., Sillin, A. N., Brett, J., Eshelman, H., & Hutchison, J. E. (2019). Experiential Learning to Promote Systems Thinking in Chemistry: Evaluating and designing sustainable products in a polymer immersion lab. *Journal of Chemical Education*, 96(12), 2863–2871. https://doi.org/10.1021/acs.jchemed.9b00336

Günter, T., Akkuzu, N., & Alpat, Ş. (2017). Understanding 'green chemistry' and 'sustainability': an example of problem-based learning (PBL)*. *Research in Science and Technological Education*, 35(4), 500–520. https://doi.org/10.1080/02635143.2017.1353964

Han, Y., Chong, W. K., & Li, D. (2020). A systematic literature review of the capabilities and performance metrics of supply chain resilience. *International Journal of Production Research*, 0(0), 4541–4566. https://doi.org/10.1080/00207543.2020.1785034

Hasibuan, N. A. P., Paristiowati, M., & Erdawati, E. (2021). Sustainability development-based agroindustry in chemistry learning to improve the preservice chemistry teachers' competence. *Tadris: Jurnal Keguruan dan Ilmu Tarbiyah*, 6(1), 125–138. https://doi.org/10.24042/tadris.v6i1.8346

Herranen, J., Yavuzkaya, M., & Sjöström, J. (2021). Embedding chemistry education into environmental and sustainability education: Development of a didaktik model based on an eco-reflexive approach. *Sustainability (Switzerland)*, 13(4), 1–15. https://doi.org/10.3390/su13041746

Holme, T. (2020). Using the chemistry of pharmaceuticals to introduce sustainable chemistry and systems thinking in general chemistry. *Sustainable Chemistry and Pharmacy*, 16(1). https://doi.org/10.1016/j.scp.2020.100234

Hugerat, M. (2020). Incorporating sustainability into chemistry education by teaching through project-based learning [Chapter]. *ACS Symposium Series*, 1344, 79–96. https://doi.org/10.1021/bk-2020-1344.ch007

Husamah, H., Suwono, H., Nur, H., & Dharmawan, A. (2022). Sustainable development research in Eurasia Journal of Mathematics, Science and Technology Education: A systematic literature review. *Eurasia Journal of Mathematics, Science and Technology Education*, 18(5). https://doi.org/10.29333/ejmste/11965

Jegstad, K. M., & Sinnes, A. T. (2015). Chemistry Teaching for the Future: A model for secondary chemistry education for sustainable development. *International Journal of Science Education*, 37(4), 655–683. https://doi.org/10.1080/09500693.2014.1003988

Juntunen, M., & Aksela, M. (2013). Life-Cycle Thinking in Inquiry-Based Sustainability Education – Effects on Students' Attitudes towards Chemistry and Environmental Literacy Življenjski krog izdelkov in učenje z raziskovanjem za trajnostni razvoj – vpliv na odnos učencev do kemije in oko. *C.E.P.S Journal*, 3, 157–180.

Klucevsek, K. (2017). The intersection of information and science literacy. *Communications in Information Literacy*, 11(2), 354–365. https://doi.org/10.15760/comminfolit.2017.11.2.7

Koutalidi, S., & Scoullos, M. (2016). Biogeochemical cycles for combining chemical knowledge and ESD issues in Greek secondary schools part I: Designing the didactic materials. *Chemistry Education Research and Practice*, 17(1), 10–23. https://doi.org/10.1039/c5rp00151j

Le, H., Janssen, J., & Wubbels, T. (2018). Collaborative learning practices: teacher and student perceived obstacles to effective student collaboration. *Cambridge Journal of Education*, 48(1), 103–122. https://doi.org/10.1080/0305764X.2016.1259389

Loste, N., Chinarro, D., Gomez, M., Roldán, E., & Giner, B. (2020). Assessing awareness of green chemistry as a tool for advancing sustainability. *Journal of Cleaner Production*, 256. https://doi.org/10.1016/j.jclepro.2020.120392

MacKellar, J. J., Constable, D. J. C., Kirchhoff, M. M., Hutchison, J. E., & Beckman, E. (2020). Toward a green and sustainable chemistry education road map. *Journal of Chemical Education*, 97(8), 2104–2113. https://doi.org/10.1021/acs.jchemed.0c00288

Mahaffy, P. G., Martin, B. E., Kirchhoff, M., McKenzie, L., Holme, T., Versprille, A., & Towns, M. (2014). Infusing sustainability science literacy through chemistry education: Climate science as a rich context for learning chemistry. *ACS Sustainable Chemistry and Engineering*, 2(11), 2488–2494. https://doi.org/10.1021/sc500415k

Mahaffy, P. G., Matlin, S. A., Whalen, J. M., & Holme, T. A. (2019). Integrating the Molecular Basis of Sustainability into General Chemistry through Systems Thinking. *Journal of Chemical Education*, 96(12), 2730–2741. https://doi.org/10.1021/acs.jchemed.9b00390

Michalopoulou, E., Shallcross, D. E., Atkins, E., Tierney, A., Norman, N. C., Preist, C., O'Doherty, S., Saunders, R., Birkett, A., Willmore, C., & Ninos, I. (2019). The end of simple problems: repositioning chemistry in higher education and society using a systems thinking approach and the united nations' sustainable development goals as a framework. *Journal of Chemical Education*, 96(12), 2825–2835. https://doi.org/10.1021/acs.jchemed.9b00270

Mkumbachi, R. L., Astina, I. K., & Handoyo, B. (2020). Environmental awareness and pro-environmental behavior: A case of university students in Malang city. *Jurnal Pendidikan Geografi*, 25(2), 161–169. https://doi.org/10.17977/um017v25i22020p161

Nurfadilah, S., & Siswanto, J. (2020). Analisis kemampuan berpikir kreatif pada konsep polimer dengan pendekatan STEAM bermuatan ESD Siswa SMA Negeri 1 Bantarbolang. *Media Penelitian Pendidikan : Jurnal Penelitian Dalam Bidang Pendidikan dan Pengajaran*, 14(1), 45–51. https://doi.org/10.26877/mpp.v14i1.5543

Paristiowati, M., Rahmawati, Y., Fitriani, E., Satrio, J. A., & Hasibuan, N. A. P. (2022). Developing preservice chemistry teachers' engagement with sustainability education through an online, project-based learning summer course program. *Sustainability (Switzerland)*, 14(3). https://doi.org/10.3390/su14031783

Perkasa, M., Agrippina, & Wiraningtyas. (2017). Pembelajaran kimia berorientasi sustainable development untuk meningkatkan kesadaran siswa terhadap lingkungan. *Jurnal Sainsmat*, 6(2), 63–72.

Perkasa, M., & Aznam, N. (2016). Pengembangan SSP kimia berbasis pendidikan berkelanjutan untuk meningkatkan literasi kimia dan kesadaran terhadap lingkungan. *Jurnal Inovasi Pendidikan IPA*, 2(1), 46. https://doi.org/10.21831/jipi.v2i1.10269

Permanasari, A. (2016). STEM education: Inovasi dalam pembelajaran sains [innovation in science learning]. *Prosiding Seminar Nasional Pendidikan Sains* VI, 23–34.

Pernaa, J., Kämppi, V., & Aksela, M. (2022). Supporting the relevance of chemistry education through sustainable ionic liquids context : A research-based design approach. *Sustainability*, 14, 1–18.

Pike, L., Shannon, T., Lawrimore, K., McGee, A., Taylor, M., & Lamoreaux, G. (2003). Science education and sustainability initiatives: A campus recycling case study shows the importance of opportunity. *International Journal of Sustainability in Higher Education*, 4(3), 218–229. https://doi.org/10.1108/14676370310485410

Pullen, S., & Brinkert, K. (2014). SolEn for a Sustainable Future: Developing and Teaching a Multidisciplinary Course on Solar Energy to Further Sustainable Education in Chemistry. *Journal of Chemical Education*, 91(10), 1569–1573. https://doi.org/10.1021/ed400345m

Schultz, M. (2013). Embedding environmental sustainability in the undergraduate chemistry curriculum: A case study. *Journal of Learning Design*, 6(1), 20–33.

Svanström, M., Lozano-García, F. J., & Rowe, D. (2008). Learning outcomes for sustainable development in higher education. *International Journal of Sustainability in Higher Education*, 9(3), 339–351. https://doi.org/10.1108/14676370810885925

Timmer, B. J. J., Schaufelberger, F., Hammarberg, D., Franzén, J., Ramström, O., & Dinér, P. (2018). Simple and effective integration of green chemistry and sustainability education into an existing organic chemistry course. *Journal of Chemical Education*, 95(8), 1301–1306. https://doi.org/10.1021/acs.jchemed.7b00720

UNESCO. (2005). Guidelines and recommendations for reorienting teacher education to address sustainability. *Education for Sustainable Development in Action*, 2, 44.

UNESCO. (2009). *Review of contexts and structures for education for sustainable development*. Division for the Coordination of United Nations Priorities in Education.

UNESCO. (2012). *Education for sustainable development*. United Nations Educational, Scientific and Cultural Organization.

UNESCO. (2017). Education for development goals learning objectives.

UNESCO. (2018). *Issues and trends in Education for Sustainable Development*. United Nations Educational, Scientific and Cultural Organization.

Wheeler, S. F., & Harvey, D. J. (2000). Negative ion mass spectrometry of sialylated carbohydrates: Discrimination of N-acetylneuraminic acid linkages by MALDI-TOF and ESI-TOF mass spectrometry. *Analytical Chemistry*, 72(20), 5027–5039. https://doi.org/10.1021/ac000436x

Wissinger, J. E., Visa, A., Saha, B. B., Matlin, S. A., Mahaffy, P. G., Kümmerer, K., & Cornell, S. (2021). Integrating sustainability into learning in chemistry. *Journal of Chemical Education*, 98(4), 1061–1063. https://doi.org/10.1021/acs.jchemed.1c00284

Wolff, L. A., Sjöblom, P., Hofman-Bergholm, M., & Palmberg, I. (2017). High performance education fails in sustainability? —a reflection on finnish primary teacher education. *Education Sciences*, 7(1). https://doi.org/10.3390/educsci7010032

Xiao, Y., & Watson, M. (2019). Guidance on conducting a systematic literature review. *Journal of Planning Education and Research*, 39(1), 93–112. https://doi.org/10.1177/0739456X17723971

Zidny, R., & Eilks, I. (2020). Integrating perspectives from indigenous knowledge and Western science in secondary and higher chemistry learning to contribute to sustainability education. *Sustainable Chemistry and Pharmacy*, 16(February), 100229. https://doi.org/10.1016/j.scp.2020.100229

Zidny, R., & Eilks, I. (2022). Learning about pesticide use adapted from ethnoscience as a contribution to green and sustainable chemistry education. *Education Sciences*, 12(4). https://doi.org/10.3390/educsci12040227

Zowada, C. (2018). Innovating undergraduate general chemistry by integrating sustainability-related socio-scientific issues. *Action Research and Innovation in Science Education*, 1(2), 3–8.

Zuin, V. G., Eilks, I., Elschami, M., & Kümmerer, K. (2021). Education in green chemistry and in sustainable chemistry: Perspectives towards sustainability. *Green Chemistry*, 23(4), 1594–1608. https://doi.org/10.1039/d0gc03313h