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Sustainable Development Issues in Chemistry Learning as Educational for Sustainable Development Implementation: A Systematic Literature Review

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Abstract

This study aims to systematically synthesize research articles on the application of Educational for Sustainable Development (ESD) in chemistry learning based on their suitability with the research theme: sustainable development issues, ESD dimensions, SDGs, and chemistry concepts. The urgency of this research is to explore the potential of sustainable development issues in chemistry concepts as an implementation of ESD to help teachers who experience difficulties in integrating sustainable development issues into chemistry concepts. This research was conducted with a systematic literature review design that synthesized 23 articles from the ERIC, Science Direct, and Google Scholar databases using the keywords "ESD in Chemistry Learning" and "Implementation of ESD". The results of the systematic review raised six sustainable development issues used in chemistry learning: the use of conventional and biodegradable plastics, green pesticide use, green experiments, water pollution and scarcity, biodiesel from palm oil, and others. The environmental dimension is studied more often than the economic and social dimensions of ESD application in chemistry learning. The implementation of ESD has made the greatest contribution to SDG 4 (Quality Education) with six chemistry concepts that are often used to integrate sustainable development issues: acids and bases, thermochemistry, the periodic table of elements, macromolecules, reaction kinetics, and green chemistry. The variety of sustainable development issues, ESD dimensions, SDGs, and chemical concepts used in the application of ESD in chemistry learning shows that there are opportunities for chemistry learning to contribute to sustainable development.

Keywords: *Educational for sustainable development, Chemistry concepts, Sustainable development issues*

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INTRODUCTION

Educational for Sustainable Development (ESD) is an education that aims to build a sustainable society by incorporating sustainable development issues into learning (UNESCO, 2012). ESD is expected to answer environmental, social, and economic challenges that exist in the 21st century (Vilmala et al., 2022). The implementation of ESD is expected to encourage changes in knowledge, skills, values, and attitudes of the community to create new solutions and ideas towards a better and sustainable future (UNESCO, 2017; Zidny & Eilks, 2020).

ESD can be implemented in schools through the curriculum, including the scope of learning, educational programs and policies, as well as practical learning (Kusumaningrum, et al., 2023; Zguir et al., 2021). The implementation of ESD in learning can help students understand sustainable development issues, such as natural resource issues, climate change, and many others (Hoerunnisa et al., 2024). Chemistry (science) learning has the potential to contribute to continuing education through sustainable development issues in sustainable chemistry topics (Eilks & Linkwitz, 2022; Zidny et al., 2021). In the research conducted by Burmeister et al (2012), it provides an overview of four ways that can be used to integrate sustainable development issues in chemistry learning: adopting green chemistry in laboratory activities, adding sustainability strategies as content in chemistry learning, using controversial sustainability issues for socio-scientific issues in chemistry learning, and chemistry learning as part of ESD-based school development.

Similarly, Purnamasari & Hanifah (2021) explained that ESD can be integrated into science learning through learning tools, learning media, and learning models.

Sustainable development issues integrated in chemistry learning are one way to connect chemistry with sustainable development (Pratama et al., 2025). For example, Li et al (2023) used the issue of the use of conventional and biodegradable plastics in the concept of green chemistry to find out whether Confucian ecological ethics can contribute to chemistry education for sustainable development. Araripe & Zeidler (2024) in their study used the issue of plastic pollution and harmful additives in children's toys to encourage critical thinking, systems thinking, and awareness of sustainability challenges. If students understand the concept of chemistry in sustainable development, then they will have an awareness of sustainable attitudes and behaviors.

However, the implementation of ESD in the curriculum of certain subjects, especially chemistry, is not widely explored due to various constraints. These constraints include teachers' difficulty integrating sustainable development issues into chemistry concepts, as well as the lack of resources and teaching materials for implementing ESD in chemistry learning (Widyawati et al., 2024; Clarisa et al., 2020). Therefore, a systematic review synthesizing research articles on education for sustainable development that focus on chemistry, sustainable development issues, ESD dimensions, SDGs (*Sustainable Development Goals*), and chemistry concepts is needed to meet current research needs.

ESD is important to be applied in chemistry learning to build sustainable societies. Previous articles have reviewed ESD research trends in chemistry learning (Rasmawan, 2024; Sihombing et al., 2024; Kusumaningrum et al., 2023: Zidny et al., 2021). Previous articles have emphasized how ESD is implemented in education through various learning strategies or models as a contribution to achieving sustainable development goals. Of these review articles, only Rasmawan's (2024) study mentions the emerging topic of ESD in chemistry learning. However, the integration of sustainable development issues into chemistry concepts is not explicitly addressed in the article. This can have an impact on teachers' difficulties in integrating sustainable development issues into chemistry concepts.Gaps in related research require up-to-date research to provide resources that support the exploration of ESD in chemistry learning. Therefore, this study systematically synthesizes sustainable development issues integrated into chemistry concepts as a form of ESD implementation in chemistry learning to provide resources that support ESD exploration in the chemistry curriculum.

This study aims to systematically synthesize research articles on the application of in chemistry, focusing on its suitability with research partners in terms of sustainable development issues, ESD dimensions, SDGs, and in the concept of chemistry. Based on these objectives, the research questions in this study are as follows:

1. What thematic codes are shown on trends on sustainable development issues used in chemistry learning?
2. What thematic codes are shown on the ESD dimension?
3. What thematic codes are shown in the SDGs?
4. What thematic codes are shown on the concept of chemistry?

METHODS

The systematic literature review steps used in this study adhere to the Preferred Reporting Items of Systematic Reviews and Meta-Analyses (PRISMA) standards. Data were collected from the ERIC, Science Direct, and Google Scholar databases using the keywords "ESD in Chemistry Learning" and "ESD Implementation." The selected articles were international and national, based on predetermined inclusion criteria. The inclusion criteria used to select relevant articles were: from reputable journals in Scopus (Q1-Q2) and Sinta (S1-S2), (related to chemistry learning and science learning with chemistry topics, the samples/participants were high school students, pre-service chemistry teachers, and chemistry teachers, the research focused on sustainable development issues, ESD dimensions, SDGs, and chemistry concepts.

The keyword search revealed 17,145 related documents. The scope of the articles was not limited to a specific year period because few articles met the inclusion criteria. The search results were selected based on their title and reputation, resulting in a total of 371 articles. Further screening was conducted using several criteria, including articles related to chemistry learning and science learning with chemistry topics, and the samples used were high school

students, pre-service chemistry teachers, and chemistry teachers. The filtering process yielded 23 synthesized articles. The database search process is summarized in the PRISMA framework shown in Figure 1.

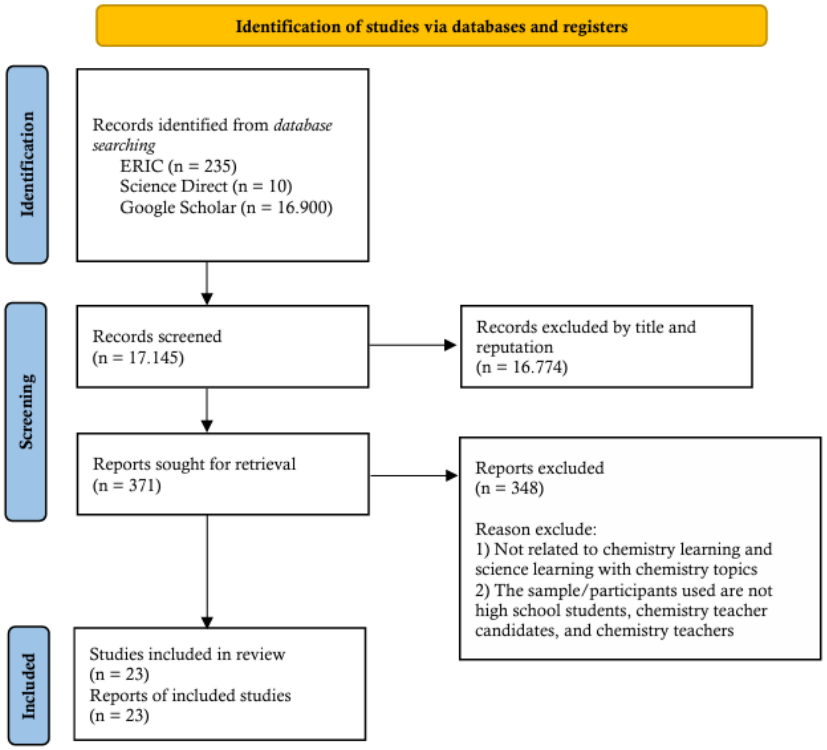

Figure 1. The search strategy flow diagram

RESULT AND DISCUSSION

The theme of sustainable development issues used in chemistry learning

The results of the article review found 6 codes that appeared on the theme of sustainable development issues used in chemistry learning. The issue of the use of conventional and biodegradable plastics is the most widely used in chemistry learning, which is found in 8 articles. Furthermore, the issue of green experiments that replace traditional laboratories with safer alternatives was also frequently used. Seven articles addressed this issue. Other sustainable development issues were also found in the articles, namely the use of green pesticides, pollution and water scarcity, and biodiesel from palm oil.

The use of conventional plastics is very worrying in various aspects, namely environmental, economic, and social. Plastic waste that is not separated and treated properly causes environmental problems in the form of bioaccumulation in various living things, ecosystem degradation, and loss of soil fertility (Sheriff, et al., 2025; Saefullah et al., 2023; Burmeister & Eilks, 2012). This conventional plastic problem can be addressed using biodegradable plastics that come from natural materials and are more environmentally friendly because they are more easily degraded (Anitha et al., 2022; Kamsiati et al., 2017). Chemistry has an important role in the process of making biodegradable plastics from natural materials such as cassava, corn cobs, and banana peels (Masahid et al., 2023; Lubis et al., 2020; Susanti et al., 2019). Therefore, the issue of using conventional and biodegradable plastics is emphasized in chemistry learning to support sustainable development. Green experiments that replace traditional laboratory practices with safer material alternatives are a solution to reduce harmful chemicals in schools. The application of these issues in chemistry learning can be done without changing the curriculum but has less risk for students and reduces the flow of hazardous waste (Cannon et al., 2023). The alternative materials used can come from natural materials that are generally safer and cheaper than synthetic chemicals (Prihatini et al., 2024). Green experiment activities can also be carried out using the principles of green chemistry, namely

prevention, less hazardous chemical synthesis, safer solvents and auxiliaries, and inherently safer chemistry for accident prevention. Kamilah & Louise (2025) carried out a green chemistry practicum on the topic of reaction rate factors by replacing synthetic chemicals with environmentally friendly materials, such as dishwashing soap, yeast, eggshells, baking soda, and vinegar. Therefore, the issue of green experiments is widely used in chemistry learning because it is in line with the application of ESD in environmental, economic, and social dimensions. The percentage of use of sustainable development issues in Chemistry learning can be seen in Figure 2.

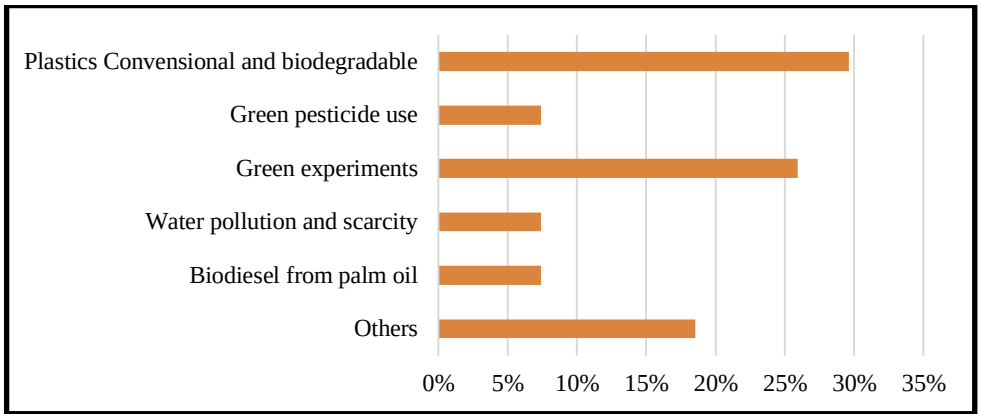

Figure 2. Sustainable development issues in chemistry learning

The theme of ESD dimension

A review of 23 articles on the application of ESD in chemistry learning, it was found that three codes appeared in this theme, namely environmental, social, and economic dimensions. The majority of these articles focus on the study of the environmental dimension in the issue of sustainable development which is integrated into the learning of Chemistry. This shows that the application of ESD in chemistry learning is more about attitudes and knowledge about resource awareness, environmental damage, and the impact of human activities and decisions on the environment (Kanapathy et al., 2018; UNESCO, 2006). Such as the research conducted by Karpudewan et al (2012) which implemented ESD through green chemistry learning. The research proves that there is an increase in environmental responsibility owned by students after the application of ESD in learning. Research conducted by Júnior et al (2024) regarding the use of periodic tables of green and sustainable chemical elements also showed an increase in students' environmentally friendly attitudes. Putri et al (2025) developed a student worksheet on eco-enzyme production as an effort to implement ESD to train students' environmental awareness. Students' awareness was observed in several aspects, namely environmental awareness, responsiveness to waste management, sensitivity to organic waste utilization, and responsibility for environmental preservation. The results showed that the worksheet was effective in shaping students' environmental awareness. Based on the study, the application of ESD in chemistry learning mostly focuses on the environmental dimension due to the increase in environmental responsibility behavior as part of sustainability awareness.

The social dimension ranks second in the application of ESD to chemistry learning. This dimension includes human rights, human health and security. Research conducted by Li & Eilks (2024) regarding the application of Confucian ethics and ESD in chemistry learning shows an increase in the social responsibility of students. The economic dimension of ESD assesses the level of personal and community consumption due to concern for the environment and social justice. The study of the economic dimension is shown by Kapurdewan's research (2020) on the integration of green chemistry in learning as part of ESD. The study shows that the use of laboratory materials from natural materials that are cheaper can reduce the consumption of synthetic chemicals. The percentage of ESD dimension studies in chemistry learning can be seen in Figure 3.

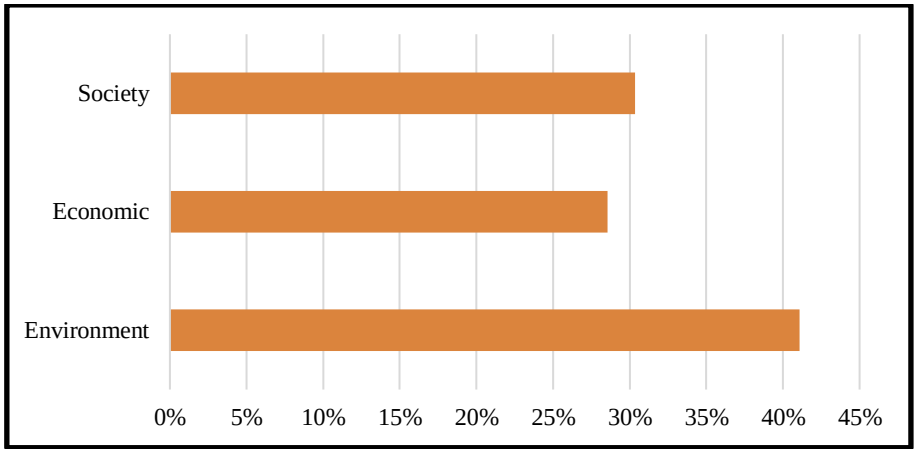

Figure 3. Dimensions of ESD in chemistry learning

The theme of SDGs in the implementation of ESD

ESD contributes to the Sustainable Development Goals (SDGs) through sustainable development issues used in learning (Yuan et al., 2022). The results of the article review obtained eleven codes that appeared on the SDGs theme, namely SDGs 3, 4, 7, 9, 10, 11, 12, 13, 14, and 15. The application of ESD in chemistry learning has the most contribution to SDGs 4 (quality education) and SDGs 13 (climate action). SDGs 4 are quality education ensuring inclusive, equitable, and promoting lifelong learning opportunities for all (UNESCO, 2017). The application of ESD in chemistry learning by including sustainable development issues is included in efforts to realize quality education. Education can be used to deal with environmental, social, and economic challenges through students' high-level thinking skills and awareness of their environment (Mesa et al., 2025; Zguir et al., 2021).

The implementation of ESD in learning can be carried out through learning tools, learning media, and learning models (innovative pedagogic techniques) (Hanley, 2024; Purnamasari & Hanifah, 2021). Many studies have been conducted to integrate sustainable development issues into chemistry concepts through various media, models, or learning strategies as an effort to realize SDGs 4, including Yusra et al (2025) integrating the concept of renewable energy material into PjBL-STEM, Apriliana et al (2025) integrating global warming issues in the STEM approach, and Arfianti et al (2025) integrating the issue of wise use of water into the socio-scientific issues approach. Therefore, the application of ESD in chemistry learning greatly contributes to SDGs 4 because it supports students' targets to acquire the knowledge and skills needed to promote sustainable development and sustainable lifestyles through quality education by incorporating sustainable development issues into learning.

SDGs 13(climate action) is an immediate action to reduce climate change and its impacts. The role of education in the realization of SDGs 13 is through climate change education which provides awareness to students about climate change and its adverse impacts on the planet, people, and natural resources (Molthan-Hill et al., 2019). Project-based learning through the exploration of climate change issues followed by the discovery of solutions to climate change problems can be applied in climate change education (Ronkainen et al., 2025). One example of the issue suggested in the implementation of ESD for SDGs 13 is greenhouse gas emissions related to energy, agriculture, and industry (UNESCO, 2017). The application of ESD in chemistry learning through the issue of the use of green pesticides, bioplastics from sugar beets, and using the context of climate change in learning are the contributions of ESD in SDGs 13 (Linkwitz & Eilks, 2022; Mahaffy *et al.*, 2014; Zidny & Eilks, 2020). Therefore, the application of ESD in chemistry learning helps students understand and criticize climate change issues in line with SDGs 13. The percentage of SDGs in the implementation of ESD can be seen in Figure 4.

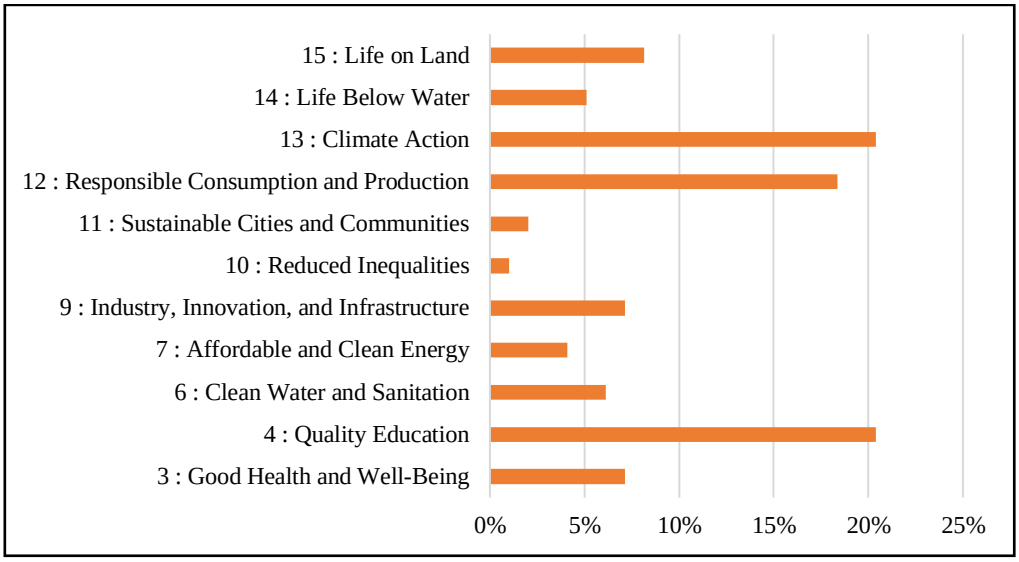

Figure 4. SDGs in the implementation of ESD

The theme of chemical concepts in the application of ESD

The results of the article review show that there are six codes that appear in the theme of chemical concepts that are used to integrate sustainable development issues: acid-bases, thermochemistry, periodic tables of elements, macromolecules, reaction kinetics, and green chemistry. Green chemistry is the most used chemical concept in the implementation of ESD. This is because green chemistry has great potential in supporting sustainable development through the issue of laboratory experiments with safer and more environmentally friendly materials, such as the use of green pesticides, the use of guava leaf extract as a natural reagent, the manufacture of bioethanol from apple juice, biodiesel from palm oil, and bioplastics from beet sugar (Martín-Alfonso & Yánez, 2024; Kiwfo et al., 2021; Zidny & Eilks, 2020; Mahaffy et al., 2014; Karpudewan et al., 2012). The use of bioactive compounds from fruit and plant extracts has driven chemical efficiency and environmental friendliness (Gonzailez-dePeredo et al., 2025: Shekhar et al, 2023). Green chemistry is a chemical concept that can be used as a means of raising awareness among students about the importance of controlling the use of chemicals and changing chemical methods according to the principles of green chemistry (Bala et al., 2025; Fuente-Ballesteros et al., 2025: Mammino, 2025). The control of the use of chemicals and chemical methods based on green chemistry is one of the efforts to reduce ecosystem destruction due to chemical waste to improve sustainable development (Rede et al., 2025; Murcia et al., 2023).

The use of macromolecular chemistry concepts is the second most common order used in the application of ESD. The concept of macromolecular chemistry is largely focused on the issue of making biodegradable plastics from natural materials that are more environmentally friendly as a substitute for conventional plastics (Li *et al.*, 2024; Linkwitz & Eilks, 2022; Burmeister & Eilks, 2012). Conventional plastics pose a significant threat to the environment, so there is a need for biodegradable plastic alternatives that reduce the ecological impact of plastic waste because it decomposes easily (Bhalerao et al., 2025; Go et al., 2025). The existence of biodegradable plastics has overcome the problem of conventional plastic processing that causes plastic pollution (Coutris et al., 2025; Marin et al., 2025). Therefore, the concept of macromolecular chemistry presents a real solution in overcoming the problem of plastic waste and pollution so that it is widely used in the application of ESD. The percentage of chemical concepts used in the application of ESD can be seen in Figure 5.

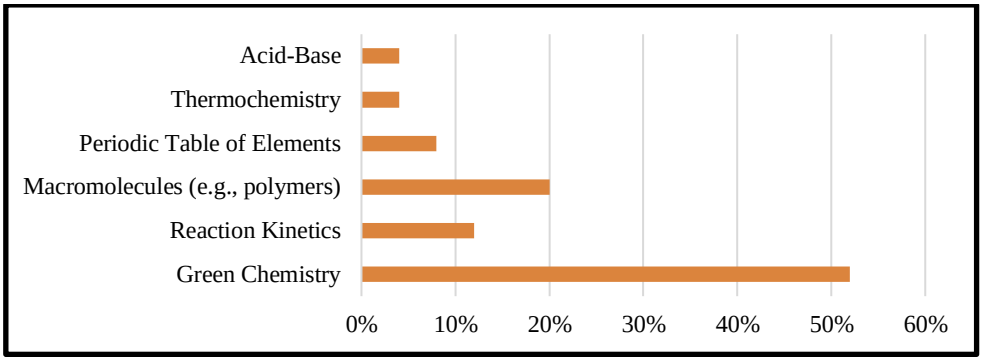

Figure 5. Chemical concepts in the application of educational for sustainable development

The results of the article review from this study are also intended as an effort to help teachers overcome difficulties in integrating sustainable development issues into the concept of chemistry. The following are the results of the review of various sustainable development issues that can be integrated into the concept of chemistry presented in Table 1.

Table 1. Integration of sustainable development issues in chemical concepts

Chemical Concepts	Sustainable Development Isues
Acid-Base	Presentation of the concept of acid-base using household ingredients
Thermochemistry	Use of climate change topics
Periodic Table of Elements	Water scarcity
Macromolecules	1. Social evaluation of competing chemical-based industrial products 2. Plastic pollution 3. Harmful additives in children's toys 4. Health risks in food chemicals
Reaction Kinetics	1. The kinetic process of herbicide absorption in soil derived from volcanic ash and its potential to contaminate groundwater 2. Reaction and catalysis efficiency 3. Environmental rescue mission using the concept of reaction rate 4. Use of simple enzymatic experiments to introduce the concept of sustainability
Green Chemistry	1. Use of conventional and biodegradable plastics 2. Green experiments as a replacement for traditional laboratories with safer and less waste-minimized material alternatives 3. Use of green pesticides 4. Making bioplastics from sugar beets 5. Making biodiesel from palm oil 6. Making bioethanol from apple pomace 7. Manufacture of natural reagents from guava leaf extract

CONCLUSION

The systematic review shows variations in sustainable development issues, ESD dimensions, SDGs, and chemical concepts used in the application of ESD in chemistry learning. The trend of sustainable development issues that is most often included in ESD is the use of conventional and biodegradable plastics conveyed in the concept of macromolecular chemistry. Chemistry has an important role in the process of making biodegradable plastics from natural materials such as cassava, corn cobs, and banana peels. The environmental dimension is most studied in chemistry learning which proves that strategic chemistry is a means

of training environmental awareness as a form of sustainability awareness. The application of ESD in chemistry learning is more about attitudes and knowledge about resource awareness, environmental damage, and the impact of human activities and decisions on the environment. SDGs 4 is a theme that has emerged many times in the implementation of ESD as a form of effort to realize quality education through learning chemical concepts by including sustainable development issues. The application of ESD in chemistry learning greatly contributes to SDGs 4 because it supports the target of students to acquire the knowledge and skills needed to promote sustainable development and sustainable lifestyles. Green chemistry as a chemical concept that is most often used in including sustainable development issues such as the issue of laboratory experiments with safer and more environmentally friendly materials is appropriate to be used because of its broad principles and matches the characteristics of chemistry learning. This study has methodological limitations in the form of articles that are synthesized not limited to a certain year period because there are not many articles that meet the inclusion criteria. As the application of ESD in chemistry learning supports students to acquire the knowledge and skills needed to promote sustainable development and sustainable lifestyles, future research should explore the sustainable lifestyles already undertaken by students as a result of ESD implementation. Further research can also be focused on educational programs and policies in schools that have been implemented as part of the implementation of ESD.

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