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Integration Green Chemistry into Learning Process

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Abstract: This research aims to synthesize the related research with green chemistry as the topic which focuses on chemistry learning research in the recent ten years from various Scopus journals and proceedings focusing on the recent ten years. After doing the searching on the national and international reputable databases by using the relevance key pattern (Pattern 1: "green chemistry" "green chemistry learning"; Pattern 2: "green chemistry" "curricula"; Pattern 3: "green chemistry" "chemistry education), from 20 relevant articles to be systematically reviewed. The systematic goal is to result in the general review and knowledge for teachers about the integration of green chemistry in the learning process. At the middle school level, the integration of green chemistry through project-based practicum activities, textbooks, modules, and games. The result shows that the chemistry topic which can be integrated with green chemistry is by making soap, fossil fuels, recycling processes, environmental problems arising from the use of fuel, chemical reactions, and plastic waste. While 12 green principles in some articles are discussed thoroughly while others don't. There are only 5 or 6 green chemistry principles integrated either in modules, games, and practicum activities. By doing the research, it is expected to give knowledge to the teachers related to green chemistry integration in the process of learning to support the Merdeka curriculum in chemistry learning.

Keywords: Chemistry learning; Green chemistry; Systematic literature review

Introduction

The analysis of United Nations Environment Program (UNEP) Global Chemical Outlook II (GCO II) program recently released focuses on chemical education. GCO II presented that chemistry is a challenge for Sustainable Development Goals (SDGs) program (Linkwitz & Eilks, 2022). Chemistry activity that used and released or resulting dangerous compounds gets serious attention in education (Mitarlis et al., 2017). This becomes a challenge for teachers to make chemistry learning with environment knowledge responsible for surroundings to achieve quality education (Paristiowati et al., 2022). Quality education is one of the goals of the Sustainable Development Goals (SDGs) in 2030. In 2030, the students are expected to get knowledge and skill to promote sustainable development through education sustainable development (ESD), sustainable lifestyle, and contributing to culture-sustainable development (Linkwitz & Eilks, 2022).

Chemistry has an important role in promoting sustainable development through green chemistry ideas: Green chemistry can be implemented in education to get education sustainability development (Paristiowati et al., 2022). Green chemistry is believed as a "preventative initiation" by resulting in new thinking methods for chemical arrangement, processes, and products that minimize the creation of toxins and waste (Gawlik-Kobylińska et al., 2020). Green chemistry, in the end, becomes an important component so chemical experts, teachers, and students need more knowledge related to green chemistry (Armstrong et al., 2018). Moreover, due to the change of curriculum in Indonesia in 2023, the recent curriculum (Kurikulum Merdeka)

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starts to implement green chemistry as new materials in chemistry learning (Meysa & Zainul, 2022).

Some of the green chemistry concepts have been developed to help sustainable development and those are based on the sustainability development early step and chemical process (Timmer et al., 2018). Green chemistry has a scientific concept that is directly connected with the environment which can increase student learning interest (Albright et al., 2021; Sajeena, 2021; Meysa & Zainul, 2022). The implementation of green chemistry in the learning process can be introduced by twelve principles that can be set as a guide to arranging a safe chemical process and resulting non-hazardous waste products (Anastas & Warner, 1998; Lokteva, 2018; Płotka-Wasylka et al., 2018). Those twelve principals are prevention, atom economy, less hazardous chemical syntheses, designing safer chemicals, safer solvents and auxiliaries, design for energy efficiency, use of renewable feedstock, reduction of derivatives, catalysis, designing for degradation, real-time analysis for pollution, and inherently safer chemistry for accident prevention (Anastas & Warner, 1998; Anastas & Zimmerman 2003; Günter et al., 2017; Mitarlis et al., 2017; Linkwitz & Eilks, 2022).

Teaching green chemistry can create a new generation who is aware of the environment, positive attitude towards environmental problems, and motivation to change behavior in a sustainable direction (Günter et al., 2017; Lokteva, 2018; Chen et al., 2020). The students become more realize of the hazardous chemical in the daily product and create a demand for safe chemical products. This, of course, demands the students' solving problems, critical thinking skills, and scientific work on the use of product and chemical processes that are environment-friendly and resource-efficient (Inayah et al., 2022). In addition, green chemistry knowledge can improve the student's understanding of science literacy concepts (Hadisaputra et al., 2019).

The previous research on green chemistry is implemented in laboratory activities. Cann (2009) has reviewed 141 chemistry textbooks about the integration of green chemistry and it is recommended to teachers interpret the concept of green chemistry as a learning source. This is supported by some research stating that green chemistry can be integrated through experiment laboratories, modules, presentation videos, games, and others (Albright et al. 2021; Cann & Dickenider, 2004; Grieger & Leontyev, 2020; Lees et al. 2020). However, teachers' skill as main role in chemistry learning related to green chemistry is still in the introduction step. Moreover, there was research done by Al Idrus et al (2009) stated that the skill of chemistry teacher candidates towards green chemistry understanding is still in the category of low.

This literature study is necessary as it provides a systematic review of a broader explanation of green chemistry in recent ten years and the explanation of green chemistry implementation to make the teachers understand what green chemistry means easier in chemistry learning. The contribution of this literature study is to be able to give concept understanding related to green chemistry in chemistry learning to the teachers and to recommend teachers integrate green chemistry in chemistry learning properly. This review discusses three research questions, first: How does green chemistry integrate with chemistry learning? What is the green chemistry principle which is discussed in the previewed article? and What are chemical materials that can be used in green chemistry implementation in chemical learning in the previewed article?

Method

The method of this research is SLR or systematic literature review which focused on the recent ten years' research (January 2013 – December 2023). The systematic literature review is a literature review to decide and synthesize all related research to determine what green topic by making a theme and template (Bağ & Çalık, 2017; Çalık & Sözbilir, 2014). The data analysis is including data reduction, data presentation, and the conclusion which step of the research can be seen in Figure 1.

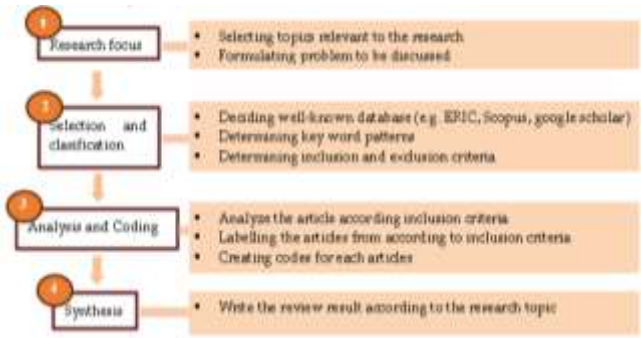

Figure 1. Systematic review research step

Research focus & Selection and Classification

The first step in doing the systematic review is choosing the research topic, which is green chemistry. The researcher searches the article in national and international databases such as Google Scholar, Scopus, link, ACS Publishing, and Eric, with relevant keywords (Pattern 1: "green chemistry" "green chemistry learning"; Pattern 2: "green chemistry" "curricula"; Pattern 3: "green chemistry" "chemistry education). Green chemistry's topic in chemistry learning or chemistry education in the articles is familiar to discuss gaining the number of articles in google scholar (n = 554), Scopus link (n = 618), dan ACS publishing (n = 26).

Researchers bring the abstract to analyze whether any green chemistry integration in chemistry learning. Not all of the articles were found to have the needed criteria. The criteria used in the research, which are called inclusion criteria, are explained in Table 1.

Table 1. Article inclusion criteria

Criteria	Description
Inclusion	▪ Related Scopus journal such as Q1, Q2, or proceedings journal ▪ The research is written in English ▪ The research is published in ten recent years (2013 – 2023) ▪ The research is done in the academic environment (middle and high school) ▪ The research is related to chemistry learning ▪ The study in the articles includes an explanation of green chemistry implementation or a description of environment-friendly – chemistry ▪ The study in this article talks about the explanation of green chemistry implementation or the description of the environment–friendly chemistry in various resources of learning.

Analysis and Coding

There are 20 articles used in the systematic literature review. The next step is labelling the articles from 1 to 20, as written in Table 2. The primer codes then are given to the selected articles based on seven groups: the research aim, research method, and sample, the integration of green chemistry in chemistry learning, chemistry concept, chemistry topic, and green chemistry principles. Next, the code analysis in all studies is involved in the narrative synthesis study process.

Synthesis

The last step is writing the result of the literature review systematical.

Table 2. Articles used in systematic literature review

Title of Journal	Name of Journal	Database	Indeks
Improvement of a sustainable world through the application of innovative didactic tools in green chemistry teaching: A review	Journal of Chemical Education	Scopus	Q2
How to motivate students to use green chemistry approaches in everyday research work: Lomonosov Moscow State University, Russia.	Current Opinion in Green and Sustainable Chemistry	Scopus	Q1
Green chemistry in higher education: state of the art, challenges, and future trends.	ChemSusChem	Scopus	Q1
Developing a Green Chemistry Focused General Chemistry Laboratory Curriculum: What Do Students Understand and Value about Green Chemistry?	Journal of Chemical Education	Scopus	Q2
Green chemistry coverage in organic chemistry textbooks	Journal of Chemical Education	Scopus	Q2
Developing preservice chemistry teachers' engagement with sustainability education through an online, project-based learning summer course program.	Sustainability	Scopus	Q1
Designing and Incorporating Green Chemistry Courses at a Liberal Arts College To Increase Students' Awareness and Interdisciplinary Collaborative Work	Journal of Chemical Education	Scopus	Q2
Understanding 'green chemistry' and 'sustainability': an example of problem-based learning (PBL)	Research in Science and Technological Education	Scopus	Q1
Student-generated infographics for learning green chemistry and developing professional skills	Journal of Chemical Education	Scopus	Q2
Facilitating Active Learning within Green Chemistry	Current Opinion in Green and Sustainable Chemistry	Scopus	Q1
The making of electronic modules on alternative fuels material based on green chemistry	Journal of Physics: Conference Series	Proceedings	
Teaching reaction efficiency through the lens of green chemistry: Should students focus on the yield, or the process?	Current Opinion in Green and Sustainable Chemistry	Scopus	Q1
Green Tycoon: A Mobile Application Game to Introduce Biorefining Principles in Green Chemistry	Journal of Chemical Education	Scopus	Q2
Design of a two-week organic chemistry course for high school students: "catalysis, solar energy, and green chemical synthesis.	Journal of Chemical Education	Scopus	Q2

Title of Journal	Name of Journal	Database	Indeks
A systems thinking department: fostering a culture of green chemistry practice among students.	Journal of Chemical Education	Scopus	Q2
Cleaning our world through green chemistry: introducing high school students to the principles of green chemistry using a case-based learning module	Journal of Chemical Education	Scopus	Q2
Integrating Green Chemistry in the Curriculum: Building Student Skills in Systems Thinking, Safety, and Sustainability	Journal of Chemical Education	Scopus	Q2
Green Machine: A Card Game Introducing Students to Systems Thinking in Green Chemistry by Strategizing the Creation of a Recycling Plant	Journal of Chemical Education	Scopus	Q2
Education in green chemistry and in sustainable chemistry: perspectives towards sustainability	Green Chemistry	Scopus	Q1
Promoting Student Awareness of Green Chemistry Principles via Student-Generated Presentation Videos	Journal of Chemical Education	Scopus	Q2

Articles used in the systematic literature review came from (Afifah et al., 2019; Albright et al., 2021; Armstrong et al., 2019; Aubrecht et al., 2019; Ballard & Mooring, 2021; Dicks, 2018; Dicks et al., 2019; Gawlik-Kobylińska et al., 2020; Grieger & Leontyev, 2020; Grieger & Leontyev, 2021; Günter et al., 2017; Johnson et al., 2020; Lees et al., 2020; Lokteva, 2018; Manchanayakage, 2013; Miller et al., 2019; Paristiowati et al., 2022; Płotka-Wasylka et al., 2018; Summerton et al., 2018; Zuin et al., 2021).

Result and Discussion

Research Purposes

The systematic review analysis tries to give a general review of the main goals to integrate green chemistry into the learning activities discussed in those articles. The results show that most of the articles focus on the usage of didactic tools in the form of innovative learning in green chemistry learning (n= 8). The example of green chemistry integration in chemistry learning with innovative learning such as games (mobile application-based), card games (green machines), and instructional videos. Introducing green chemistry in chemistry learning with innovative learning may obtain the students' interest and motivation (Lokteva, 2018). Innovative learning using online learning media is a useful source used to introduce the students not only to green chemistry but also to use the systematic thinking approach (Gawlik et al., 2020; Lees et al., 2020; Miller et al., 2019; Perosa et al., 2019). The other articles (n= 3) explain green chemistry in the middle and high schools' curriculum generally and thoroughly (e.g sustainability issues such as environmental degradation & learning source development, for instance, modules and learning media (Platform Moodle dari Federal University of São Carlos (UFSCar) about the concept of sustainability issues and Education for Sustainable Development). Moreover, article (n=3) integrates green chemistry through traditional learning (e.g. practicum activity), while article (2) interactive chemistry learning using a project-based learning model and socio-environment problem solving and green chemistry perspective. Another aim of the reviewed article (n=2) is to develop continuous green and environment-friendly products.

Research Method and Sample

The reviewed article is based on the used research method, for instance, literature review both qualitative and quantitative. Most of the research articles (n=9) focused on quantitative research in the form of implementing green chemistry in the learning process with various models, especially project-based learning. Articles (n=7) focused on reviewing research related to the implementation of green chemistry. The integration of green chemistry described in several review articles is through various didactic technologies (e-learning platforms, virtual reality platforms, and videos), integrating green chemistry through projects in the high school and in the curriculum in the undergraduate & graduate courses, and describing related learning models that can be used to introduce green chemistry, such as project-based learning, inquiry-based learning, experiential learning, just-in-time teaching, contextualized learning, and cooperative learning. Articles (n=3) are qualitative research, such as analyzing the implementation of green chemistry into 15 organic chemistry textbooks. Article (n = 1) is in the form of research and development research, namely developing green chemistry-based learning resource products.

Most of the samples used (n=11) were students (dominated by university students). The article (n=7) has no sample because it is a review article that explains the history of green chemistry, the integration of green chemistry in learning, and learning models in green chemistry material. Article (n=1) sample in the form of 15 organic chemistry textbooks.

Green Chemistry Integration in Chemistry Learning

Green chemistry is one of the strategies which can be integrated with chemistry learning related to a sustainable environment and transformative learning. It is important to promote green chemistry as a thinking pattern in teaching and working in a laboratory (Mitarlis & Yonata, 2018; Mitarlis Yonata, 2018; Timmer et al., 2018). Green chemistry may be able to increase the student's knowledge such as metacognitive knowledge and critical thinking skill for example evaluation and creation. If it is compared with usual curricula, green chemistry integration into the curricula and learning process increases responsibility and social atmosphere in the class (Valenzuela et al., 2020). This is also supported by the research done at Scranton University. It is stated that implementing green chemistry in the learning process increases the student's awareness of the environment (Cann, 2004). The green chemistry concept which is integrated with education, is known as green chemistry education. Green chemistry education gives a chance to integrate the concept and 12 green chemistry principles which can be integrated with the curricula and learning, especially in chemistry learning to develop environmental awareness attitudes (Rahmawati, 2018).

There are several learning strategies to encourage teachers to integrate green chemistry into the students through chemistry learning (Chen et al., 2020). Based on the number of reviewed journal articles, most of them focus (n=8) on practicum activity. Most of them have green chemistry learning through laboratory activity (Klingshirn et al., 2008; Galgano et al., 2012; Buckley et al.,2013; Purcell et al., 2016; Rand et al., 2016). The students can integrate green chemistry principles in practicum activity in a laboratory such as using environment-friendly materials or using less hazardous chemical materials resulting in less waste or unhazardous waste. At the high school level, using hibiscus, butterfly pea flower, turmeric, shallot skin, and ketapang leaves can be used as natural indicators in acid-base theory experiments. Orange, tomato, and apple are also can be used as a replacement for acidic solutions that can conduct electric current in redox experiments (Mastura et al., 2017).

Integrating green chemistry in chemistry learning can use learning models such as inquiry, problem-based learning (PBL), and project-based learning (PjBL). Practicum activity by integrating green chemistry commonly designed with project-based learning. According to the analyzed articles (n=5), in the last meeting, students are expected to present the continuous project results. The project aims to increase the student's awareness related to the health and environmental impact of the designed product and process and also to improve their speaking and teamwork skills. The project may be presented using Powerpoint or in the form of videos (Grieger & Leontyev, 2020; Paristiowati et al., 2022). The project can be in the form of making innovative face masks made from coffee (Paristiowati et al., 2022). Project-based learning can be done by inquiry models or problem-based learning. The students are given some daily phenomenon problems which are then analyzed and done by integrating green chemistry (Günter et al., 2017).

Green chemistry integration in the learning process can be put in learning sources such as textbooks and learning modules (n=5). Green chemistry both in modules and textbooks can help the students appreciate continuous chemistry. The article stated that modules are used to highlight green chemistry principles. Those principles are waste prevention, atomic economy, designing safer chemicals, and using safer solvents. Case studies about phenomena related to scientific concepts introducing sustainability innovation to the students are both in textbooks and learning modules (Ballard & Mooring, 2021; Johnson et al., 2020). In addition, green chemistry integration can be done through interactive learning (n=4) such as games or mobile-based games. Green chemistry integration through games is innovative learning which can attract students' attention to appreciate the environment-friendly chemistry in the chemistry process. Games also lead the student to think systematically and introduce competitive vibes (Miller et al., 2019; Lees et al., 2020). Games can be delivered in the form of problems in various fields (e.g continuous industry field). The next is, the students are asked to do the game by giving the solution to consider the materials, chemical process, transportation line, factory infrastructure, and its waste processing aspects, as it leads to sustainability.

Chemistry Concept and Topic

Most of the green chemistry perspective is discussed in organic chemistry (n=12). The integration of green chemistry in education is prominent in the context of optimizing organic synthesis, which is an aspect repeatedly discussed in the articles used. The chemistry topic in organic chemistry discussed in the analyzed articles used stated that some reactions such as synthesis of ibuprofen, catalytic production of linear alkylbenzenes, hexanal formation reaction, aldol condensation to form dibenzalacetone, formation of alkenes, recrystallization, esterification, and soap making. In the school environment, green chemistry in organic chemistry can be applied and introduced in the activity of making soap. Other articles discussing the chemistry concept in the environmental chemistry field (n=9), which explain environmental issues, can be done by implementing green chemistry principles. Those issues are including the making of bioplastic from sugar beet, scenarios containing shellfish samples (Pb^{2+}), study scenarios in Hungary (analyzing Al^{3+}), biorefining,

biomass, fossil fuels, recycling processes, and environmental problems arising from the use of fuel.

Furthermore, there are discussions about physic chemistry (n=6, discussing thermodynamics), organic chemistry (n=4, discussing redox flow batteries, redox reactions, atomic structure, atomic characteristics, and chemical bonds), general chemistry (n=3, discusses stoichiometry, chemical equilibrium, chemical kinetics, factors affecting reactions, and solubility), and analytical chemistry (n =2 by discussing electrochemistry), which reflects the importance of the introduction of green chemistry in various field in chemistry. At the middle school level, the teachers can explain the chemistry topic related to soap making, fossil fuels, recycling processes, environmental problems arising from the use of fuel, chemical reactions (photosynthesis, baking bread, iron rusting, and incomplete combustion), and plastic waste.

Green Chemistry Principles

The environmental issues provided in the chemistry learning leads the students to give the solution by implementing the green chemistry concept studied in the class. The argumentation about the solution can use one or more of the twelve principles of green chemistry (Manchanayakage, 2013). Based on the analyzed articles, most of the green chemistry principles integrated with chemistry learning is atomic economy (green chemistry principle 2 n =13). The principle of atomic economy is a measure of the number of atoms of starting materials that are found in products that are useful at the end of a chemical process, thus avoiding excessive wastage of atoms (Ballard & Mooring, 2021).

Prevention principle (green chemistry principle 1 n=11), safer solvent and auxiliaries (green chemistry principle 5 n=11), and use of renewable feedstocks (green chemistry principle 7 n=11), easy to integrate with the middle school because the use of natural materials (e. g. household ingredients: eggshells, shallot skins, salt, vinegar, vegetables and so on) and water solvents suitable these three principles. At the high school level, students can apply at least one green chemistry principle by reducing waste or reagent use while using additional safety measures. The usage of catalysis (green chemistry principle 9 n=10), less hazardous chemical syntheses (green chemistry principle 3 n=8), designing safer chemicals (green chemistry principle 4 n=8), design for energy efficiency (green chemistry principle 6 n=8), and design for degradation (green chemistry principle 10 n=9), inherently safer chemistry for accident prevention (green chemistry principle 12 n=8). Meanwhile, reducing derivatives (green chemistry principle 8 n=5) and real-time analysis for pollution prevention (green chemistry principle 11 n=5), little is discussed in this article due to the principle of green chemistry 8, the use of derivatives to protect certain functional groups is not widely applied in practicum activities in high schools.

Conclusion

A systematic literature review is done to give a general review and knowledge for teachers related to green chemistry which can be integrated with chemistry learning to support quality education. The recent articles used in this systematic review give information related to green chemistry in the process of learning at the high school level can be integrated through project-based practicum activities. Those are also integrated with textbooks, modules, and games. The results show that organic chemistry topics dominate in green chemistry integration. In middle school, it can be implemented in soap-making materials, fossil fuels, recycling processes, environmental problems arising from the use of fuel, chemical reactions, and plastic waste. While 12 green principles in some articles are discussed thoroughly while others don't. There are only 5 or 6 green chemistry principles integrated either in modules, games, and practicum activities. The recommendation for the next researcher is to review more about a daily phenomenon or controversial issues that integrate green chemistry which can be used in chemistry learning.

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Author Contributions

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Conflict of interest

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