Green Chemistry Activities in School Level Chemistry Learning: Systematic Literature Review in the Last 10 Years

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Abstract. Emphasis on products and chemicals that are environmentally friendly and for health is the main goal of green chemistry. Green chemistry (GC) education in chemistry learning is a method of solving environmental problems that teaches students about sustainable development. In a learning model that has GC, it is hoped that students can build concepts into knowledge that enters long-term memory so that their learning outcomes improve. A systematic review is very important to carry out in literature studies to map research topics related to Green Chemistry in chemistry learning in the last ten years at the high school level and opportunities for implementing Green Chemistry in chemistry learning at the high school level. The journal that publishes the most GCs in the field of education is the Journal of Chemical Education, followed by Chemistry Education Research and Practice and the Indonesian Science Education Journal. The fields of postgraduate education and e-learning had the lowest percentage of papers analyzed. Furthermore, the most trending GC topics are in environmental chemistry. Then, the most GC implementation was in laboratory activities in the last decade. A systematic literature review has revealed that GC is feasible to be applied in any field, including integration with other fields. In the GC presentation, at least ten thought patterns can be used that can be developed for students to gain meaningful learning experiences and encourage the development of various skills needed to prevent environmental pollution.

Keywords: activity chemistry green , learning chemistry , school , systematic literature review

1. Introduction

Increasingly, various areas of natural ecosystems are experiencing a crisis, thus putting significant pressure on the lives of humans and other living creatures [1]. One of the sectors that contributes most to environmental quality degradation is chemical activities in the mining industry [2]. Chemical activities that produce or release harmful compounds are the main cause of environmental degradation and pollution.

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Green chemistry activities (GCA) answer ecological challenges at a global level to minimize the use of hazardous materials and procedures in the production of chemical products [3]. Environmental issues are closely related to green chemistry activities (GCA). Using the 12 principles of green chemistry is expected to be able to overcome urgent environmental problems such as energy shortages, waste processing, pollution, and workplace safety and security. Emphasis on products and chemicals that are environmentally friendly and for health is the main goal of green chemistry. Students' abilities in problem solving, critical thinking skills, and scientific work can be realized and improved through GCA-oriented education by contributing to the use of environmentally friendly and resource-saving chemical products and processes [4].

Green chemistry education in chemistry learning is a method of solving environmental problems that teaches students about sustainable development [5]. According to Nuswowati [6] a learning model that has a green chemistry vision, it is hoped that students can build concepts into knowledge that enters long-term memory so that their learning outcomes increase. In addition, by implementing a learning model with a green chemistry perspective, it is hoped that it can facilitate a balance of body and mind skills in skills that are expected to improve student learning outcomes.

A systematic review is very important because it can provide a systematic mapping of research topics in chemistry learning in the last ten years at the high school level and opportunities for implementing Green Chemistry in chemistry learning at the high school level. Therefore, this systematic observation aims to analyze the current status and provide an overview of Green Chemistry research at the upper secondary level between 2012 and 2022. The benefit that can result from this review study is to provide recommendations regarding appropriate Green Chemistry opportunities to be implemented in chemistry learning at high school level and in accordance with the specific characteristics of chemistry subjects.

2. Method

This writing method uses the Systematic Literature Review (SLR) method. A systematic literature review (SLR) is a literature review that uses established rules to find and synthesize all relevant research to assess what is known about the topic under investigation [7]. The author started by searching for literature sourced from scientific papers, journals and reports via digital search engines for the last 10 years from 2012 to 2022 by looking for publications whose titles, abstracts or keywords met the conditions of "Green Chemistry". An overview regarding searching for journals in databases using various search applications, namely publish of perish, google schoolar, springer, science direct, crossref and connected paper.

The results of the search using the application found 200 papers related to the topic studied based only on the scope of inclusion. Of the 200 papers, the abstracts were read and then reduced to 180 manuscripts by considering the suitability of the abstract content and inclusion requirements. Next, 62 manuscripts were read in full text, and 30 manuscripts were obtained that met all the predetermined inclusion criteria.

The inclusion criteria for the search for papers included: 1) Green chemistry papers in chemistry learning at school or university level; 2) Publication between 2012-2022; 3) Publication in reputable journals/Scopus; 4) Papers must be written in English;

5) Full text, journal papers and open access; 6) For the record, books or book chapters, conference proceedings, editorial materials, and corrections are not included in the analysis. The process of searching and filtering journals in this writing is depicted through the literature flow diagram in Figure 1.

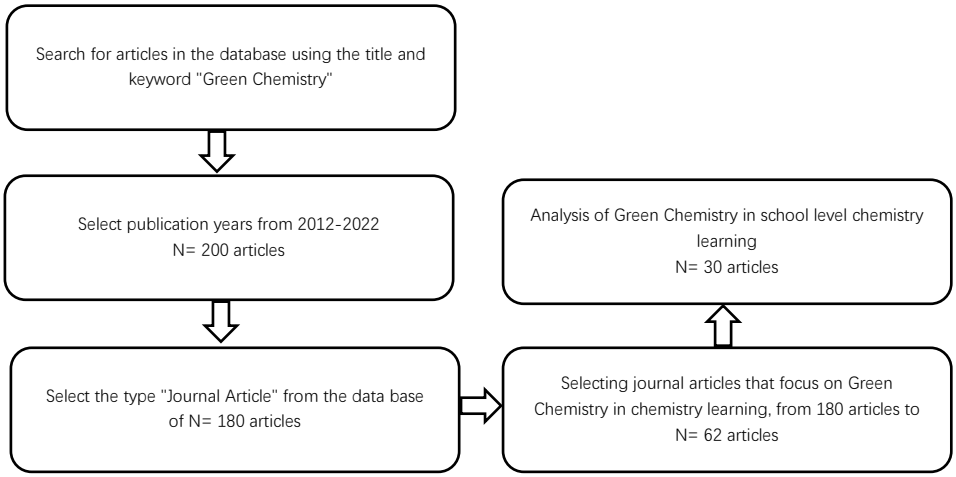

Figure 1. Flowchart of Stages of Searching for Papers in the Database

The writing uses narrative synthesis to examine and synthesize findings from all papers that meet the inclusion criteria. According to Petticrew & Roberts (2008) there are three stages of synthesizing, namely extraction and coding, tabulation of codes (findings), and analysis of codes within and/or across all included studies, followed in the narrative synthesis process of this writing. Furthermore, in collecting the data needed for analysis and synthesis, the extraction code is based on five writing elements, namely participants, intervention, comparison, results, and setting. The results of data extraction are then presented in a matrix for evaluation and consideration of whether the research conducted reaches the same conclusions and the main role of the matrix is to show the findings in an orderly way to facilitate the synthesis of findings [4]. Below are presented the selected papers in Table 1.

Table 1. Selected Papers

No.	Title	Journal Name
1	Implementation of problem-based learning with green chemistry vision to improve creative thinking skills and students' creative actions [6]	Indonesian Science Education Journal
2	Teaching Green Chemistry with Epoxidized Soybean Oil [8]	Journal of Chemical Education
3	Graduate Student Designed and Delivered: An Upper-Level Online Course for Undergraduates in Green Chemistry and Sustainability [9]	Journal of Chemical Education

No.	Title	Journal Name
4	Simple and Effective Integration of Green Chemistry and Sustainability Education into an Existing Organic Chemistry Course [10]	Journal of Chemical Education
5	Green Machine: A Card Game Introducing Students to Systems Thinking in Green Chemistry by Strategizing the Creation of a Recycling Plant [11]	Journal of Chemical Education
6	The development of PBL-based worksheets integrated with green chemistry and ethnoscience to improve students' thinking skills [12]	Indonesian Science Education Journal
7	The integration of green chemistry principles into small scale chemistry practice for senior high school students [13]	Indonesian Science Education Journal
8	Improvement of a sustainable world through the application of innovative didactic tools in green chemistry teaching: A review [14]	Journal of Chemical Education
9	Developing a green chemistry focused general chemistry laboratory curriculum: What do students understand and value about green chemistry? [15]	Journal of Chemical Education
10	High-school chemistry teaching through environmentally oriented curriculum [16]	Chemistry Education Research and Practice
11	Promoting pro-environmental attitudes and reported behaviors of Malaysian pre-service teachers using green chemistry experiments [17]	Environmental Education Research
12	Promoting student awareness of green chemistry principles via student-generated presentation videos [18]	Journal of Chemical Education
13	Cleaning our world through green chemistry: Introducing high school students to the principles of green chemistry using a case-based learning module [19]	Journal of Chemical Education
14	Design of a two-week organic chemistry course for high school students: "Catalysis, solar energy, and green chemical synthesis" [20]	Journal of Chemical Education
15	Fostering pre-service teachers' self-determined environmental motivation through green chemistry experiments [21]	Chemistry Education Research and Practice
16	Student-generated infographics for learning green chemistry and developing professional skills [22]	Journal of Chemical Education
17	An empirical test of self-determination theory as a guide to fostering environmental motivation [23]	Environmental Education Research
18	The effects of "Green Chemistry" on secondary school students' understanding and motivation [24]	Asia-Pacific Education Researcher

No.	Title	Journal Name
19	The role of green chemistry activities in fostering secondary school students' understanding of acid-based concepts and argumentation skills [25]	Chemistry Education Research and Practice
20	Science writing heuristics embedded in green chemistry: A tool to foster environmental literacy among pre-university students [26]	Chemistry Education Research and Practice
21	Assessing awareness of green chemistry as a tool for advancing sustainability [27]	Journal of Cleaner Production
22	Lipase-catalyzed esterification: An inquiry-based laboratory activity to promote high school students' understanding and positive perceptions of green chemistry [28]	Journal of Chemical Education
23	Overcoming students' misconceptions in science: Strategies and perspectives from Malaysia [15]	Journal of Chemical Education
24	High school students' environmental education in Taiwan: Scientific epistemic views, decision-making style, and recycling intention [29]	International Journal of Science and Mathematics Education
25	Pre-service teachers' knowledge and perceptions of the impact of mitigating climate actions and their willingness to act [30]	Research in Science Education,
26	Voting for change: An international study of students' willingness to support measures to ameliorate climate change [31]	Research in Science Education
27	Higher education, norm development, and environmental protection [32]	Higher Education
28	Climate change ignorance: An unacceptable legacy [33]	Australian Educational Researcher
29	Exploring individual and school-related factors and environmental literacy: Comparing US and Canada using PISA 2006 [34]	International Journal of Science and Mathematics Education
30	Exploring environmental identity and behavioral change in an environmental science course [35]	Cultural Studies of Science Education

In the final stage, the researcher synthesizes the main paper by identifying key questions that arise and research to report the findings. The variables that will be discussed in this paper are: 1) Journals where green chemistry studies are published, 2) Educational fields of selected papers, 3) Trends in topics of selected papers, and 4) Analysis of the implications of green chemistry activities for skills development.

3. Results and Discussion

3.1 Number of Papers in the Journal

Research related to the topic of GC has been widely studied both in Indonesia and abroad. Journals that regularly publish GC on databases use various type application

search in education between 2012 and 2022 such as publish of perish, google schoolar, springer, science direct, crossref dan connected paper.. The following is a list of journals that present it place its publication deep GC research field education level school period 2012-2022.

Table 2. Papers Published Based on Journals

Journal	N	%
Journal of Chemical Education	12	40%
Chemistry Education Research and Practice	4	13%
Indonesian Science Education Journal	3	10%
Environmental Education Research	2	7%
International Journal of Science and Mathematics Education	2	7%
Research in Science Education	2	7%
Asia-Pacific Education Researcher	1	3%
Australian Educational Researcher	1	3%
Cultural Studies of Science Education	1	3%
Higher Education	1	3%
Journal of Cleaner Production	1	3%
Total	30	100%

Most of the 30 papers came from Journal of Chemical Education (40%) and the rest came from the journal Chemistry Education Research and Practice (13%), Indonesian Science Education Journal (10%), Environmental Education Research (7%), International Journal of Science and Mathematics Educatio (7%), Research in Science Education (7%), Asia-Pacific Education Researcher (3%), Australian Educational Researcher (3%), Cultural Studies of Science Education (3%), Higher Education (3%) and Journal of Cleaner Production (3%) with all reputable indexes. This shows that research activities are taking place throughout the world. Because international journals are journals published by researchers from various countries in the world.

3.2 Education Sector Selected Journals

The educational sector that published the most GC-related publications in the 2012-2022 period based on the results of a review of thirty selected papers, namely secondary education (37%), followed by higher education (23%) and teacher learning (17%).

Table 3. Field of Education Selected Papers

Field of education	N	%
Middle education	11	37%
higher education	7	23%
Teacher Education	5	17%
Continuous Learning	3	10%

Field of education	N	%
Experiment	2	7%
Postgraduate Chemistry	1	3%
e-learning	1	3%
Total	30	100%

3.3 Trending Selected Paper Topics

The types of topics frequently used in GC research in the education sector in the 2012-2022 period refer to the categories used in research conducted by Inayah , namely: organic chemistry, polymer chemistry, toxicology chemistry, industrial chemistry, general chemistry, environmental chemistry, and consumer chemistry which discusses catalysts, energy, chemical synthesis, environmental pollution, and chemical products (plastics, oil, cosmetics, etc.). The thirty selected papers were classified into these categories as shown in Table 4.

Table 4. Trending Selected Paper Topics

Trending Topics	N	%
Chemical environment	15	50%
General Chemistry	7	23%
Organic Chemistry	5	17%
Consumer Chemistry	3	10%
Total	30	100%

The most trending topics discuss GC in environmental chemistry at 50% and GC in general chemistry at 23%. Meanwhile, other trending topics are organic chemistry 17% and consumer chemistry 10%. This indicates that to promote the use of environmentally friendly, resource-saving chemical products and processes, GC-oriented education can help students develop problem solving, critical thinking, and scientific skills.

3.4 Analysis of the Implications of Green Chemistry Activities for Skills Development

The implications of GC in the education sector for the development of various 21st century skills in the 2012-2022 period are presented in Table 5.

Table 5. Skill Analysis on GC Papers

Skills	Analyzed in Selected Papers
Creativity	(Nuswowati et al., 2017)
Collaboration	(Mandler et al., 20 1 2)
Concept Understanding	(Karpudewan et al., 2015; Karpudewan et al., 2016; Shamuganathan & Karpudewan, 2017; Duangpummet et al., 2019; Armstrong et al., 2019 ; Tolppanen et al., 2021; Boon, 2015)

Skills	Analyzed in Selected Papers
Critical thinking	(Sudarmin et al., 2019; Luan et al., 2022)
Knowledge	(Loste et al., 2020; Duangpummet et al., 2019; Boon, 2015; Lin & Shi, 2014)
Behavior	(Karpudewan et al., 2012a; Karpudewan et al., 2012b; Shamuganathan & Karpudewan, 2017; Luan et al., 2022; Tolppanen et al., 2021; Skamp et al., 2021; Harring et al., 2020; Boon , 2015 Boon, 2015 ; Lin & Shi, 2014; Blatt, 2013) (Karpudewan et al., 2012a; Karpudewan et al., 2012b; Shamuganathan & Karpudewan, 2017; Luan et al., 2022; Tolppanen et al., 2021 ; Skamp et al., 2021; Harring et al., 2020; Boon, 2015; Lin & Shi, 2014; Blatt, 2013)
Motivation	(Darner, 2012; Karpudewan et al., 2015)
Decision-making	(Barcena et al., 2017)
Digital Skills	(Miller et al., 2019; Gawlik-Kobyli ńska et al., 2020 ; Grieger & Leontyev, 2020) Gawlik-Kobylińska et al., 2020; Grieger & Leontyev, 2020)
Design Thinking	(Miller et al., 2019)
Awareness	(Sudarmin et al., 2019; Grieger & Leontyev, 2020; Lin & Shi, 2014) (Sudarmin et al., 2019; Grieger & Leontyev, 2020; Lin & Shi, 2014)
Laboratory	(Barcena et al., 2017; Timmer et al., 2018; Listyarini et al., 2019; Armstrong et al., 2019; Ballard & Mooring, 2021; Albright et al., 2021; Grieger & Leontyev, 2021; Duangpummet et al. al., 2019) (Barcena et al., 2017; Timmer et al., 2018; Listyarini et al., 2019; Armstrong et al., 2019; Ballard & Mooring, 2021; Albright et al., 2021; Grieger & Leontyev , 2021; Duangpummet et al., 2019)

The implication of GC on skills development shows that there are direct learning experiences that have a positive impact, namely laboratory skills. Laboratory skills were the most important result from the analysis of the 30 selected papers. These findings are in line with the potential that students need from highly trained chemists and specialists from various interdisciplinary *linear domains* where practicum activities are oriented towards efforts to reduce, eliminate and replace the use of toxic and hazardous chemicals used in experiments in order to reduce levels of pollution and waste volume [4] .

3.5 Discussion

Research related to the topic of green chemistry has been widely studied, both in Indonesia and abroad. Terms used in the example paper include green chemistry and green chemistry in learning at the school level to find related articles. To ensure that the papers included were relevant to the research objectives, researchers identified the titles, abstracts and keywords of the papers manually. Searches carried out in the last 10 years (2012-2022) in this study succeeded in collecting 200 articles related to the

topic of green chemistry. The researcher then read each paper and rechecked all documents to ensure that the paper in question met the criteria and there were no duplications. To select the final article for review, the researcher first checks the title, then the abstract, and finally the full text. After filtering the data, there were only 30 articles that met the research objectives.

Furthermore, the 30 articles were read in full and met the inclusion criteria for the article search that had been carried out. Most of the 30 articles are from JCE (40%) which is the most prolific in Green Chemistry research. A possible reason is that the Journal of Chemical Education (JCE) published an empirical study reviewing research in chemistry education, and its target audience included chemistry instructors from high school through graduate school and some scientists in commerce, industry, and government. This journal is published by the American Chemical Society's Educational Chemistry Division and was founded in 1924 by Neil Gordon.

Currently, in preparing for educational demands to face complex global challenges, it encourages the expansion of students' learning experiences [36]. However, judging from the results of the study, the field of e-learning is in a minor position (3%). According to Tantayanon [37] in the deployment of the Distance Education Program provides teaching resources for GCs using live satellite and internet based video conferencing technology in addition to online resources. Additionally, many institutions offer open courses on GC and continuous learning [14] and general courses on environmentally focused GC technologies [16].

Meanwhile, little has been published about the application of GC in postgraduate study curricula. Although Haley [20] acknowledged the development of the GC Doctoral program, he did not discuss how this program was implemented. Thus, there is a need for new empirical research, particularly in experimental, pedagogical, and case study approaches to graduate studies. One way to publicize GC education in graduate studies is through research engagement and outreach.

Green chemistry paper topics in chemistry learning mostly discuss the environment. This is related to the production process of chemical compounds which turns out to cause environmental problems such as acid or base waste and other dangerous compounds [38]. Environmental pollution can be prevented by applying the twelve principles of green chemistry which must be taught in secondary schools and universities as well as in laboratories where students will carry out experiments with chemicals. Green chemistry-based practical activities are carried out in laboratories in an effort to reduce, eliminate and replace the use of toxic and dangerous chemicals used in experiments in order to reduce pollutant levels and waste volume.

Therefore, green chemistry provides enormous opportunities in learning chemistry. This is because practical activities in the laboratory are an important part of green chemistry, and students are given the opportunity to analyze each process, as well as the properties of the chemicals that will be used, both solvents and reagents used are not dangerous or environmentally friendly [4].

4. Conclusion

The journal that publishes the most GCs in the field of education is *the Journal of Chemical Education* , followed by *Chemistry Education Research and Practice* and the

Indonesian Science Education Journal with the same publication volume. The field of postgraduate education and e-learning had the lowest percentage of the thirty papers analyzed. Furthermore, the most trending GC topics are in environmental chemistry. Then, the most GC implementation was in laboratory activities in the last decade.

In conclusion, a systematic literature review has revealed that GC is feasible to be applied in any field, including integration with other fields. In the GC presentation, at least ten thought patterns can be used that can be developed for students to gain meaningful learning experiences and encourage the development of various skills needed to prevent environmental pollution.

5. Limitations and Recommendations

A thorough review of previous literature results is considered to have provided in-depth insight and knowledge so that it has the potential for further research. There are limitations in analyzing literature, namely: 1) There are still many scientific data bases that can be used as sources for searching papers; 2) Research is only limited to a certain time period and is only focused in the form of journal articles; and 3) There are still many duplicate articles from different search sources, which makes writers have to be very careful in eliminating papers.

Based on the limitations above, it is necessary to analyze the literature from reputable sources to obtain Scopus standard papers over a longer period of time to produce a more comprehensive view of the implementation of GC in education.

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