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RECENT STUDIES ON INTEGRATING SUSTAINABLE DEVELOPMENT PRINCIPLES INTO CHEMISTRY EDUCATION

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ABSTRACT

This study examined current research on the integrating sustainable development principles into chemistry education published in the Journal of Chemical Education between 2019 and 2023. The researchers employed a systematic literature review to select, categorize, and analyze content based on the study's findings, including the researcher's nation, target audience, and content focus. The findings were analyzed using descriptive statistics such as means and percentages. The study revealed that European countries, particularly the United Kingdom, published the most research. The research focused mostly on students. The content focus was divided into three topics that integrate the principles of sustainable development (SD): 1) Curriculum, with the major focus on fostering 1.1) awareness and social responsibility related to climate change, pollution, and sustainable use of natural resources, 1.2) critical thinking abilities, evaluating evidence, and developing conclusions on societal issues related to sustainable development, 1.3) problem-solving through creative thinking, collaboration, and initiative in discovering solutions for sustainable development. 2) Learning activities that emphasized 2.1) hands-on learning through experiments and projects, and 2.2) participation by encouraging thinking, questioning, and cultivating curiosity, 3) Assessment for learning, which evaluated students' abilities to apply concepts in real-world circumstances and analyze long-term sustainable behaviors.

Keyword: sustainable development principles, chemistry education, recent studies

1. Introduction

SDGs have become a fast-growing area of research, especially in the context of improvement in students' understanding of chemistry, with the development of environmental consciousness and social responsibility. Integrating SDGs into chemistry education is not only crucial for the solution of global sustainability problems but also for the preparation of students with knowledge and skills for the contribution to sustainable development. The integration of SDGs into the learning of chemistry includes reduction of waste, use of safe solvents, and energy efficiency. These principles need to be integrated in order to enhance sustainable practices within the field of chemistry. This transformative approach will help in attaining goals as stated by the United Nations for the development of a more sustainable and equitable world. By embedding SDG principles into chemistry education, teachers can inspire students to think critically about the role of chemistry in addressing global challenges and to act responsibly as future scientists and citizens. (Eaton et al., 2019; Zuin et al., 2019; MacDonald et al., 2022; Karmakar et al., 2023)

Despite these positive trends, there are a number of challenges that have to be addressed in the effective integration of SDGs into chemistry education: the need for novel pedagogical strategies that will help promote sustainability in future professionals; preparing the teachers to teach systems thinking effectively; interdisciplinary approaches and a new kind of scientist with a deep understanding of their discipline and links to other disciplines; the use of Systems Thinking to situate knowledge of sustainability within the chemistry curriculum. Overcoming such challenges will be important for ensuring that chemistry education makes its full contribution to global sustainability. (Blonder & Rosenfeld, 2019; Eaton et al., 2019; Michalopoulou et al., 2019; Zuin et al., 2019) The Journal of Chemical Education (JCE),

cosponsored by the ACS Division of Chemical Education and ACS Publications, has been published since 1924. JCE serves as a means of communication among people across the world who are interested in the teaching and learning of chemistry. The journal typically addresses chemical content, laboratory experiments, instructional methods, and pedagogies

Therefore, studying research published in the journal provides an overview of current research in chemical education. This helps other researchers gain a clear perspective on the research being conducted, understand the latest directions in research activities, expand their research in broader context, and foresee future research

2. Research objective

Based on these reasons, we examined "Recent studies on integrating sustainable development principles into chemistry education" in the JCE, focusing on the following aspects:

1) researcher's nation which produce the research
2) target audience of research
3) content focus that the researchers aimed to address

3. Research methodology

In this study, we analyzed the current research on the integration of sustainable development principles into chemistry education in the Journal of Chemical Education from 2019 to 2023. We utilized systematic reviews developed by the Evidence for Policy and Practice Information and Coordinating Centre (EPPI-Centre) Institute of Education, University of London, for the analysis and synthesis of research. And then the articles are thoroughly analyzed by content analysis according to research objective. Because content analysis is a quality research technique, which can be used to make replicable and valid inferences from text (Krippendorff, 2004) it is used for the systematic review. The research tool was the Research Findings Record Form and self-developed by the researcher, and the sample consisted of research articles.

This approach consists of four steps, as follows:

3.1) Article Selection

Research related to the integration of Sustainable Development principles was selected utilizing the search term: "Sustainable Development principles" and "Sustainability". A total of 306 research studies were found, these were removed when duplicated. Based on the abstracts, results were narrowed down to 53 papers subsequently. Exclusion criteria for an abstract was that the article did not mention SDGs. These 53 papers were read through and removed if they did not meet the following criteria in addition to mentioned earlier: The articles 1) did not concentrate specifically on sustainability (only used in the reference for example), or 2) did not focus on integration sustainability into chemistry classroom as a starting point. Finally, 26 papers remained to be reviewed.

3.2) Identifying and Generating Systematic Categories

To identify and establish categories, we determined the analytical framework by dividing into three categories, as follows: 1) authors' nation, 2) target audience, and 3) content focus, as illustrated in Table 1:

3.3) Analyzing and synthesizing

To categorize and identify research issues related to the integration of Sustainable Development principles into chemistry education, a thorough content analysis was conducted. Each article was reviewed in detail to extract relevant information aligned with the analytical framework.

3.4) Summary and discussion

We utilized descriptive statistics, such as means and percentages, to summarized and discussed each of the study issues.

Table 1 displays the categories studied and respective definitions.

Categories	Definitions
1) Authors' nation	the geographical location of the primary authors was recorded to understand regional contributions and trends in conducting research.
2) Target audience	the primary demographic or educational level addressed by each study was identified, such as secondary school students, undergraduate students, or teachers.
3) Content focus	The primary focuses, specific themes or issues that the researcher aims which drive the research.

4. Results

According to studied in the Journal of Chemical Education, which included 26 relevant research papers, the proposed results reveal that

4.1) The authors' nation, which published the research papers

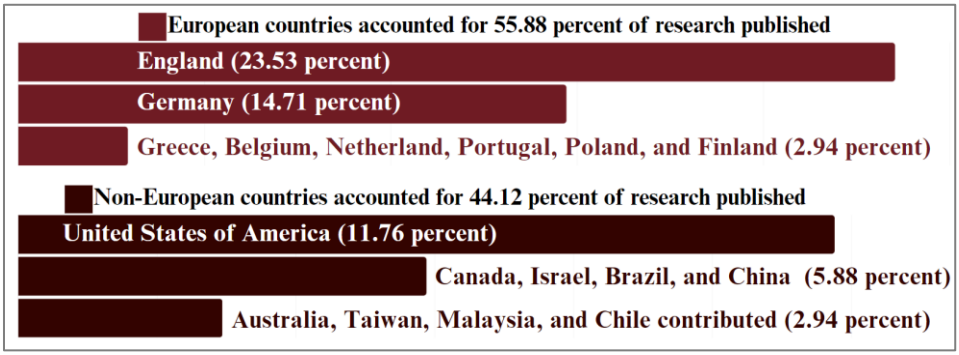

Figure 1 Stacked row chart of authors' nations

Based on the analysis findings, the country that published the highest number of research papers on integrating sustainable development principles into chemistry education between 2019 and 2023 represented a diverse range of nationalities across the 17 countries worldwide. Initially, European countries such as England led with the most research papers (23.53 percent), Germany subsequently (14.71 percent) and Greece, Belgium, Netherland, Portugal, Poland, and Finland (2.94 percent) contributed in succession. Collectively, these nations accounted for 55.88 percent of research published. And non-European countries such as United States of America led with the

most research papers (11.76 percent), followed by Canada, Israel, Brazil, and China (5.88 percent), and Australia, Taiwan, Malaysia, and Chile contributed (2.94 percent), respectively.

4.2) The target audience of research

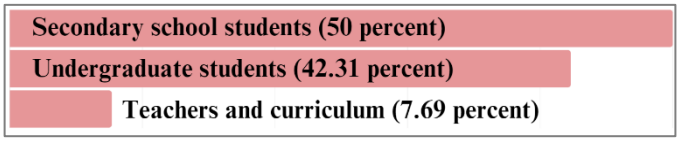

Figure 2 Stacked row chart of target audiences

According to the analysis findings, primarily the researchers focused on secondary school students (50 percent) (for instance: Eaton et al., 2019; Seibert et al., 2020; Stachowiak et al., 2020), undergraduate students subsequently (42.31 percent) (for instance: Mahaffy et al., 2019; Karmakar et al., 2023; Chen et al., 2023), and the remaining 7.69 percent of the study emphasized teachers and curriculum (for instance: Blonder & Rosenfeld, 2019; Chiu et al., 2019).

4.3) Content focus

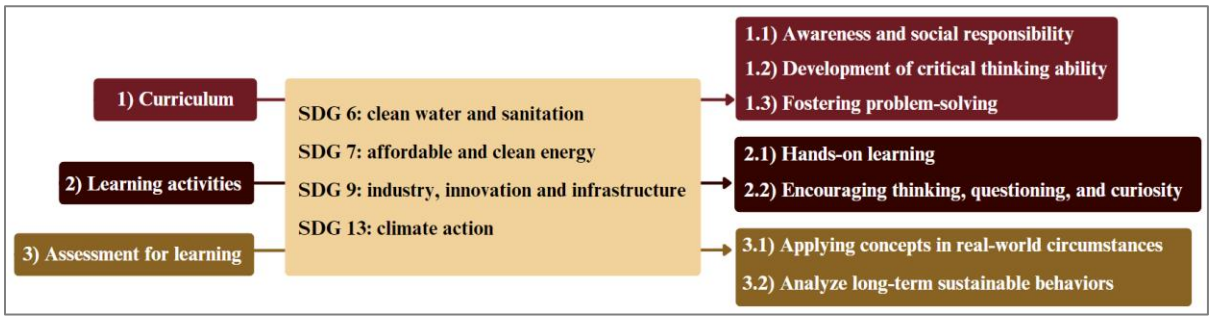

Figure 3 Content focus of researchers' investigations

The primary issues on which the researchers focused were divided into three main topics, namely: 1) integrating sustainable development principles into the chemistry curriculum, with a specific emphasis on 1.1) awareness and social responsibility regarding climate change, pollution, and the sustainable use of nature resources, such as integrating sustainable development principles of SDG 6: clean water and sanitation, which students were studied in aspects of chemical water, water cycle, and water pollution, including enhancing analytical skills in water quality and treatment, SDG 7: affordable and clean energy, students evaluated the environmental impacts and sustainability of energy utilization and were studied in various aspects of chemical energy sources, including fossil fuels, renewable energy, and nuclear energy, SDG 9: industry, innovation and infrastructure, students were studied about chemical materials, production processes, industrial pollution, skills development in sustainable design, and methods for reducing industrial pollution, and SDG 13: climate action, students conducted for addressing climate action, specifically chemical greenhouse effect, impacts of climate change, and strategies for mitigation, 1.2) development of critical thinking ability for problems, evaluating evidence and summarizing for societal issues onward sustainable development and 1.3) fostering problem-

solving through creative thinking, collaboration, and initiative in discovering solutions for sustainable development 2) Learning activities that emphasized 2.1) hands-on learning through experiments and projects, 2.2) participation by encouraging thinking, questioning, and cultivating curiosity. 3) Assessment for learning, which evaluated students' abilities to apply concepts in real-world circumstances and analyze long-term sustainable behaviors.

5. Discussion

5.1) The authors' nation, which published the research papers

According to the analysis over a five-year period, research on integrating sustainable development principles into chemistry classrooms was predominantly published by European countries, due to the EU being a member and leading donor of official development assistance (ODA) globally to supported the establishment of the Sustainable Development Goals (SDGs) in 2015. The EU has made a positive and constructive contribution to the development of the 2030 Agenda and is committed to implementing the SDGs across all policies, including education, through initiatives like Horizon Europe and Erasmus+, while encouraging EU countries to follow suit (European Union, 2024). Consequently, from 2015 to 2030, researchers have continuously focused on publishing pertinent research.

In contrast, nations contributed fewer research papers, and many countries did not appear in the result that may result from restricted access to capital and facing language barriers. Researchers in non-English-speaking countries might hurdled in publishing their articles as the main language that included this journal as well (Altbach & Knight, 2007).

5.2) The target audience of research

The researchers mostly focused on students, especially in secondary school, to foster awareness of sustainability, including their transition to implement sustainable development principle in their work or universities. Furthermore, emphasizing undergraduate students, especially in science, technology, engineering, and mathematics (STEM) fields along with pre-service student teacher (those training to become teachers) aims to instill in them a consideration of the environmental, social, and economic impacts of their actions and innovations. This preparation will enable them to implement sustainable practices in their future careers (Apriani et al., 2022; Kucuk, 2022)

5.3) Content focus

5.3.1) SDGs Chemistry Curriculum Emphasizing Awareness and Social Responsibility

SDGs chemistry curriculum emphasized building into the students a strong foundational concept in sustainability issues; therefore, these principles allow bringing the topics of chemistry towards the global challenges posed through SDGs as followed

SDG 6: Clean Water and Sanitation

Chemistry classes should, therefore, cover such topics as water management and conservation through subjects as pollution control, chemical analysis of water, and water purification techniques. This might involve the proposal of various group projects in which the students are to test some local water sources for contaminant levels, recommend potential remedies, and then prepare presentations of their results to peers or community members.

SDG 7: Affordable and Clean Energy

Energy-related chemical subjects should support students to evaluate the impact on the environment from different energy sources. Preparation of lessons guided by such concepts as energy efficiency, chemistry of renewable energy resources, and contribution of fossil fuels to greenhouse gas emissions can be carried out. Students may, for instance, compare the combustion efficiency in fossil fuel with biofuels as an exercise.

SDG 9: Industry, Innovation, and Infrastructure

Chemistry education should contribute to knowledge on sustainable industrial practices, including green chemistry principles, industrial waste minimization, and environmentally benign product design. For instance, lessons on polymer chemistry could be incorporated into discussions on the preparation of biodegradable plastics; or students could be taken through innovation challenges in which they make prototypes for sustainable materials or industrial processes, such as waste-to-energy conversion systems.

SDG 13: Climate Action

Learning about principles of climate chemistry, For instance, the greenhouse effect and carbon sequestration-allows students to tie chemical phenomena to strategies in climate change mitigation. The class project could be development of a detailed proposal on reduction of carbon footprints either within their school or community using support from chemical data and principles of sustainability.

5.3.2) Learning Activities

Learning activities are instruments for the translation of abstract ideas of sustainability into concrete experiences, since hands-on activities can enhance students' comprehension by applying theoretical knowledge in real-life contexts. Conducting experiments that model environmental processes or performing experiments designed to replicate environmental processes, such as testing the acidity of soil or analyzing air quality, and assigning long-term projects, such as building and testing a microfluidic paper-based device for water testing, integrating knowledge of chemistry with engineering and design skills. Moreover, educators can implement the Question Formulation Technique (QFT) where students generate their own questions related to sustainability, such as “How might we reduce energy waste in schools using chemical principles?” This builds curiosity and further drives inquiry-based learning.

5.3.3) Assessment for Learning

Assessments should test students' ability to apply chemistry concepts to real-world sustainability problems. For instance, educators should replace traditional tests with project-based assessments where students design experiments to address sustainability issues or let students implement self-reflection, such as journaling about how students apply sustainability principles in their daily lives or students' willingness to adopt sustainable practices in daily life, subsequently.

6. Conclusion

This further emphasizes embedding the principles of sustainable development within the education of chemistry. Giving priority in the curriculum, hands-on learning, and innovative assessments related to SDGs allow chemistry education to become central for preparing the necessary generations against global sustainability challenges. In the future, educators and

researchers should develop and extend inclusive, interdisciplinary approaches that will enable all students to acquire knowledge and skills for the sustainable future. However, a shift in thinking is required for education to move forward. According to Thomas Kuhn, a paradigm shift required for scientific progress is much more about destroying the old paradigm, or the accepted mode of thought, than it is about creating a new one.

7. Future directions

The suggestion of directions for researchers or anyone interested in continuing this study is as follows: 1) while the research highlighted EU countries, a more comprehensive global picture could be provided by exploring trends in other regions such as Asia, Africa, South America, or the authors' hometown, 2) and the next study should investigate effective approaches for preparing and supporting teachers to integrate SDGs into their teaching practices. This includes professional development programs that equip teachers with the knowledge and skills to teach sustainability concepts and systems thinking and 3) many educators lack the training or resources to effectively integrate these principles into their classrooms, therefore, develop training workshops that focus on sustainable chemistry concepts, green chemistry principles, and the SDGs is required.

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