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Profile of Green Chemistry on Chemistry Education Students: Study on Developing Green Chemistry Practical Module to Support Sustainable Development Goals (SDGs)

Mutiara Dwi Cahyani[1], Tania Avianda Gusman[1*], Ari Yustisia Akbar[2]

[1] Prodi Pendidikan Kimia, Universitas Muhammadiyah Cirebon, Cirebon, Indonesia.
[2] Badan Riset dan Inovasi Nasional, Tangerang, Indonesia.

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Corresponding Author:
Tania Avianda Gusman
tania.ag@umc.ac.id
Ari Yustisia Akbar
ariy005@brin.go.id

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Abstract: The Society 5.0 era emphasizes production efficiency by transitioning from conventional to renewable energy sources. Thus, the Society 5.0 Era aligns with one of the goals of the SDGs, which is that industrial processes become more environmentally friendly and more efficient in using energy resources while increasing their value. *Green chemistry* is a comprehensive approach that designs safe chemicals ranging from environmentally friendly chemical products and processes to reducing the formation of harmful chemical substances. The type of research is descriptive and aimed at describing the student's early understanding of green chemistry. The subject of this study is a student of Prodi Education Chemistry at the University of Muhammadiyah Cirebon. The test instrument consists of 4 description questions compiled to measure the student's initial understanding of green chemistry. The analysis results show that the students understood the terminology for green chemistry. However, students still need to understand the 12 principles of green chemistry and their applications in everyday life.

Keywords: Green chemistry; Knowledge of green chemistry; Principle of green chemistry

Introduction

The Society 5.0 era played an essential role in creating innovations that can meet the needs of society and accelerate sustainable development or Sustainable Development Goals (SDGs). In the era of Society 5.0, more emphasis was placed on production efficiency by transitioning from conventional to renewable energy sources. It is in line with Presidential Decree No. 59 of 2017 on achieving sustainable development goals that focus on the environmental, social, and economic areas, accompanied by developments in technology and information systems (Perpres, 2017).

The role of colleges in education regarding the SDGs is to provide knowledge, innovations, and solutions to the SGDs. Colleges can integrate the educational elements of the SDNs into most activities in the learning process. Students are equipped with the necessary skills to implement the SDGs in the learning process. The skills provided by the college to students include strategic vision, thinking, social responsibility and problem-solving, initiative skills, and interdisciplinary collaboration science. The provision of skills can be integrated into learning by identifying problems that occur in the surrounding region, and then students can innovate to solve such problems in collaboration. The current environmental problems or pollution issue is urgent, and the government needs to meet the SDG targets, especially in processing waste into renewable energy.

Sustainable Development which has been targeted as set forth in the 17 goals SDGs which are categorized

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into three pillars namely social, economic, and environmental (Purvis et al., 2019). The environmental pillar involves sustainable chemistry or green chemistry. Education and chemistry learning contribute to the two SDGs pillar goals for environmental aspects (Evans et al., 2017). Actions to save the environment can be carried out early on through education to support the achievement of sustainable development targets, one of which is green chemistry.

Green chemistry principle could benefit human health, environment, and economic sustainability, which are highly related to SDGs. Figure 1 shows how Green chemistry principle are beneficially related to SDGs (Chen et al., 2020).

Aspects	Key Factors	Related SDGs
Human Health	Enhanced safety for workers in the chemical industry	SDGs 3, 8 and 12
	Safer chemical products for consumers	SDGs 3 and 12
	Better food security	SDG2
	Less exposure to toxic substances	SDGs 3, 6, 12 and 14
Environment	Less release of hazardous chemicals to air	SDGs 3, 7 and 11
	Less release of hazardous chemicals to water	SDGs 3, 6, 11 and 14
	More innocuous products into environment	SDGs 2, 6, 9, 12 and 14
	Less harmful to plants and animals	SDGs 12 and 15
	Lower potential for global warming, ozone depletion, and smog formation	SDGs 11, 13 and 14
	Less chemical disruption of ecosystems	SDGs 12, 14, 15
	Less use of landfills	SDGs 11, 12
Economy	Higher chemical yields	SDGs 9, 12
	Fewer synthesis steps	SDGs 9, 12
	Reduction of wastes and lower treatment cost	SDGs 9, 11, 12
	Better performance of final products	SDGs 9, 12
	Reduced use of petroleum products	SDGs 9, 12, 13
	Reduced footprint of manufacturing plant	SDGs 9, 12
	Increased product values	SDGs 9, 12
	Improved competitiveness of chemical manufacturers	SDGs 9

Figure 1. The linked between green chemsitry application to the SDGs

Those principles might be the main source for achieving several SDGs including improved health and welfare, clean water, and clean-energy production and consumption. These SDGs were also interconnected to others such as SDG 11(environmental benefits such as sustainable cities and communities) and SDG 14 (life below water). From the economic aspect, industrial innovation and infrastructure (SDG 9) and responsible consumption and production (SDG 12) would be the main objective, describing the contribution of GCP to the industry. In order to achieve the SDGs which could integrate GCP and sustainability, the sustainable chemistry has been interested in the development of: new types of chemicals, a comprehensive evaluation framework covering the environmental, economic, and social aspects, and a long-term vision for sustainable development (Halpaap et al., 2018).

Green *chemistry* is a comprehensive approach that designs safe chemicals from products and processes (Anastas et al., 2001). Green chemistry is also called sustainable chemists used to design chemical products and procedures that reduce the formation of harmful chemicals. The principle of green chemistry is fundamental in laboratory experiments because chemicals can produce waste. As a chemical lab user, the school has already begun to apply the Green Chemistry Principles (Aubrecht et al., 2015) and is applied in the chemistry curriculum (Karpudewan et al., 2015). Teachers perceived the importance of GC in the curriculum, and they were able to integrate GC, but the scope of their integration is a mere scratch of a deep pro-active pedagogical approach that aims to highlight sustainability practices.

According to Haack et al. (2005), green chemistry education provides an opportunity to integrate the concept and implementation of the 12 principles of green chemistry in the curriculum and learning. Implementation of this is an attempt to develop the learners' environmental awareness. Chemical education plays a central role in education for sustainable development (Burmeister et al., 2012). Therefore green chemistry which is the main pillar of sustainable development has not been properly socialized at school. It is therefore necessary to investigate the understanding of students on Green Chemistry can be integrated in the learning process.

Method

Table 1. Green Chemistry's Principle

Principe Green Chemistry
Prevention of Atomic Pollution
Atom Economy
Less Hazardous Chemical Syntheses
Designing Safer Chemicals
Safer Solvents and Auxiliaries
Design for Energy Efficiency
Use of Renewable Feedstocks
Reduce Derivatives
Catalysis
Design For Degradation
Real-time analysis for pollution prevention
Inherently Safer Chemistry for Accident Prevention

The type of research is quantitative descriptive and aimed at describing the student's early understanding of green chemistry. This research uses pre-experimental research designs involving one group of subjects. According to Cresswell (2017), pre-experimental research was done on only one group of subjects without a comparator group. The subject of this study is a student who is a professor of chemical education at Muhammadiyah University of Cirebon. The initial understanding test of the measurement of green chemistry is a description test that contains their understanding of green chemistry, green chemistry principles, their applications, and their experience with projects in the utilization of the concept of green chemistry.

Result and Discussion

Knowledge of the concept of Green Chemistry or what is often referred to as green chemistry is very important for students of chemical education in the core course of the chemical concept because students must understand the impact of chemicals activities on the environment. By studying green chemistry, they will be more aware of the dangers that may be caused by the use of harmful chemicals and the importance of reducing such negative impacts (Zimmerman et al., 2020). Based on the understanding tests carried out by the students showed that the students' understanding of the concept of green chemistry is good.

Based on students' initial understanding of test answers, they are familiar with green chemistry. This can be seen from various students' answers, who answered that green chemistry is the use of chemicals or chemical processes that are environmentally friendly, amounting to 91.7%.

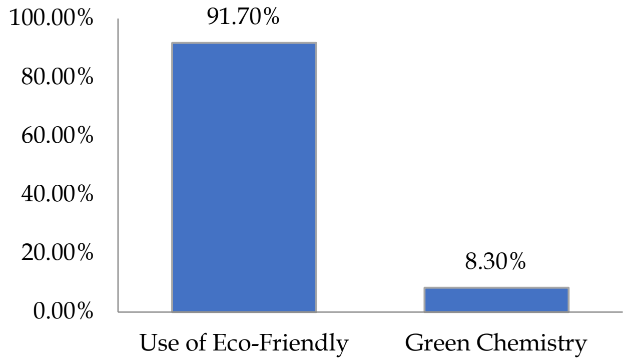

Figure 2. Percentage of understanding green chemistry concept of umc chemistry education students

Green chemistry has 12 principles that can be adapted to be applied in human attitudes and actions to save the environment. The principles of green chemistry can be adapted to be applied in human attitudes and actions, primarily through lectures to save the environment, which can be realized through green education. UMC Chemistry Education Students still need to learn all of the 12 Principles of Green Chemistry (Anastas et al., 1998). Students also need help understanding the 12 principles of green chemistry.

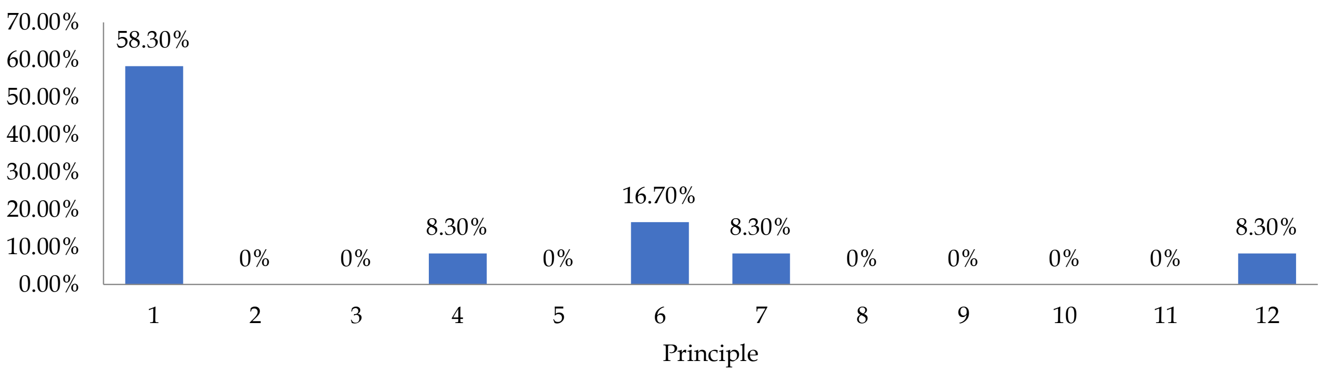

Figure 3. Knowledge of green chemistry principles of UMC chemistry education students

Based on the initial knowledge test results on the principle of green chemistry in Figure 3, UMC Chemical Education students have learned 5 of the 12 existing principles of green chemistry. UMC Chemistry Education Students have learned and understood that green chemicals are chemical processes that produce products by minimizing the amount of waste produced, using solvents that are safe for the environment, identifying variable raw materials, using environmentally friendly catalysts as well as incorporating considerations of green chimney in the early stages of product planning and design and chemical procedure.

Figure 3 shows that principle 1, with a presentation of 58.3%, is the most comprehensive principle possessed by the student's understanding. This principle is a principle on the prevention of atomic pollution. Activities on the principle of prevention from atomic contamination give students a sense of designing chemical processes to produce products with the minimum amount of waste and avoid the formation of unwanted additional products that can damage the environment. In addition, a presentation of 8.3% belongs to principle 6, which is to prevent hazardous raw materials. This principle teaches students to find chemicals that are safe for human health and the environment and to be a reactor capable of producing products that are also safe for humans and the environment. There is many household chemicals can also be used in green chemistry experiments, which are typically safer and less expensive than those from a chemical supplier (Wissinger et al., 2020).

While the lowest principles are principles 7 and 12 regarding the use of environmentally friendly and preventive catalysts in chemical design, scholars have not yet been able to provide ecologically and human-health-friendly chemicals. Apart from that, the student, still needs help to complete a chemistry practice based on green chemistry in chemical processes.

Artificial Intelligence have been introduced in green chemistry. One of the example artificial intelligence that can be used in green chemistry is application in smartphone that can be used in laboratory. The paper by Peiretti et al. (2018) shows application of AI for the synthesis of new organic compounds used as drugs and medicaments. It is claimed that this method might be better and faster. By using green chemistry principle can increase safety in the classroom and minimized the hazardous substances.

Green chemistry aims to reduce or eliminate the use of hazardous chemicals by designing chemical products and their processes, thus applying these 12 principles to chemical learning, both in theoretical form and in practical activities. Understanding the concept of green chemistry can be achieved by creating a Green Chemistry-based course learning module that contains the principles of Green Chemistry that can be integrated into the characterization of the core course concept. Almost teachers know the term of Green Chemistry, but generally believed and have perception that Green Chemistry did not need to be integrated into the learning process. Integrating green chemistry into the curriculum of chemistry education in learning process can enhance students' critical thinking, problem-solving, and communication skills needed in the understanding process (Afiyanti et al., 2014).

Studying green chemistry in class is beneficial to students in helping students better understand the chemical impact on the environment and make them more interested in the conservation of nature and sustainable environment (Sheldon et al., 2020), thus forming the character of students who care about the environment (Sudarmin, 2013). Implementing the concept of green chemistry in practice can help raise students' awareness of the importance of environmental and human health in using chemicals. Green Chemistry encourages students to think about improving chemical processes' efficiency and reducing waste, which can generate innovations in various industries (Aftab et al., 2023).

The green chemistry practicum path can be implemented by developing a practicum manual. Developing a guide to chemical practices based on green chemistry aims to ensure that experiments minimize the negative impact on the environment, reduce the use of hazardous substances, and promote sustainability principles (Septiayuni, 2021).

Based on the initial knowledge test results, it can be concluded that the student's knowledge of the principles of green chemistry could be higher. A low student's initial understanding of test results will affect the teaching objectives of chemistry courses in the chemical education industry. The cause of the factors that influence the student's life have yet to be identified with the principle of green chemistry in the activities of the lectures. Chemical education must not only understand education but also the concept of chemistry. As a prospective teacher, a chemistry student will introduce a safe chemical concept to his pupils later. *Green chemistry* is an approach that needs to be applied in the learning of chemistry in high school. There are five GC Principles that can be integrated in chemistry learning to support education for sustainable development (Jusniar et al., 2023). There were atomic pollution, safer solvent, design for energy efficiency, use of renewable feedstock and inherently safer chemistry for accident prevention.

Curriculum is a pillar of education, how learning process can be implemented is based on curriculum. By incorporating Green Chemistry principles into the chemistry curriculum, these future educators can provide students with a positive message about what chemists are doing for the environment in fulfilling the obligation and responsibilities of environmental stewardship (Auliah et al., 2018). The new curriculum certainly requires teaching modules that are appropriate and relevant to the learning material so that students can understand learning concepts well (Farhana, 2023). Therefore, efforts are needed to develop comprehensive and high quality modules that can be used by students in learning (Mardianti et al., 2020). Green chemistry integrated project-based learning is a model and concept of meaningful learning which uses authentic situations in the real world as an a priori in the application of learning (Fauziah et al., 2019).

Therefore, the development of e-exercise modules based on green chemistry has a strong influence on the learning process. Based on the results of the student's initial knowledge test, the initial stage was undertaken in developing the green chemistry-based practicum module, i.e. (1) digging basic questions or cases on environmental issues to stimulate students to understand the concept of green chemists; (2) providing examples of practicum activities that have not yet applied the 12 green chemicals principles; (3) assigning students to provide solutions to practicum activity that has not yet implemented the green chemistry principle; (4) students conduct a green-based practice using environmentally friendly solvents with app on mobile phones.

Therefore, the development of e-exercise modules based on green chemistry has a strong influence on the learning process. The development of an integrated green chemistry teaching module is suitable for improving students' science process skills and learning independence (Fitri et al., 2024). Based on the results of the student's initial knowledge test, the initial stage was undertaken in developing the green chemistry-based practicum module, such as digging basic questions or cases on environmental issues to stimulate students to understand the concept of green chemists, providing examples of practicum activities that have not yet applied the 12 green chemicals principles, assigning students to provide solutions to practicum activities that have not yet implemented the green chemistry principle, students conduct a green-based practice using environmentally friendly solvents with apps on mobile phones.

Digging basic questions about the environmental problems in the surroundings is an early activity that can be displayed in a practical guide. During this time, the practicum guides still need to be contextualized, so students do not know the purpose and implementation of the practicum that they will do in everyday life. This activity is an initial activity that trains students' problem-solving skills and students' critical and creative thinking skills. Applying the 12 principles of green chemistry to practical activities gives students an insight into how the principles can solve environmental problems in daily life. Applying practical activities using the principle of green chemistry is still very rare. Therefore, providing examples of applying green chemistry principles to practicum activities can give students an understanding of any chemicals that can be used in practical activities that do not damage the environment or harm the practice. Through the green chemistry experiments, students develop a systematic approach to analyzing questions of environmental attitude; and to provide them with a framework for thinking critically about their own personal environmental attitude (Karpudewan, 2011).

Conclusion

The development of green chemistry-based practicum guides requires a student's initial understanding of the concept and the principles of green chemistry. Based on the initial knowledge test results, students were found to have understood the terminology concerning the concept of green chemistry. However, students still need to understand the 12 principles of green chemistry and their applications in everyday life. It is, therefore, necessary to develop practical guidelines based on green chemistry that can be used in the learning process.

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