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EVIDENCE ON GREEN CHEMISTRY: A MIXED METHODS RESEARCH

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Abstract

This study aimed to examine students' perspectives on green chemistry This study was in the form of a mixed methods research, which involved 40 students from the Department of Chemistry Education of Universitas Tanjungpura. A questionnaire, an essay test, and an interview were used to obtain data. The results of the analysis show that the majority of students have an understanding of green chemistry at the average level. They gain knowledge about green chemistry mostly through courses. They believe that green chemistry is very important to learn. The understanding of green chemistry contributes to students' attitudes toward chemistry and the environment.

Keywords: Curriculum, Green chemistry, Students' perception, Sustainable development.

1. Introduction

Our environment is constantly changing. However, as the environment changes, we must also raise awareness of the problems that surround it [1-5]. With a variety of environmental problems that are being faced such as global warming [6], ozone depletion [7], plastic waste [8, 9], industrial waste [10], and many other problems related to the environment, people need to realize the importance of this problem to then take a role in finding solutions.

Environmental problems have now become a global issue. The United Nations (UN) has made it a crucial challenge for the survival of humanity. Based on this, the UN then initiated 17 sustainable development goals (SDGs) which are the answers to these challenges. All education practitioners of UN members must participate in supporting the achievement of the SDGs [11]. To achieve the SDGs, every individual should be able to become an agent of sustainability change [12-16]. They need knowledge, skills, values, and attitudes that empower them to participate in sustainable development. Education is one of the important media in achieving this [17]. The education approach that can promote sustainable development is called Education for Sustainable Development (ESD). ESD is an approach that can be applied at various levels, including at the tertiary level [18, 19]. However, not many studies have been carried out related to the application of ESD in lectures, especially at Universitas Tanjungpura.

One of the important subjects is green technology [20-26]. Green chemistry (GC) is the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances [27]. GC is a concept in chemistry that is in line with the concept of sustainable development. Through this perspective, a chemist must pay attention to every consequence of science. Chemists are people who can manipulate matter. This chemical knowledge and skills become a technology that is beneficial to all aspects of human life. Useful chemical technologies include those related to the chemical industry and across chemical enterprises [28].

Graduates have the competence to work professionally as chemistry teachers and chemists. Providing students with knowledge related to ESD and GC has become the attention of lecturers as curriculum designers [11, 29]. But before that can be done, an analysis of the extent to which students understand GC must be done immediately. Some studies have reported an improvement in students' awareness of environmental issues after the GC concept had been taught during the course [30, 31]. However, an assessment of students' prior knowledge of GC before the course has never been done. This study aims to assess students' prior knowledge of GC through a cross-sectional study.

2. Literature Review

GC is a framework in chemistry and chemical engineering that focuses on designing products and processes of chemistry that minimize or eliminate the use and generation of hazardous substances. The ultimate goal of GC is to reduce the environmental impact of chemistry [27]. The principles of GC can be applied throughout the entire life cycle of chemical products, including design, manufacture, use, and final disposal. The design of chemical products and processes that reduce or eliminate the use or generation of harmful substances is known as sustainable chemistry. The principles of GC is shown in Fig. 1.

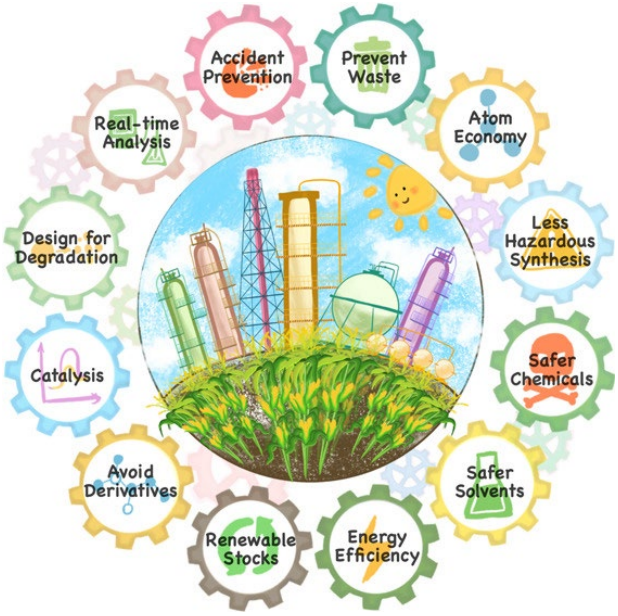

Fig. 1. The principles of GC [32].

3. Method

An explanatory sequential design of mixed methods research is used in this study. This study was carried out in Pontianak at Universitas Tanjungpura. The respondents were 40 students of the Department of Chemistry Education consisting of first year to fourth year, starting from the year of 2019 to 2022. This was done in two phases. The first phase of the study was conducted quantitatively by questionnaire and essay test. The questionnaire consists of questions as follows: (i) how good is your understanding of GC? (ii) from what sources do you get the knowledge of GC? and (iii) is GC important to learn?

The essay test questions students' understanding of every principle of GC. The collected data was then analysed using frequency, mean, standard deviation (SD), and Kendall's Tau B test. The second phase of this study was conducted qualitatively by interviewing the respondents about the reason of implementation GC in education. 10 respondents were randomly selected to participate in this session. The data obtained was then transcribed and then analysed using the thematic analysis method. Figure 2 shows the methodology framework used in this study. Before the study was conducted, the researcher asked for permission from the Department of Chemistry Education of Universitas Tanjungpura. After obtaining permission, the researcher personally explained the informed consent and questionnaire through Google form that personal information would be confidential. The researchers explained that the findings would be published in a Scientific Journal. Researchers also explained that respondent participation is voluntary. Respondents can choose whether to participate in the study or not.

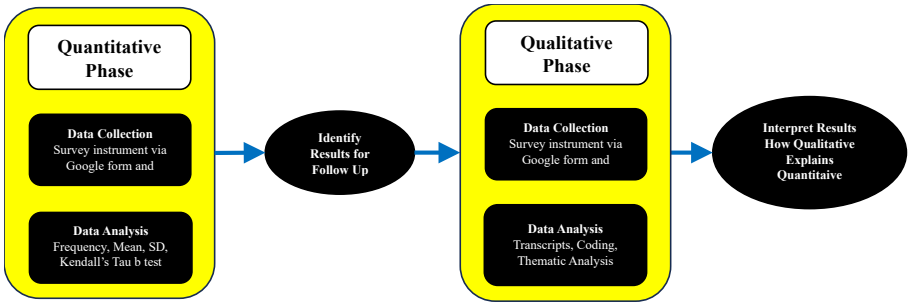

Fig. 2. Methodology framework.

4. Result and Discussion

4.1. Demography

There were a total of 40 respondents who participated in this study. Of the 40 respondents, there are 5 men and 35 women. The distribution of respondents by academic year-gender is as follows: 1) academic year of 2019 (two males and nine females); 2) academic year of 2020 (two males and fifteen females); 3) academic year of 2021 (five females only); 4) academic year of 2022 (one male and six females). Female respondents are the biggest. It illustrates the great interest of women in continuing their studies at the undergraduate level. It also shows that the most enthusiastic applicants are women [33]. But it also indicates the possibility that men cannot compete with women for college.

This finding will also trigger other research regarding the interest and competence of senior high school students in competing for college admission regarding gender. According to the academic year, respondents are spread relatively evenly. It is very beneficial, especially in generalizations, since no dominant group of the academic year exists.

4.2. Students' perceptions

The results of the Q1 are as follows; very poor = 1; poor = 3; average = 19; good = 17; excellent = 0. The results of the Q2 are as follows: course = 16; social media = 7; seminar = 3; internet = 12; scientific article = 2. The results of the Q3 are as follows: unimportant = 2; important = 38; no idea = 0. According to this result, most of the respondents perceive themselves to have good and average levels of understanding. With this finding, students with a good understanding will be potential agents that can promote sustainable development. Students who have positive self-efficacy will display a positive attitude as well [34, 35]. Lecturers can develop learning programs that accommodate GC equipped with a variety of case examples adapted to local issues.

Students obtain the information of GC from their regular courses. This finding shows that the course programs have crucial roles as primary resources for students to extend their knowledge of GC. The lectures can also be included with other media to enrich the materials. Relevant pedagogy may be helpful especially if that can accommodate various potential resources such as information from the internet, and social media. The majority of students agree that GC is an important thing to

learn. These findings show a high awareness of the application of GC principles to support sustainable development. It is a powerful motive for students to learn GC.

4.3. Students' understanding

Students' understanding of GC is essential for achieving SDGs since much research shows a positive relationship between them [34, 35]. The student's understanding of GC is shown in Table 1. According to test results and questionnaire, there is a significant correlation between perception (Q1) and student understanding. This is a positive value for institutions in their participation in achieving SDGs through education. However, the study also showed that there is no significant relationship between perception (Q3) and student understanding.

Table 1. Result of students understanding test.

Green Chemistry Principles	Mean	SD	Interpretation
Prevention	3.50	0.50	Excellent
Atom Economy	1.58	0.54	Average
Lees Hazardous Chemical Synthesis	3.58	0.49	Excellent
Designing Safer Chemicals	3.38	0.66	Excellent
Safer Solvents and Auxiliaries	3.58	0.54	Excellent
Design for Energy Efficiency	1.88	0.51	Average
Use of Renewable Feedstocks	3.45	0.59	Excellent
Reduce Derivatives	1.18	0.38	Poor
Catalysis	1.13	0.33	Poor
Design for Degradation	1.38	0.48	Average
Real-Time Analysis for Pollution Prevention	1.80	0.56	Average
Inherently Safer Chemistry for Accident Prevention	3.45	0.71	Excellent
Average	2.49	1.51	Average
Poor (0.00-1.33); Average (1.34-2.67); Excellent (2.68-4.00)			

The result of inferential statistics is shown in Table 2. Another finding related to the strength of the relationship between perception (Q1) and student understanding is that the strength of the relationship is at a moderate level. In other words, the success of learning that integrates green chemistry can be seen from the positive perception built by students about green chemistry itself. At a higher level, students are expected to be able to apply green chemistry values to their daily lives in the form of practical actions. It should be noted to educators that belief in the importance of green chemistry is not a reference to the level of student understanding.

Table 2. Result of Kendall's tau B test.

	Understanding	
	P Value	**Correlation coefficient**
Perception (Q1)	0.017	0.373
Perception (Q3)	0.633	0.076
alpha value = 0.05; none (0.00); weak (0.01-0.25); moderate (0.26-0.50); strong (0.51-0.75); very strong (0.76-0.99); perfect (1.00)		

According to Table 1, students have a level of understanding of GC in the average category with a very good understanding of the principle of prevention, less hazardous chemical synthesis, designing safer chemicals, safer solvents and auxiliaries, and inherently safer chemistry for accident prevention. This is in line with the results of interviews that have been conducted. According to

thematic analysis of interview data, respondents agreed that everyone must protect the environment in which they live. They state that it can be done from small actions around them such as throwing garbage in its place as mentioned by one of the respondents: "If you look at it from my perspective, actually this GC reminds us to protect our environment, for example, such as littering. While GC in particular is concerned with the production of goods to pay attention to environmental problems."

This description shows that students have applied green chemistry in their daily lives and shows that green chemistry is important to them as it relates to their own lives. Their understanding of GC fosters awareness of the importance of environmental health in which we live. Students mentioned that protecting the environment is everyone's responsibility, including chemistry students who understand the dangers of waste to the environment. Chemistry students are role models for the surrounding community. Students also stated that environmental issues should also be of concern to the government as policymakers. As mentioned by one of the respondents: “Protecting the environment is important for everyone, and we as chemistry students must be role models for society. The government should also create programs related to environmental health.”

Respondents claim that GC is a framework related to chemists, including chemistry education students. This framework should be a reference for chemistry students to take the right stance about chemicals. As mentioned by one of the respondents:"GC is like an environmental awareness movement for chemists or chemistry students."

GC is an approach to answering the challenges of energy and environmental issues [36]. Its application in the chemistry education curriculum is a very strategic step [11]. Chemistry education becomes the only one that can combine the concepts of education and chemistry integrally including teaching GC [37]. Teaching GC can provide authentic chemistry learning [38]. This learning can make students sensitive to environmental issues globally. Thus, the role of the curriculum designer becomes very crucial. Lecturers have a great responsibility in accommodating this challenge.

In developing a curriculum that is integrated with the principles of GC, a lecturer needs to conduct an in-depth analysis of the needs of their students, including how students perceive GC. Students who place GC as an important concept have a strong motivation to learn it [39-41]. This motivation will determine learning success. Success in learning GC will be a steppingstone for the achievement of SDGs.

5. Conclusion

Students’ understanding of GC is essential especially its impact on achievement of SDGs in the field of education. Since the majority of students have an understanding of GC at the average level, lecturers must give lectures by implementing GC principles, especially on the principles of reduced derivatives and catalysis. Students believe that GC is very important but unfortunately, they gain this knowledge mostly through courses. Lectures may use a variety of teaching materials showing the context where GC is applied.

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