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Students' Learning Obstacles in Understanding Green Chemistry Within the Context of Soap-Making Process

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Abstract: This study aims to investigate students' learning obstacles in understanding Green Chemistry within the context of a soap-making activity. As sustainability becomes an increasingly important issue in science education, it is essential to understand how students engage with environmentally oriented chemistry concepts. This study employs qualitative case study approach. The participants consisted of five grade XI students (second-year high school), comprising two boys and three girls. The interviews were conducted at a private school in Bandung. Data were collected through semi-structured interviews with five main questions. The responses were analyzed using thematic analysis to identify key themes related to students' learning challenges in understanding green chemistry, which were categorized into five main themes. The findings reveal that students face significant challenges in understanding Green Chemistry, particularly due to abstract concepts, limited classroom engagement, and teacher-centered instruction. Moreover, students often struggle to connect the theoretical principles of Green Chemistry with real-life applications, such as waste reduction or the use of renewable materials in everyday chemical processes. These findings highlight the importance of designing more interactive, context-based, and student-centered learning strategies. It is expected that the results of this study can serve as a foundation for developing instructional designs that better support students' understanding of sustainability-oriented chemistry.

Keywords: Green Chemistry; Learning Method; Learning Obstacles; Soap-making processLearning Obstacles, Soap-making process, Learning Outcome,

Introduction

In an era defined by pressing global challenges, the role of science education, particularly chemistry, helps students to develop their skills (Ridwan et al., 2021). The 21st century skills are needed to keep students addressing global challenges. As the world evolves, numerous environmental problems are arising, predominantly because of human actions. As future generations, students should be more conscious of environmental problems. There is one term called "green chemistry". Integrating Green Chemistry into the school curriculum is one of the strategies that can be employed to address environmental issues through education (Linkwitz & Eilks, 2022).

In the 1990s, Green chemistry appeared as an approach to turn chemical synthesis less waste, less energy, and more safety for workers and the environment (Zuin et al., 2021). According to Zuin et al. (2021) Green Chemistry was defined by Anastas and Warner as "the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacturing and application of chemical products" (Anastas & Warner, 1998). Anastas and Warner suggested 12 principles of green chemistry, the objectives are using greener methods,

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making safer products, and choosing renewable resources instead of fossil fuels more often. The suggestions were based on the European Union, the US Environmental Protection Agency, the Organisation for Economic Cooperation and Development (OECD) (Zuin et al., 2021).

Table 1 presents the 12 principles of Green Chemistry that have been integrated into the school chemistry curriculum. In chemistry education in Indonesia, Green Chemistry has been introduced in the national curriculum since 2023 (Kemendikbudristek, 2022). The topic of Green Chemistry is taught at the first level of senior high school, which is Grade 10.

Table 1. Principles of Green Chemistry *(Anastas & Warner, 1998)*

No.	Principles
1.	Prevent waste
2.	Maximize atomic economy
3.	Designing safe chemicals and chemical products
4.	Design a less dangerous chemical synthesize
5.	Use safe solvents and reaction conditions
6.	Improve energy efficiency
7.	Using renewable raw materials
8.	Avoid chemical derivatives
9.	Using a catalyst instead of a stoichiometric reagent
10.	Design chemicals and products that can decompose after use
11.	Analyze in real-time to prevent pollution
12.	Minimize the potential accidents

Integrated green chemistry into school curriculum helps students to develop their environmental awareness (Chen et al., 2020; Mitarlis et al., 2023) while also fostering awareness and support for the Sustainable Development Development Goals (SDGs) (Sánchez Morales et al., 2024). Sustainable Development Goals can be achieved by green chemistry integrated learning in education, especially for target numbers 12 (responsible consumption and production), 13 (climate action) (Mitarlis et al., 2023), 6 (clean water and sanitation), and 3 (good health and wellbeing) through application of green chemistry principles (Hoffman & Dicks, 2023; Sharma S.K., 2022).

Green Chemistry principles highlight the importance of preventing pollution, utilizing renewable feedstocks, and designing chemical products that are safe for both human health and the environment (Abdussalam-Mohammed et al., 2020; Ivanković, 2017). Introducing these principles in education helps students grasp the real-world impact of chemical reactions and substances on ecological and societal well-being (Abdussalam-Mohammed et al., 2020). For instance, teaching Green Chemistry can be linked to real-world problems that are familiar to students, such as transforming waste into valuable products (Koulougliotis et al., 2024).

Applying effective teaching methods also has a significant impact on students' learning outcomes (Dr. Yamini Shukla, 2024; Haetami et al., 2023; Sormin, 2023). Green Chemistry is highly suitable to be integrated with various active learning methods that emphasize student engagement, real-world problem solving, and collaboration (Chen et al., 2020; Vaz et al., 2025). For instance, approaches like Problem-Based Learning (PBL) and Project-Based Learning (PjBL) are considered effective because they involve students in addressing authentic problems or creating projects aligned with Green Chemistry principles, including waste reduction, the use of renewable resources, and the design of safer chemical processes (A. R. P. Sari et al., 2024; W. P. P. Sari & Atun, 2023). Many studies have shown that the use of these methods effectively enhances students' understanding, skills, and awareness of sustainability (Chen et al., 2020).

Although several studies have discussed green chemistry in the learning process, most of them have focused on learning outcomes or the teaching methods used, without examining students' obstacles in understanding green chemistry. In fact, identifying these learning obstacles is essential for developing more contextual and effective teaching strategies.

This study aims to explore the learning obstacles faced by students in understanding Green Chemistry concepts, with the intention of using these findings as a foundation for developing effective instructional design. Understanding these obstacles is essential to ensure that Green Chemistry education not only builds scientific knowledge but also fosters students' competencies in sustainability and real-world problem solving.

Method

The research design of this study is qualitative case study. In case study, researchers develop an in-depth analysis of a case of a process, or an event and the researcher should collect detailed information (Creswell, 2014). The participants consisted of five grade XI students or second graders of high school, comprising two boys (L1 and L2) and three girls (P1, P2, and P3). The interviews were conducted at private school in Bandung. Qualitative data employ triangulation techniques to develop a comprehensive understanding and enhance the validity of qualitative data. The type of triangulation used is data source triangulation, which involved comparing information obtained from students, teachers, and learning outcome documents (Patton, 1999).

The data were collected through semi-structured interviews with 5 main questions. The students being asked questions about green chemistry and in the context of the soap making process. There are 5 main questions explored through a set of probing questions. A total of 20 questions were analyzed qualitatively to identify patterns in students' response. The data were anayzed using thematic analysis to identify key themes related to students' learning challenges in understanding green chemistry. The results of the analysis from the questions are summarized into 5 themes that serve as the focus of the discussion. Table 2 presents the five main discussion themes to be addressed.

Table 2. The five main themes

No.	Theme
1.	Students' learning obstacles based on their experiences in learning green chemistry
2.	Obstacles faced by students in learning green chemistry
3.	Strategies used by students and teachers to overcome green chemistry learning difficulties
4.	Students' opinion about PjBL as a solution in learning chemistry
5.	Students' learning obstacles based on their prior knowledge in the context of the soap-making process

These themes provide the basis for further interpretation in the discussion section. The themes range from learning difficulties, student-teacher strategies, to students' perspectives and prior knowledge related to green chemistry and the soap-making context.

Result and Discussion

Students' learning obstacles based on their experiences in learning green chemistry

The first theme explains students' learning obstacles based on their experiences in learning green chemistry, particularly during classroom activities. These experiences were drawn from their time in grade X. Some students stated that they did not clearly remember their experiences in learning green chemistry during classroom activities. The interview results indicate students' understanding of green chemistry is limited to the idea of converting toxic materials into greener ones. The following are the findings from one of the students' interviews regarding their learning experiences in green chemistry.

Researcher	:	Kamu pernah ga belajar green chemistry
Student	:	*Pernah*
Researcher	:	Di kelas?
Student	:	*Di kelas*
Researcher	:	Pengalamannya gimana belajar green chemistry?
Student	:	*Awal-awal kan bingung ya bener-bener baru pengenalan si kata itu terus setelah dipelajari lumayan oke sih*
Researcher	:	Emang green chemistry itu apa?
Student	:	*Green chemistry itu kaya mengubah sebuah limbah yang bahannya berbahan kimia itu menjadi bahan kimia yang lebih ramah lingkungan*
Researcher	:	Kalau prinsipnya tau?
Student	:	*Engga*
Researcher	:	Ada berapa tau?
Student	:	*Engga*
Researcher	:	Lupa ya?
Student	:	*Iya lupa*

Almost all the students stated the same answer, that they did not remember the principles of green chemistry, which suggest a limited understanding of the topic. This indicates that the understanding or concept of green chemistry was not effectively conveyed during classroom activities.

Based on the students' responses, their learning experience in chemistry or green chemistry at school mainly involved lectures using PowerPoint and whiteboard media. The instructional approach appeared to be teacher-centered, with discussions taking place only when initiated by students. This indicates that the learning process was mostly passive and did not encourage active student engagement. As a result, students had limited opportunities to explore and deepen their understanding of green chemistry concepts. The following are the findings from one of the students.

Researcher	:	Terus kalau pas belajar green chemistry waktu itu kan sama guru ya, metodenya apa tu?
P3	:	*Metodenya itu biasanya gurunya kalo ga di papan tulis, pake PPT*
Researcher	:	Oke jadi gurunya menerangkan, Student mendengarkan? Dibagi kelompok ga diskusi gitu
P3	:	*Kadang ada buat diskusi itu*
Researcher	:	Pas green chemistry?
P3	:	*Iya, lebih banyak menjelaskan karena biar kitanya juga sambil kaya, eh kitanya ngerti gitu*
Researcher	:	Berarti tidak praktikum ya
P3	:	*Tidak*
Researcher	:	Medianya apa?
P3	:	*PPT sama papan tulis*
Researcher	:	Ada media tambahan selain itu?
P3	:	*Engga*

Obstacles faced by students in learning green chemistry

The second theme describes students' obstacles that they faced in learning green chemistry. In this topic, students seem to not understand the concept of green chemistry well. According to the interviews from theme 1, students indicated partial knowledge about green chemistry, they believe that green chemistry is the process of converting toxic materials into greener ones. This indicates that the students truly did not understand the principles of green chemistry. The following are findings from one of the students regarding their understanding of the concept of chemistry.

Researcher	:	Waktu itu bingungnya di konsep yang kaya gimana atau misal ada gambar kamu bingung dimana?
L1	:	Waktu yang ada zat kimia gitu jadi si zat kimia berbahaya itu jadi diubah jadi estereton atau apa gitu ya aku lupa lagi nah itu tuh kaya bingung kok itu tuh bisa diubah jadi tidak bahaya lagi.
Researcher	:	Jadi lebih ke konsep prosesnya ya? Terus kamu bingungnya itu kenapa?
L1	:	Iya. Kaya yang bingung gitu kaya tiba tiba itu tuh kan awalnya berbahaya jadi tidak berbahaya gitu

One of the students mentioned that he was confused about the process of converting toxic materials into safe materials. This again indicates a limited understanding of the green chemistry topic.

Moreover, two of five students (P3 and L2) explained they were confused about how to classify toxic and non-toxic materials. This difficulty arises because students observed that in their daily lives, they often encounter various chemicals. As a result, they feel the need to pay attention to which chemicals are safe to use and which are not. However, this difficulty reflects a lack of deep understanding of the principles of green chemistry. The following are excerpts from the interview.

Researcher	:	Jadi masih belum paham, lanjut ya, adakah kesulitan saat kamu mempelajari green chemistry khususnya di kelas ya
P3	:	Kalau itu ada sih
Researcher	:	Konsep apa yang bikin bingung atau misalnya ada gambar itu bikin bingung ga gitu
P3	:	Lebih ke konsep yang kaya kan ada ga semua bahan kimia tuh berbahaya gitu ya terus ga semua bahan kimia itu bagus juga jadi kita tuh bingung apa bahan kimia yang bisa kita ubah atau bahan yang gabisa kita ubah
Researcher	:	Okey jadi bingungnya lebih ke bahaya atau ngga bahayanya ya
P3	:	Iya
Researcher	:	Kenapa sih kamu bisa kepikiran itu? Kenapa kamu menganggap itu sulit?
P3	:	Karena kalau dilihat dari lingkungan kita kan banyaknya si zat-zat kimianya bahkan dari semua yang kita pake pun ada bahan kimianya jadi kita tuh harus tetep merhatiin bahan kimia apa yang bis akita pake untuk kita dan ada yang gabisa.
Researcher	:	Jadi kamu lebih ke aware kan kita pake bahan kimia nih, masa kita pake yang berbahaya
P3	:	Iya gitu
Researcher	:	Apa yang membuat kamu mengalami kesulitan dalam konsep tersebut?
P3	:	Itu sih yang gabisa ngebedain

Strategies used by students and teachers to overcome green chemistry learning difficulties

Theme 3 describes strategies used by students and teachers to overcome difficulties in understanding green chemistry. The students attempted to overcome their learning difficulties by re-reading difficult materials, exploring further information on topics of interest, watching videos to aid their understanding, and seeking help from teachers or engaging in peer discussions.

Researc her	:	Terus kan waktu itu kamu mengalami tuh bingung terus bingung sulit tuh memahaminya, kamu melakukan apa supaya kamu tidak bingung lagi, upayanya apa
L1	:	*Mempelajari atau melihat sebuah video yang ada di internet jadi kaya oh ini tuh masih prosesnya jadi kaya biar tahu lagi.*
Researc her	:	Oh oke jadi kamu menggali lagi lebih dalam, research lagi jadi sehingga tau jawabannya seperti itu ya, prosesnya. Oke jadi tadi kamu sudah mencari informasi melalui video terus mendapatkan prosesnya, kemudian diskusi ga sama teman tentang video - video itu tentang kesulitan kamu?
L1	:	*Tidak, jadi cuman mandiri doang*
Researc her	:	Oh jadi sendiri aja gitu ya, oke, berarti kamu tidak melakukan diskusi. Tapi kamu pernah ga melakukan suatu diskusi tentang suatu materi green chemistry dengan teman?

L1	:	*Oh pernah tapi tidak di satu sekolah ini tapi sekolah lain karena saya punya temen sekolah lain juga jadi saya menanyakan tentang pembelajarn green chemistry, emang sekolah lain itu mempelajari materi itu dan saya menanyakan kepada teman saya gimana sih cara kita mengetahui apa itu green chemistry jadi teman saya pun menjelaskan apa itu green chemistry dan bagaimana kita cara menerapkan green chemistry itu.*

One of the students took the initiative to invite a friend from a different school to discuss the topic of green chemistry.

The teachers helped the students to overcome their learning difficulties. When students did not understand certain topics, they asked the teacher for clarification. The teacher responded by offering additional explanations, either through one-on-one support or by addressing the issue during class. Students stated that the teacher was highly supportive in helping them manage their academic challenges. Beyond giving explanations, a student responded that the teacher also assisted students by assigning additional tasks to enhance their understanding of the subject matter. Furthermore, real-life examples were provided to help students better comprehend the context of the lesson.

Researcher	:	Saat kesulitan dalam mempelajari green chemistry, guru itu membantu ga?
P3	:	*Pastinya membantu sih*
Researcher	:	Kamunya yang nanya atau gurunya yang langsung ngejelasin aja
P3	:	*Kalau guru yang kemarin itu harus kita yang nanya, baru nanti dijelasin lebih Panjang sama gurunya*
Researcher	:	Jadi guru itu membantu kalau misalkan kamu kesulitan
P3	:	*Iya*
Researcher	:	Tapi kamu waktu itu bertanya?
P3	:	*Bertanya*
Researcher	:	Bertanya dan dibantu ya
P3	:	*Iya*
Researcher	:	Cara guru membantu selain menjelaskan apalagi?
P3	:	*Ngasih contoh kaya ngasih contoh yang lebih mudah kita mengerti jadi dijelasin lagi dengan contoh di kehidupan langsungnya kaya gimana*
Researcher	:	Secara personal atau di depan kelas
P3	:	*Di depan kelas, tapi kalau emang ditanyainnya satu-satu itu personal*

The teacher's efforts in helping students to overcome their learning difficulties were commendable, including providing further explanations, assigning additional tasks, and offering real-life examples to support understanding. However, it would be more effective if the teacher implemented scaffolding strategies to assist students, such as asking guiding questions that lead students to discover the answer themselves. As Keiler (2018) suggests, the teacher should no longer act as the primary source of information, but rather serve as a facilitator, coach, and model problem-solver for students.

Students' opinions about PjBL

Theme 4 focuses on the students' perspective regarding project-based learning in class activities. The students claimed that they had never experienced project-based learning as an instructional method in chemistry class. Several students were unfamiliar with what project-learning is, so the researcher had to explain it first. After the explanation, some students recalled having done project-based learning, but in other subjects such as art.

The students believed that green chemistry would be well-suited to project-based learning (PjBL). They felt that learning green chemistry through PjBL would be more engaging and help them understand the material more easily, as it allows them to apply theoretical concepts in practice, create tangible products, and demonstrate concepts in a real-world context. Ultimately, this approach enhances understanding and makes the learning process more interesting and interactive compared to simply reading theoretical content.

Researcher	:	Kalau menurut kamu pembelajaran di green chemistry itu bisa ga menggunakan pembelajaran proyek?
P2	:	*Bisa sih soalnya dari yang aku baca kan tadi ada produk yang dihasilkan juga nah kalo misalkan buat proyek bakalan lebih seru juga karena dari aku sendiri lebih suka langsung kerja secara langsung.*
Researcher	:	Perlu ga di green chemistry?
P2	:	*Perlu sih soalnya kalo misalnya Cuma baca doang kan belum tentu ngerti banget terus kalo misalkan secara langsung sambil proyek itu dijelasin sambil kita ngerjain juga*
Researcher	:	Bakal menarik ga kira-kira?
P2	:	*Menarik banget sih bu, karena kitanya kerjanya langsung gitu nyata gitu sambil ngebuktiin bener ga sih tentang micro greens itu*

Many studies shown that the implementation of the project-based learning model can enhance various students skills and even increase their motivation to learn (Ubaidah & Loeis, 2022). Students agreed that learning through project-based learning would make the learning activities more enjoyable, as they would be directly engaged in solving real-world problems.

Students' learning obstacles based on their prior knowledge in the context of the soap-making process

Theme 5 discusses students' understanding of the context of soap-making. The focus of this study is the production of bar soap from used cooking oil. Therefore, the researcher asked students about their understanding of soap. Students responded that soap functions as a cleaning agent. However, they were not familiar with the main ingredients contained in soap.

Students also lacked understanding of the soap-making process. As a result, when the researcher asked about the impacts of soap production or usage, most students focused only on the waste produced by soap factories. None of them mentioned the issue of land expansion for palm oil plantations, even though palm oil is the primary raw material used in soap production.

Researcher	:	Apakah dampak dari pembuatan atau penggunaan sabun terhadap lingkungan?
P2	:	*Dampak bahayanya?*
Researcher	:	Iya
P2	:	*Kalau dari pembuatannya mungkin kan cara si pabrik itu buat ngeluarin limbahnya gimana, harus lebih diiniin lagi karena kalau misalkan dibuang sembarangan kan nanti malah jadi yang kena dampaknya lingkungan tu sama lingkungan sekitar hewan kaya gitu-gitu.*
Researcher	:	Jadi lebih ke bekas..
P2	:	*Bekas proses pembuatannya.*
Researcher	:	Kalau dari penggunaan sabun menurut kamu ada ga?
P2	:	*Kalau itu aku kurang ngerti*
Researcher	:	Jadi tidak ada maksudnya belum ada jawaban lagi?
P2	:	*Iya belum*

When the researcher asked about the connection between green chemistry and soap, students responded that there is a relationship between the two. They shared ideas about producing soap in a more environmentally friendly way. However, only a few mentioned that the main ingredients in soap could be substituted with natural materials or waste products that are no longer used.

Researcher	:	Menurutmu, jika kamu mendengar kata sabun adakah hubungannya dengan green chemistry?
P1	:	*Kayanya ada sih kalau misalkan sabun pengen kaya green chemistry kayanya bisa buat jadi sabun natural gitu pake minyak nabati sama perisa tumbuhan, yah kaya gitu lah kalo ga salah bisa kayanya*

Although students expressed such arguments, they were still unable to connect their ideas to the principles of green chemistry. The researcher assumed that their responses were likely based on information from social media, advertisements, or from peers who had already participated in the interview.

Students lacked knowledge about the raw materials used in soap and the soap-making process itself, which led to a limited understanding of the environmental impacts of soap usage. This suggests that they may not have received sufficient information through classroom instruction and instead relied on surface-level knowledge from media sources or advertisements, which often lack depth and accuracy.

Given this gap in understanding, the application of a project-based learning model centered on making bar soap from used cooking oil becomes highly relevant and important (Putri et al., 2024). Through this project, students would no longer be passive recipients of information but would be actively involved in the entire learning process. They would directly experience and understand how to choose raw materials, why used cooking oil is a viable option, the chemical process of saponification, and how to evaluate the environmental impact of their soap products compared to commercial ones. As a result, learning would become more contextual, in-depth, and meaningful (Guo et al., 2020).

Based on the interview analysis of five students across five themes, it was found that students experienced several learning obstacles during the learning process. One of the main challenges was difficulty in understanding green chemistry concepts, such as its fundamental principles. As a result, students tended to define green chemistry merely as the process of converting hazardous substances into environmentally friendly ones. Green chemistry is not simply about converting hazardous substances into safer products; rather, it focuses on preventing pollution and minimizing risks at the source by redesigning chemical products and processes. It is an approach that aims to reduce or eliminate the use and generation of hazardous substances. Green chemistry is guided by 12 fundamental principles, as shown in Table 1.

The findings revealed that students faced difficulties in understanding green chemistry concepts. These obstacles appeared to stem from ineffective instructional delivery, as the learning process was primarily teacher-centered. Students mainly listened to the teacher's explanations without actively engaging in the learning process, which led to difficulties in understanding the concepts.

According to Vygotsky theory (1934), the obstacle may indicate that the content lies beyond the students' Zone of Proximal Development (ZPD). The ZPD is the gap between what a student can do independently and what they can achieve with guidance. Obstacles often occur when the tasks are too easy that cause boredom or too difficult, that cause frustration (Chaiklin, 2003). The ZPD can be effectively supported through appropriate scaffolding provided by teachers or more capable peers (Daniels, 2016). Teachers can use concept mapping for meaningful learning (Novak, 1990). Concept mapping helps students visualize relationships between ideas, making it easier to anchor new knowledge to what they already know (Novak, 1990). This reduces misunderstandings and helps prevent rote memorization, a common learning obstacle (Horton et al., 1993; Machin et al., 2004).

Conclusion

In conclusion, the findings reveal that students face significant challenges in understanding green chemistry due to limited classroom engagement and teacher-centered instruction. These learning barriers hinder students from connecting theoretical concepts to real-life applications. Therefore, implementing a project-based learning approach such as making bar soap from used cooking oil offers a relevant and meaningful solution. This method promotes active student participation, deeper conceptual understanding, and contextual learning aligned with the principles of green chemistry. This study suggests further implications for teachers to emphasize more adaptive teaching strategies that are responsive to students' difficulties. Instruction should go beyond content delivery and aim to identify and address learning challenges early in the process. This highlights the importance of implementing scaffolding-based approaches and formative assessments to support students in reaching their Zone of Proximal Development (ZPD). In addition, incorporating inquiry-based instruction can further enhance students' engagement and conceptual understanding by encouraging them to explore, question, and construct knowledge actively. Through guided inquiry, students are provided with meaningful learning experiences that connect prior knowledge with new concepts, which are essential for overcoming learning obstacles in science education.

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Author Contributions
For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, X.X. and Y.Y.; methodology, X.X.; software, X.X.; validation, X.X., Y.Y. and Z.Z.; formal analysis, X.X.; investigation, X.X.; resources, X.X.; data curation, X.X.; writing—original draft preparation, X.X.; writing—review and editing, X.X.; visualization, X.X.; supervision, X.X.; project administration, X.X.; funding acquisition, Y.Y. All authors have read and agreed to the published version of the manuscript." Please turn to the CRediT taxonomy for the term explanation. Authorship must be limited to those who have contributed substantially to the work reported.

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