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Exploring Learning Obstacles of Senior High School Students in Green Chemistry on the Topic of Biodegradable Plastic

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ABSTRACT

Purpose – This research aims to identify the learning obstacles experienced by senior high school students in studying green chemistry.

Methodology – This study used a qualitative descriptive design with a learning obstacle analysis approach. Data were collected through in-depth interviews with students at a senior high school in Indonesia. The interview guideline covered several themes, including student learning experiences, conceptual understanding, learning methods, and the obstacles that students faced in applying green chemistry to everyday life. The collected data was then analyzed and categorized to identify any obstacles encountered.

Findings – The results indicate that students' primary obstacles are epistemological, including limited prior knowledge, a superficial understanding of Green Chemistry principles, and difficulties in applying these concepts to real-life contexts. Students rarely experience project-based learning and mainly rely on rote learning and repeated explanations from teachers, which do not fully resolve their conceptual gaps.

Contribution – This study highlights the use of lesson design that provides more interactive and contextual learning, helping students connect chemistry learning in green chemistry with everyday practices. This research also provides insights for teachers in designing effective learning by anticipating students' learning obstacles, thereby supporting the realization of sustainable chemistry education.

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INTRODUCTION

Education is one of the main pillars of human civilization, a continuous process that shapes both individuals and society. Furthermore, in developing quality human resources, education plays a crucial role through various disciplines as an effort to improve the achievement of the Sustainable Development Goals (SDGs) (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2020; Urata et al., 2023). According to Sorooshian (2024), the United Nations has established 17 global goals to be achieved by 2030 as part of its 2030 Agenda for Sustainable Development. Education may cause, enable, or even equip the community to raise awareness, concern, or take action towards sustainability (García-González et al., 2020; UNESCO, 2017). Through accomplishing these goals, sustainability is undoubtedly expected to be attained. As a result, the concept of Education for Sustainable Development (ESD) emerged, which seeks to incorporate environmental, social, and economic issues equally into the learning process (Prabawani, 2021). School children learn how to live sustainably through ESD, i.e., education for sustainable development. Thus, it can help to enhance more contextual and more effective learning (Firdaus & Kamaruddin, 2025; Vioreza et al., 2023).

Building on the idea of integrating sustainability into education, science education has excellent potential to link scientific concepts with sustainable practices, because it equips students with scientific concepts and awareness of environmental issues (Fajarwati et al., 2025). Science education, especially chemistry, plays a crucial role in understanding the changes in matter and its applications in everyday life (Artini & Wijaya, 2020; Priliyanti et al., 2021). Green chemistry is an approach to chemistry that aligns with the concept of Education for Sustainable Development (ESD). The goal of this approach is to design more effective and efficient chemical processes that minimize the potential health and environmental hazards posed by the processes and their products (Anastas & Warner, 1998; Venkatesan et al., 2024). This approach enables students to connect chemical concepts with real-world phenomena, thereby enhancing their understanding of the context in which they learn (Septiana, 2023).

One context that relates to everyday life problems is plastic. Excessive use of plastic in everyday life has a negative impact, resulting in the accumulation of plastic waste. Plastic waste takes hundreds to thousands of years to decompose naturally in the soil. As a result, plastic poses significant environmental and health problems (Jiang et al., 2020; Kumar et al., 2021). One alternative solution to address this problem is to develop environmentally friendly plastic technology, or biodegradable plastic (Baiti et al., 2024). Integrating this topic into chemistry education can help students connect chemical concepts through the reactions that occur with real-life problems they face. In this way, education can encourage environmental awareness in students.

However, the implementation of chemistry learning that integrates Green Chemistry principles at both secondary and higher education levels still faces various challenges. These problems often arise due to learning obstacles that disrupt the learning process, resulting in suboptimal learning outcomes. Brousseau (in Sukeimi, 2022) divides student learning barriers into three categories: ontogenic barriers related to students' mental readiness to learn, didactic barriers related to teachers' teaching methods, and epistemological barriers related to students' limited knowledge. Therefore, this study is crucial as it aims to identify the specific learning obstacles that students face when learning about Green Chemistry, particularly in the context of biodegradable plastics. The novelty of this research lies in uncovering these specific learning obstacles, which remain understudied despite their recognized importance (Baiti et al., 2024). This data is beneficial for predicting students' responses and can provide insight for developing targeted and effective didactic strategies to improve Green Chemistry education (Suryadi, 2019).

Based on this explanation, it was concluded that, at present, students' chemistry learning in the classroom still encounters various problems that can hinder them from achieving their learning objectives. Students often encounter obstacles that are unrecognized, prompting teachers to develop learning strategies that are insufficient in regularly addressing learners' learning difficulties in chemistry. Therefore, this study aims to deeply identify the learning obstacles that students face in chemistry learning within the context of Green Chemistry, particularly concerning the topic of Biodegradable Plastic. The findings will serve as the basis for designing didactical strategies.

METHODOLOGY

Research Design

This study uses a descriptive qualitative research method. This method was chosen to provide a comprehensive overview or explanation of a phenomenon experienced by an individual or group using easily understood language (Sandelowski, 2000). This method is flexible, allowing for the use of various theoretical studies, sampling techniques, and data collection methods. In line with this explanation, the qualitative research method employed in this study is a case study, which facilitates the researcher's investigation process by utilizing various data sources (Creswell, 2014). The strength of this approach lies in its contextual nature, enabling the production of detailed descriptions of a phenomenon, the development of possible explanations for it, or the evaluation of the phenomenon (Gall et al., 2003). The use of qualitative methods is to gain an in-depth understanding of the obstacles students face in learning Green Chemistry. The stages in this study follow the steps commonly used in qualitative approaches, as shown in Figure 1.

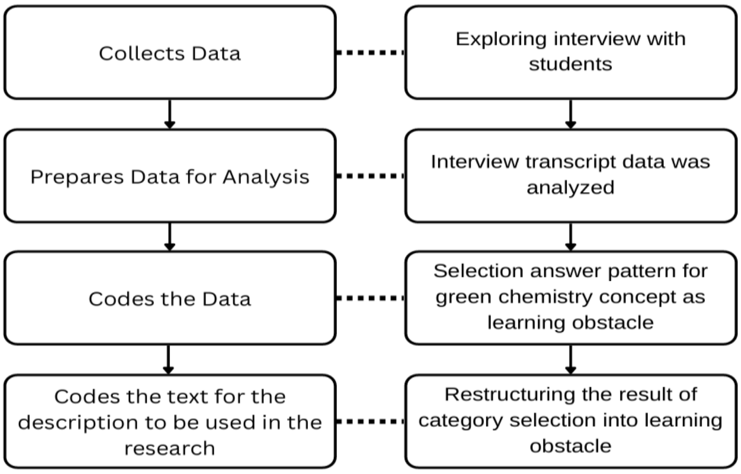

Figure 1. Research Stages

Participant

The participants involved in this study were five eleventh-grade students from a senior high school in Bandung who had already learned Green Chemistry. Participants in this study were selected using purposive sampling. Students selected included those with high, medium, and low abilities. This selection was made to ensure that the students' experiences were relevant and could provide meaningful information for the study.

Data Collection

Data was collected using semi-structured interviews based on an interview guide. This guide contains general questions organized into five main themes, presented in sequence. These themes covered:

Table 1. Themes of the General Questions

No	Themes
1	Students' learning obstacles based on their experiences in learning green chemistry
2	Students' learning obstacles in green chemistry
3	Strategies used by students and teachers to overcome green chemistry learning difficulties
4	Students' opinions about PjBL (Project-Based Learning) and its application to Green Chemistry
5	Students' learning obstacles in the context of biodegradable plastic production and its relationship to the principles of Green Chemistry.

Instrument

The primary instrument used in this study was a semi-structured interview guide. All interviews were conducted in person and were audio-recorded with the participant's consent. Each interview was held individually to allow participants to express their thoughts freely. The categories and numbering of the interview questions are presented in Table 2**.**

Table 2. Categories of Questions on The Interview Sheet

Categories	Question Number
Students' learning obstacles based on their experiences in learning green chemistry	1 – 4
Students' learning obstacles in green chemistry	5 – 7
Strategies used by students and teachers to overcome green chemistry learning difficulties	8 – 10
Students' opinions about PjBL and its application to Green Chemistry as a Solution.	11 – 14
Students' learning obstacles based on the context of biodegradable plastic production and its relationship with Green Chemistry principles.	15 - 22

Data Analysis

Subsequently, a learning obstacle analysis was conducted based on students' responses during the interviews. The interview data were first transcribed verbatim and then read repeatedly to familiarize the researchers with the content. Next, the data were coded to identify recurring themes and patterns related to students' conceptual understanding and the difficulties they encountered in Green Chemistry. These codes were then categorized into broader themes representing specific types of learning obstacles. In-depth discussions were conducted to refine these categories and ensure they were consistently interpreted. The findings from this analysis served as the basis for formulating didactic anticipations in the lesson design.

FINDINGS

The present study aims to explore the learning obstacles experienced by senior high school students when studying green chemistry. Understanding the barriers students face can help in designing context-based and effective learning programs that connect chemistry content to sustainability problems. Student barriers to learning can be identified by evaluating their prior knowledge and understanding of the subject matter. Consistent with Piaget's constructivist approach, student knowledge is gained not by passively receiving it, but by actively constructing their own understanding through interacting with experiences and reflecting upon them. Thus, to facilitate students' learning of green chemistry concepts, they need to associate new information with their prior knowledge (Nugraha & Herdiana, 2024).

Students' Learning Obstacles Based on Their Experiences in Learning Green Chemistry

The interview results with eleventh-grade students were analyzed for each question category to obtain information about the factors affecting students' understanding of Green Chemistry. The interview questions were grouped into five primary themes. The first category focuses on learning barriers experienced by students based on their experiences in learning green chemistry. Students were asked four questions related to their experiences, perceptions, and initial understanding of green chemistry. Furthermore, this category also aimed to identify the learning methods and teaching media commonly used by teachers during lessons. The students' responses for Category 1 are presented in Table 3.

The results indicate that most students have limited and inconsistent experiences in learning Green Chemistry. Although some students were introduced to the topic in grade 10, this was mainly through basic explanations without further elaboration, practical activities, or project-based tasks. Others did not clearly recall teaching it at all. These findings suggest that chemistry learning in green chemistry remains uneven and lacks standardization across classes, due to various factors, including limited learning methods and media. Additionally, students reported that they did not actually utilize any interactive learning methods, such as lab work, group discussions, or independent study. Effective learning should facilitate active student engagement, thus promoting meaningful and contextual learning (Sinaga & Silaban, 2020). The lack of variety in teaching methods and practical activities means that students do not have enough opportunities to connect Green

Chemistry concepts with their real-life experiences. Limited and monotonous learning approaches can also reduce students' visual and cognitive engagement (Anisa & Yuliyanto, 2017).

Table 3. The Results of Interview Analysis of Question Category 1.

Interview Topics	Interview Result
Have you ever studied green chemistry?	Most students mentioned they had learned about Green Chemistry in grade 10. Additionally, one out of five students did not clearly recall studying it in 10th grade, but instead had only a general understanding of environmental protection gained from junior high school education.
Students' experience in learning green chemistry.	All of the students stated that their learning experience was not very memorable because the topic was only explained in a few meetings.
Teaching methods are typically used in Green Chemistry instruction.	4 out of 5 students reported that their primary teaching method was teacher-centered lectures and writing on the whiteboard. Some students mentioned the occasional use of PowerPoint.
Media or learning materials commonly used by teachers.	All students mentioned that the learning materials were mainly limited to textbooks and teacher explanations.

Students' Learning Obstacles in Green Chemistry

The findings in category 2 (shown in Table 3) indicate that students experience difficulties in learning Green Chemistry, both conceptually and practically. Green Chemistry is an approach that focuses on designing chemical processes and products to minimize hazards (Anastas & Warner, 1998). Understanding this approach is crucial for raising students' awareness of sustainable solutions that connect theory with practice. Despite its importance, interview data suggest that most students struggle to recall the fundamental concepts and principles of Green Chemistry. This suggests that students are encountering epistemic challenges in their learning. The current learning approach implemented in schools may not be effective in helping students build a strong conceptual understanding. The results of the students' responses in category two are shown in the following table.

Table 4. Results of Interview Analysis of Question Category 2

Interview Topics	Interview Result
Students' learning obstacles in green chemistry	Most of the students experienced difficulties in understanding Green Chemistry.
Which concepts are complex for you to understand? Who do you usually ask when you find it challenging to understand the material?	Four out of five cannot remember and explain basic principles, such as the twelve principles of Green Chemistry. They also struggle to relate abstract concepts to real-life examples because they lack experience with practical activities or projects related to this topic. They usually asked the teacher (4 students), discussed with friends (2 students), or searched for information on the internet (3 students).
Factors that Cause Students' Learning Obstacles in Green Chemistry.	All students stated that the teacher caused them difficulties, including infrequent class attendance, a lack of practical activities, monotonous teaching methods, and unfamiliarity with Green Chemistry concepts, which lacked concrete examples.

The results indicate that most students encountered difficulties in grasping the fundamental principles of Green Chemistry. However, interview results indicate that students encountered difficulties due to external factors, including the teacher's delivery of learning materials, peer influence, and ineffective learning (Muderawan et al., 2019a). These findings suggest that students need learning strategies that enable them to gain an understanding and apply green chemistry principles in real-world contexts. This can also be supported through the use of diverse learning media that can help students more easily grasp the terms and principles in the learning materials (Anisa & Yuliyanto, 2017). This strategy can not only help overcome epistemological barriers but also support the development of critical thinking and problem-solving skills oriented towards sustainability.

Strategies Used by Students and Teachers to Overcome Green Chemistry Learning Difficulties

Building on the previous findings, in the third category, three questions were posed to explore the strategies used by students and teachers to overcome learning obstacles in green chemistry. The aim was to identify students' independent efforts and the support provided by teachers. The results of the students' responses are shown in Table 5.

Table 5. Results of Interview Analysis of Question Category 3

Interview Topics	Interview Result
What efforts did you make to overcome the learning difficulties you faced? Did you discuss green chemistry with your friends?	Most students said they try to re-read textbooks, look for information on the internet, or ask the teacher for help. A few students mentioned that they discuss the material with friends when they find it difficult to understand.
Did your teacher help you with the difficulties you encountered?	Most students said the teacher helps by re-explaining the material or giving examples.
How did your teacher help you overcome these difficulties?	All of the students stated that the teacher usually answers questions individually or repeats the explanation.

Based on the results of interviews in Category 3 (shown in Table 5), it was found that most students had attempted to overcome their learning difficulties through methods such as re-reading books, searching the internet for information, or asking teachers directly. Students' efforts to overcome learning barriers demonstrate Self-regulated Learning Skills. This skill enables students to plan and evaluate their own learning process (Zimmerman in Umairah & Dabi, 2023). However, teacher assistance is still needed to guide students in their exploration and provide scaffolding when the material is difficult to understand. Teacher assistance in the form of re-explanations is also necessary, but tends to be ineffective in the long term because it does not support students' active learning. Consequently, student learning barriers remain unresolved. This underlines the importance of exploring new and practical learning approaches. Therefore, teachers need to provide more diverse learning approaches that stimulate active student engagement, such as group discussions, simple experiments, or projects that facilitate understanding based on real-life experiences. Existing strategies, which often rely on repetition, should be enriched with more strategic and contextual methods to help students move beyond surface-level understanding and develop a deeper grasp of Green Chemistry concepts.

Students' Opinion about PjBL and Its Application to Green Chemistry as a Solution

The findings in the previous category suggest that current learning strategies do not fully support students in active learning and also fail to promote contextual learning. Consequently, learning is less effective in addressing students' conceptual difficulties. To address this problem, Project-Based Learning (PjBL) is one approach that can be implemented. Implementing PjBL enables more interactive and contextual learning through real-life projects (Luma et al., 2022). PjBL encourages students to apply concepts through hands-on activities and collaborative problem-solving, which can help reduce learning obstacles related to abstract and theoretical material (Almulla, 2020). Therefore, in the following category, four questions were posed to explore students' perspectives on the potential use of PjBL as an alternative strategy to make Green Chemistry learning more interesting and easier to apply in real-life contexts. The students' answers are shown in Table 6.

Table 6. Results of Interview Analysis of Question Category 4

Interview Topics	Interview Result
What did you know about Project-Based Learning (PjBL)? Have you ever done project-based learning at school? What is the biggest challenge you face when working with your classmates?	4 out of 5 students are not very familiar with the term "Project-Based Learning." However, they have experienced similar activities through P5 (*Projek Penguatan Profil Pelajar Pancasila*) as well as in subjects like art or social studies. The biggest challenges they face are dividing tasks fairly, managing their time effectively, and communicating clearly with their classmates.
What is your opinion about applying project-based learning in Green Chemistry?	Most students believe that project-based learning would be a practical approach for Green Chemistry because it makes the lessons more practical and meaningful.
In your opinion, does Green Chemistry need to be taught through project-based learning?	All students agreed that using project-based learning for Green Chemistry is important in helping them better understand the concepts and apply them in real-life situations.
Do you think this learning approach can make the topic more interesting and easier to understand? Please explain.	Most of the students explained that project-based learning can make Green Chemistry more interesting and easier to understand because they can work on real-world examples and collaborate with classmates, rather than just memorizing the theory.

The results show that students generally have a positive attitude toward using Project-Based Learning (PjBL) in Green Chemistry. Although students are not yet thoroughly familiar with the formal term "project-based learning", they have experienced similar activities through P5 (*Projek Penguatan Profil Pelajar Pancasila*) or other subjects. Most students agreed that PjBL can help them better understand concepts by allowing them to work on real-world examples and collaborate with classmates, rather than just memorizing theory. On the other hand, students also mentioned several obstacles they experienced when working in groups on project learning, such as difficulties in dividing tasks, managing time, and communicating. The data indicate that students have a good perception of PjBL as a contextual learning approach. However, it also highlights the need for additional support in addressing issues related to teamwork and time management. While PjBL can help students connect Green Chemistry concepts to real-world contexts, the outcome of such learning depends on students' understanding of the practical and conceptual aspects of the topic (Noberta & Noberta, 2024). To implement PjBL successfully, teachers provide clear instructions, structured guidance, and opportunities for collaboration and teamwork. Moreover, identifying what students understand regarding a particular aspect of sustainability is also significant, in addition to effective learning strategies related to Green Chemistry.

Students' Learning Obstacles Based on The Context of Biodegradable Plastic Production and Its Relationship with Green Chemistry Principles.

After examining the potential of PjBL in increasing student engagement and understanding in Category 4, eight questions were posed to explore students' learning obstacles in understanding the context of biodegradable plastic production and its relation to Green Chemistry principles. Therefore, in this category, students are presented with questions related to environmental issues, namely plastic waste. The analysis in this category is divided into two main themes: (1) students' basic understanding of plastic and its impact on the environment, and (2) the connection between biodegradable plastic production and the principles of Green Chemistry. The results of the analysis of students' responses on this theme are shown explicitly in Table 7.

Based on the results of the interviews on theme 1 (Table 9), students generally knew that plastic is widely used in everyday life and understood its benefits for packaging, storage, and household needs. They also realized that plastic waste is difficult to decompose and contributes to pollution in soil, water, and air. However, when students were asked about the raw materials used to make plastic, none of them could specifically name them. The result suggests that students have only a basic understanding of plastic. As per Shah et al. (2025), despite being a synthetic polymer, plastic is one of the most widely used materials due to its lightweight, durable, flexible, and malleable properties (Shah et al., 2025). However, most of the plastic used today is conventional plastic produced from petroleum and is non-biodegradable, resulting in persistent waste that poses a threat to ecosystems (Thakur et al., 2018). A clear understanding of the raw materials and production process of plastic is crucial, as it serves as the foundation for exploring more sustainable alternative materials.

Table 7. Results of Interview Analysis of Question Category 5 (Theme 1)

Interview Topics	Interview Result
Theme 1: Students' knowledge about plastic	
What do you know about plastic?	All students (5 students) know that plastic is a material that is often used in everyday life, but it is difficult to decompose and becomes waste that pollutes the environment.
What are the benefits of plastic?	Most students mentioned that plastic is suitable for packaging, storage, household items, and as an alternative to shopping bags.
What materials are commonly used to make plastic?	All students were unaware of the specific materials commonly used to produce plastic.
Are there any environmental impacts from producing or using plastic?	All students are aware that plastic has a detrimental impact on the environment. Most students (4 out of 5) mentioned that plastic is difficult to decompose and causes waste accumulation. Additionally, students noted that plastic can pollute soil, water, and air, and one student specifically mentioned the health risks from microplastics.

Students' limited understanding of the scientific aspects of plastic shows a gap between their everyday experiences and conceptual knowledge. To address this issue, students also need to consider scientific alternatives. In line with this discussion, Theme 2 addresses the context of biodegradable plastic production and its relationship with the principles of Green Chemistry, consisting of four questions. These questions aim to assess students' understanding of biodegradable plastic as a potential solution to the plastic waste problem. Based on the results, most students experienced significant obstacles, particularly in connecting practical ideas with theoretical Green Chemistry principles. The results of the analysis of students' responses on this theme are shown explicitly in Table 8.

Table 8. Results of Interview Analysis of Question Category 5 (Theme 2)

Interview Topics	Interview Result
Theme 2: The context of biodegradable plastic that supports Green Chemistry	
Do you think there is a connection between plastic and Green Chemistry?	Most students are aware of the connection, particularly in relation to environmental protection. One out of five students mentioned global warming and ozone depletion due to plastic waste accumulation.
If you were asked to make plastic, how would you make it more environmentally friendly?	Most of the students mentioned that plastic should be made from organic materials. 2 out of 5 students mentioned the use of food waste (such as cassava, sweet potatoes) so that it is easier to decompose. Additionally, some students mentioned the use of edible or water-soluble materials.
What should be considered when making eco-friendly plastic? Connect your answer with Green Chemistry principles!	Most students (4 out of 5) mentioned the need to pay attention to the selection of raw materials that contain minimal hazardous chemicals, which are easily decomposed in nature.
Do you think using eco-friendly plastic supports the principles of Green Chemistry?	Most students agreed, but some were unable to explain how the principles work in practice.

In Theme 1, the primary obstacles include a lack of detailed knowledge about raw materials and a limited ability to articulate how plastic production impacts the environment beyond basic facts. These challenges reveal gaps in both conceptual and contextual understanding. This gap becomes more pronounced when students are asked to consider alternative solutions, such as the production of more environmentally friendly plastics. In Theme 2, students struggle to connect practical ideas—like using organic materials—with the formal principles of Green Chemistry. Students often struggle to clarify these concepts and connect them to specific actions they take. They often refer to “less pollution”, but are unable to show how these principles are implemented in practice when producing.

The importance of context-based and practice-based learning strategies is evident from these findings, allowing students to connect abstract green chemistry concepts to their applications—for example, a project to produce biodegradable plastic from natural materials of renewable origin. Teachers should offer well-structured explanations, as well as practical activities and examples, to minimize learning barriers concerning the same. Overall, the findings of this study suggest that the learning barriers faced by students in Green Chemistry are complex and interconnected, with epistemological and didactic barriers being the predominant ones. These barriers are illustrated in the following diagram.

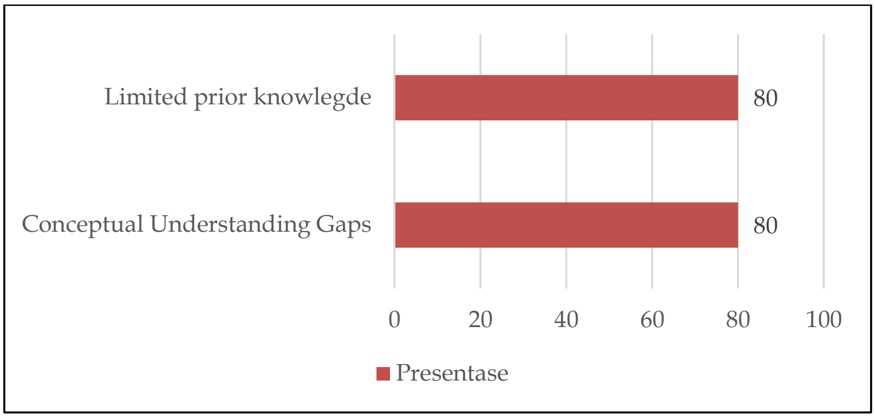

Figure 2. Peresentasion of the epistimologi obstacles in Green Chemistry

The obstacles experienced by students can arise from a lack of conceptual understanding, specifically a limited understanding of basic knowledge without a more profound mastery. In this study, the identified obstacles suggest a relationship in which epistemological and didactic obstacles can reinforce each other. The diagram shown above illustrates this relationship, where limitations in prior knowledge, abstract conceptual understanding, and inadequate contextual application can be exacerbated by ineffective teaching practices and a lack of student engagement. Consequently, these obstacles limit students' ability to apply Green Chemistry principles meaningfully, resulting in a lack of in-depth understanding, less honed problem-solving skills, and a lack of student awareness in addressing sustainability challenges through scientific inquiry. This situation suggests that students require a learning approach that can help them overcome these obstacles more effectively, enabling them to achieve their learning objectives.

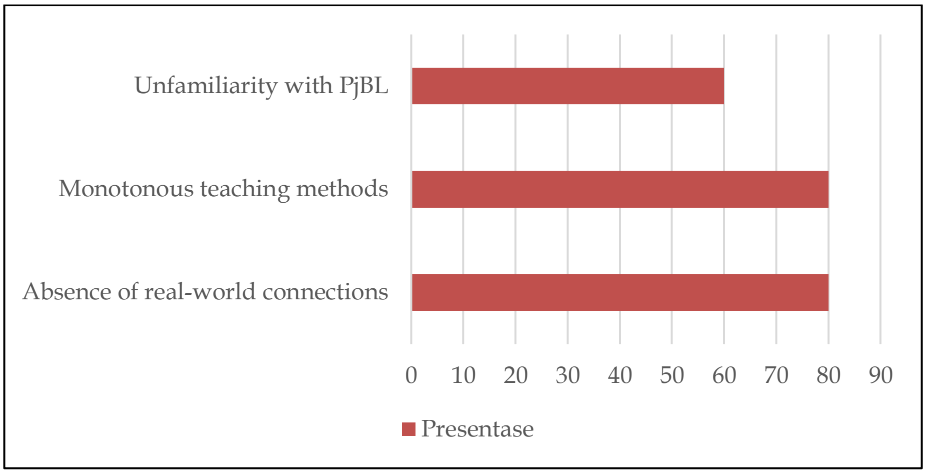

Figure 3. Peresentasion of the didactical obstacles in Green Chemistry

DISCUSSION

This study was conducted to identify the learning barriers faced by high school students in Green Chemistry, related explicitly to biodegradable plastics. Overall, the main findings of this study indicate the presence of didactic and epistemological barriers, which simultaneously hinder students' understanding. The findings of this study align with Brousseau's theory of learning barriers, which categorizes them into three types: ontogenic, didactic, and epistemological. Furthermore, the finding that students struggle to connect Green Chemistry principles to everyday life contexts, coupled with a lack of relevant practical learning experiences, reinforces the existence of these barriers. This pattern is consistent with previous studies, such as Muderawan et al. (2019b) and Sinaga & Silaban (2020), which also identified abstract chemical concepts as a significant challenge for students. The limited exposure to project-based or contextual learning revealed during interviews further supports the argument that passive learning approaches are ineffective for complex topics, such as Green Chemistry.

Building on these findings, the study provides a strong practical basis for improving chemistry learning design. The lack of project-based experience indicates the need to design learning units that integrate Green Chemistry principles with real-world problems, such as the issue of biodegradable plastics. Student-centered learning, for example, through a Project-Based Learning (PjBL) approach, can be a solution to overcome didactic and epistemological obstacles. The novelty of this study lies in mapping these interconnected obstacles specifically in the context of Green Chemistry and biodegradable plastics. This directly addresses the urgency outlined in the introduction—bridging the gap between students' theoretical knowledge and their ability to apply chemical concepts to sustainability issues. This study outlines the challenges that can inform the design of didactical anticipations and lesson plans based on contextual, collaborative, and project-based learning, aiming to overcome the identified challenges.

From a scientific perspective, this study offers a valuable case that enriches the understanding of learning barrier theory in modern sustainability-focused chemistry education. These findings show how didactical obstacles can directly trigger epistemological obstacles, contributing to a more detailed model of in-class interactions. In this case, the teacher plays a crucial role in directing the learning strategy to make it more effective and relevant (Khaerudin et al., 2023). Identifying the learning difficulties of students in the Green Chemistry topic, particularly in relation to biodegradable plastic, can serve as the basis for didactic anticipation and contextual lesson design. Suppose students' responses to a didactic situation are unexpected by the teacher (or incorrectly identified). In that case, the learning obstacle may remain unaddressed or even unnoticed, which can block the entire learning process, as data on learning barriers is crucial for identifying the difficulties students face and informing the design of learning.

In the long term, these insights provide a valuable foundation for developing lesson design and supporting teacher professional growth. They have the potential to foster more profound conceptual mastery, ecological awareness, and critical thinking—competencies essential for preparing students to address real-world sustainability challenges. Ultimately, this aligns with and advances the broader goals of Education for Sustainable Development, ensuring that chemistry education is both relevant to current environmental issues and effective in equipping students for the demands of the future. Therefore, data on learning obstacles is essential for better understanding students' difficulties and for serving as a basis for designing learning that effectively supports the achievement of learning goals.

CONCLUSION

This study reveals that senior high school students still face significant learning obstacles in understanding Green Chemistry, particularly regarding the topic of biodegradable plastics. These barriers are mostly epistemological in nature, manifesting as gaps in students' conceptual knowledge and their inability to connect theory and practice. Students lack in-depth knowledge, and their understanding is superficial. They may not have much opportunity to apply Green Chemistry principles. Students can be self-directed learners, but they may benefit from more structured guidance and varied teaching strategies to enhance their understanding. Therefore, addressing these obstacles requires innovative, contextual, and interactive learning designs that connect abstract concepts to practical applications. Teachers play a crucial role in this process by identifying students' learning obstacles and preparing didactic anticipations that can guide students to build stronger, more meaningful understanding. The findings of this preliminary study are expected to serve as a foundation for developing lesson designs that help teachers facilitate Green Chemistry learning more effectively, especially by integrating project-based learning and sustainability issues relevant to students' daily lives.

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