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Need analysis of green chemistry-based practicum guidelines incorporating local wisdom on redox topic

Haritsma ✉ [1], **Anti Kolonial Prodjosantoso**[2]

[1, 2] Department of Chemistry Education, Universitas Negeri Yogyakarta, Indonesia

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Abstract

Laboratory work in chemistry is crucial for students to develop their skills and enhance their understanding of chemical concepts. However, traditional laboratory methods often involve hazardous chemicals, posing risks to health and the environment. To address these concerns, integrating green chemistry principles and local wisdom into laboratory activities is necessary. This study explores the perspectives and needs of in-service chemistry teachers regarding practical work that incorporates green chemistry and local wisdom, specifically focusing on the redox topic. A qualitative approach was employed, using a semi-open-ended questionnaire to gather data from six in-service chemistry teachers. The questionnaire addressed six key aspects about practicum. The findings indicate that teachers recognize the importance of integrating green chemistry and local wisdom into practical activities, which enhances students' comprehension of chemistry concepts and promotes environmental sustainability and cultural appreciation. However, challenges such as limited resources, time constraints, and the need for appropriate materials remain. The study highlights the urgent need for developing laboratory instructions based on green chemistry and local wisdom, particularly for redox topics, to create a more relevant and effective chemistry education experience.

✉ Corresponding Author:
Haritsma
haritsma.2021@student.uny.ac.id

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INTRODUCTION

Laboratory work is essential to the study of chemistry (Ismawati et al., 2023). Through chemistry laboratory work, students actively develop their skills and reinforce their comprehension of chemical concepts and theories (Anatasya & Putra, 2024). It is important to link chemical theory with laboratory practice, even though it involves significant expenses for equipment and materials (Redhana et al., 2021). High school chemistry laboratory work in Indonesia is typically conducted in a conventional manner, adhering to procedures outlined in textbooks or modules. Many of these chemistry experiments employ chemicals that pose environmental hazards (Dewi & Listyarini, 2022; Lisyarini et al., 2019). In 2021, Redhana et al. conducted an analysis of three high school chemistry textbooks, revealing that these books utilize conventional or traditional laboratory methods. Traditional laboratory work involves the use of hazardous chemicals, such as NaOH, HCl, Na_2SO_4, $FeCl_3$, and $Pb(NO_3)_2$ (Redhana et al., 2021). This is inconsistent with environmentally friendly principles as chemistry laboratory work produces waste, including leftover chemicals, residual reagents, solvents, and harmful byproducts. Additionally, there are potential health risks within the laboratory for students, teachers, and staff (Dewi & Listyarini, 2022;

Lisyarini et al., 2019). Therefore, more environmentally sustainable methods for chemistry practical are needed.

Furthermore, to reduce the hazard posed by chemical laboratory waste to the environment and health, it is necessary to minimize the use of hazardous chemicals or substitute them with more sustainable alternatives. This necessitates the development of novel approaches to chemistry practicals, such as the implementation of green chemistry principles (Dewi & Listyarini, 2022). The purpose of the suggested green chemistry principles was to create cleaner processes, safer products, and greater use of renewable resources than fossil resources (Zuin et al., 2021). To achieve environmental sustainability and transformative learning, green chemistry becomes a viable strategy to integrated into chemistry learning, particularly within laboratory activities. The development of green chemistry-based practical experiment has been extensively conducted by researchers, particularly in chemistry topics such as equilibrium shift (Redhana & Suardana, 2021), rate reaction (Redhana, 2023), acid-base (Patmawati, 2021), electrochemistry (Fajriyati, 2023), and redox (Najahi, 2024). The topic of redox (reduction-oxidation) is one of the fundamental concept in chemistry that has wide applications in everyday life and industry, such as in batteries, corrosion, and metabolic processes (Ali et al., 2024; J. H. Clark et al., 2022; Jahan et al., 2024). A strong understanding of redox is essential for students (Tang et al., 2024). However, redox experiments frequently utilize harmfull chemicals or generate dangerous byproducts (Brown, 1971; Hancock, 2019; Redhana et al., 2021). Therefore, a more environmentally friendly approach is needed.

On the other hand, laboratory activities can also be integrated with local wisdom. To enhance chemistry education, incorporating local materials can effectively illustrate concepts like natural compound properties and reactions, teachers can connect theoretical knowledge to practical examples helping student understand the real word relevance of chemistry (Anzalina et al., 2024). Integrating local wisdom-based learning is important, as it can introduce and foster a knowledge for the surrounding environment. The learning process can be carried out using a scientific approach that includes activities such as observing, questioning, experimenting, reasoning, and communicating. In practice, local wisdom-based learning can be implemented through various media used in the learning process (Shufa, 2018). Furthermore, Shufa explained that in reality many teachers have not integrated local wisdom into learning process so that educational goals have not been achieved, in addition to not being familiar with local wisdom in their environment.

In practice, laboratory activities are inherently linked to the presence of practical guidelines (Bayim et al., 2022). Practical guidelines in chemistry are vital for ensuring both the effectiveness and safety of practical acivities conducted in the laboratory (Paterson, 2019; Wijayanti et al., 2023). Well- defined and comprehensive practical guidelines guarantee that every procedure is performed safely, reducing the likelihood of acciddents like chemical spills, fires, explosions, or injuries (Freese et al., 2024; Sudiana, 2022). Laboratory work in high school or intermediate chemistry entails significant cognitive challenges, highlighting the importance of clear and cohesive instructions for student success and safety. Well-structured guidelines assist students in handling their cognitive workload while promoting safe and precise laboratory practices (Paterson, 2019).

In recent years, both the topic of green chemistry and local wisdom in chemistry learning has attracted considerable interest from scholars and practitioners. Numerous studies have indicated that green chemistry and local wisdom are suitable for integrate in chemistry learning including laboratory activities, underscoring the necessity for a more comprehensive understanding of integration green chemistry and local wisdom in chemistry laboratory activities especially for redox topic. For example, a study conducted by Redhana et al. in 2021 revealed that the green chemistry teaching materials focused on reduction and oxidation reactions are crucial for development, demonstrating validity, practicality, and effectiveness in enhancing high school students' learning outcomes. These materials serve as an alternative to improve student performance. Moreover, research conducted by Redhana et al. in 2024 shows that integration of local culture into teaching materials helps students understand chemistry concepts better. However, despite the growing acknowledgement of the importance of green chemistry and the integration of local wisdom, currently many existing chemistry laboratory guidelines do not adequately address these two aspects, especially those concerning the topic of redox. These results lay the groundwork for the forthcoming research, which seeks to explore in-service chemistry teachers' perspectives and requirement for a green chemistry-based practical guideline incorporating local wisdom specifically focusing on redox topic. Teacher opinions and needs obtained from the exploration will be used as a basis for the development of a green chemistry-based practical work guideline, containing local wisdom, focusing on redox. This guideline is expected to be a learning resource for teachers and students in Indonesia, and to create laboratory work that is safer for the environment.

METHOD

This research study conducted during of the second semester of the 2024/2025 academic year. This section outlines the methods used to conduct the research.

Type and Design of the Research

This research used qualitative approach of exploratory survey. In this study, there are no experimental interventions provided to the research participants. The focus of this research is to explore the perceptions and the needs of in-service chemistry teachers regarding green chemistry-based practical work integrated with local wisdom on the topic of redox reaction.

Participants and Context of the Research

A number of 6 in-service high school chemistry teachers from 4 national high school in Bantul regency Indonesia was selected as participants for this research using purposive sampling. All participants held at least a bachelor's degree in education, which is a requirement for becoming a chemistry teacher. The chemistry curriculum is taught over the three years of high school, resulting in a diverse range of teaching experiences among the in-service high school chemistry teachers. Additionally, the participants varied in term of gender, participation in Teachers' Professional Development Program (TPDP), age, and length of teaching experience. The demographic characteristics of the participants are presented in Table 1.

Table 1. The demographic data of the research participants

Demographic Data	Frequency	Pencentages (%)
Gender		
Male	1	16,67
Female	5	83,33
Taken TPDP		
Yes	6	100
No	-	
Age		
< 25 years old	-	
25-35 years old	1	16,67
35-45 years old	2	33,33
> 45 years	3	50
Teaching Experience		
1-10 years	1	16,67
11-20 years	2	33,33
> 20 years	3	50
Teaching grade		
X and XI	1	16,67
X and XII	1	16,67
XI and XII	1	16,67
X, XI, and XII	3	50

The purpose of the persepectives and needs of in-service chemistry teachers concerning a practical guide that utilizes green chemistry principles and incorporates local wisdom particularly in the context of redox reactions. The insights gathered from teachers will inform the development of a practical work guideline that emphasizes green chemistry, incorporates local knowledge, and centers on redox concepts.

Data Collection Technique and Instrument

The research gathered data on in-service chemistry teachers' views and requirement for a green chemistry-based practical guideline that incorporates local wisdom related to the redox topic. This was achieved through a semi-open-ended questionnaire designed to assess teachers' perspective and requirement for a green chemistry-based practical. The questionnaire was created to examine the views and needs of in-service chemistry teachers regarding a green chemistry-based practical guideline that integrates local wisdom on the redox topic. It addresses six key areas or aspects: (1) teaching methods, (2) implementation of practical work, (3) topics of practical activities, (4) challenges faced during practical sessions, (5) guidelines for conducting practical work, and (6) the overall need for practical guidelines. These aspects were identified from existing literature (Arini & Darmayanti, 2022; Laili & Fardhani, 2023) and subsequently developed into 19 questions. To ensure the quality of the data collected in this research, the developed questionnaire underwent a validation process conducted by expert in chemistry learning. See the Table 2 for the instrument grid of questionnaire used in this research.

Table 2. Instrument grid

Aspect	Indicator	Question Number
Teaching methods	Chemistry learning methods	Q1
	The importance of chemistry lab works	Q2
	The effectiveness of chemistry lab works	Q3
Implementation of practical work	Laboratory facilities to support chemistry lab works	Q4
	Frequency of chemistry practical activities	Q5
	Management of chemical laboratory waste	Q6
Topic of practical activities	Chemistry lab works on redox topic	Q7
	Green chemistry on chemistry lab works	Q8, Q9
	Chemistry learning contains local wisdom	Q10
Challenges faced during practical sessions	Chemistry practical constraints	Q11
	Constraints on chemical practicums on redox material	Q12
	Constraints of green chemistry-based chemistry practicums	Q13
Guidelines for conducting practical work	Use of practical instructions	Q14
	Criteria and characteristics of green chemistry practical instructions	Q15
	The need for chemical theoretical in practical instructions	Q16
	Confidence in green chemistry-based practical instructions	Q17
The overall need for practical guidance	The need for green chemistry-based practical instructions containing local wisdom	Q18
	Development suggestions and recommendations	Q19

Data Analysis

Following of Milles and Huberman, the qualitative data analysis was conducted iteratively, involving data reduction, data display, and verification. This research utilized content analysis on a question-by-question basis, incorporating both inductive and interpretative coding methods. Each questionnaire question featured a different number of categories due to the diverse responses from in-service chemistry teachers. Therefore, the results included both frequency counts and the percentage for each category. To enrich the discussion of the findings, direct quotes from participations labelled T1 through T6 were included as illustrative examples.

FINDINGS AND DISCUSSION

This section outlines the findings and discussions of the research. A content analysis was conducted on each question across six aspects resulting in the following six aspects: (1) teaching methods, (2) implementation of practical work, (3) topic of practical work, (4) challenges in practical work, (5) guidelines for conducting practical work, and (6) the overall need for practical guidelines.

Learning methods

The questionnaire included three questions (Q1, Q2, and Q3) designed to examine the learning methods of in-service chemistry teachers. The Q1 specifically seeks to explore the teaching methods employed. The question directed at chemistry teachers was, "*What teaching methods do you usually apply in your chemistry classes?*" All participants reported that they utilize practical teaching methods in their chemistry instruction, indicating that they have all engaged in chemistry practical activities. Taber clarify while hands-on activities can be a valuable tool in chemistry education, their effectiveness varies depending on the subject matter. Experienced chemistry teachers understand how to strategically incorporate lab work to maximize its impact on student learning. When implemented thoughtfully and for the right reasons, practical experiments continue to be a vital component of chemistry classes (Taber, 2015).

Once the teaching methods used in the classroom were established, the Q2 aimed to assess the significance of practical teaching methods in chemistry learning. The question asked was, "*In your opinion, is the practical method important in chemistry learning? Please explain your reasons*!" All participants expressed agreement that practical methods are indeed important in chemistry learning. Subsequently, the responses from participants were categorized into groups such as better understanding, real experience, and improve skills. The findings of this analysis, along with the corresponding frequencies and percentages, are presented in Table 3.

Table 3. Answer to the Q2

Categories	Participants	Frequency	Percentage (%)
Better understanding	T1, T2, T4	3	37,50
Real experience	T2, T5, T6	3	37,50
Improve students' skills	T1, T6	2	25

Based on the categories in Table 3. there are several reasons regarding the importance of practical work in chemistry learning, namely better understanding, real experience, and improving students' skills. See some original expression of the participants below.

"*Practical work helps to better understand concepts and enhances skills and critical thinking abilities*" (T1)

"*Students receive hands-on learning and can understand concepts directly*" (T2)

"*Through practical work, students can try out what they have learned and perform tasks on their own, making it easier to remember when tested later (gaining meaningful experience)*" (T6)

Students generally favor lab activities as they offer valuable insights into chemistry and its practical relevance. These experiences help them develop a stronger conceptual understanding of chemistry's connection to the world around them (Harta et al., 2019). In addition, practical activities also provide direct or real experience for students. Practical work fosters active participation, giving students the opportunity to investigate concepts through direct experience, which strengthens their understanding and improves their ability to recall information (Clark, 2006). Practical activities offer students hands-on experiences that enhance their learning. These hands-on experiences are essential for developing competencies (Phi et al., 2019). Furthermore, chemistry practical activities significantly improve students' skills especially in areas such as critical thinking, collaboration, and science process skills (Ekaputra, 2024; Rahayu & Sardiana Sari, 2023).

Following this, the Q3 sought to determine which practical activities are effective in chemistry learning. The question directed at participants was, "*What kind of practical activities do you believe are effective in chemistry learning*?" The answers provided by the participants were categorized and analyzed, with the resulting frequencies and percentages displayed in Table 4.

Table 4. Answer to the Q3

Categories	Participants	Frequency	Percentage (%)
Contextual/related to daily life	T2, T4, T5, T6	4	40
Supports green chemistry	T2, T6	2	20
Supports the chemistry topics	T1, T6	2	20
Project activities	T3	1	10
Easy practical methods	T5	1	10

Based on the categories in Table 4, effective practicums according to participants include practicums that are contextual or related to everyday life. See the example of participants' original response toward Q3 below

"*Contextual practical work that minimizes the use of hazardous chemicals in accordance with green chemistry principles*" (T2)

"*Practical work that is easy to perform, using tools and materials related to everyday life*" (T5)

"*Practical work that uses tools and materials available in the school environment, utilizing natural materials and easily accessible resources that are relevant to the topic being studied*" (T6)

This type of practicum can help students see the relevance of chemistry around them, bridging the gap between abstract theories in class and real experiences (Supriatni, 2022). The support for green chemistry demonstrates an awareness of the importance of safe and environmentally friendly laboratory practices. It also reflects an understanding that chemistry learning is not only about concepts but also about environmental responsibility (Lestari et al., 2024). Next, supports the chemistry topics emphasizing on practical work that directly strengthens the understanding of the subject matter being discussed (Shana & Abulibdeh, 2020). Meanwhile, project activities imply a desire for project-oriented or problem-solving practicums where students can design and carry out their own experiments (Pratiwi & Ikhsan, 2024). The last category for the Q3 was easy practical methods which reflects the need for practicums that are not too complicated in their implementation, both in terms of tools and materials and procedures. This is also related to laboratory facilities in the implementation of chemical practicums.

Implementation of practical work

Following the examination of high school in-service chemistry teachers' perspectives on practical work teaching methods, the next discussion addresses to the implementation of chemistry practical work. Three questions: Q4, Q5, Q6 were asked regarding the execution of chemistry practical work, which included the existence of chemistry laboratories, the frequency of practical activities, and the management of laboratory waste. The Q4 aimed to assess whether schools have laboratory facilities to support practical activities. The question posed was, "*Does your school have a chemistry laboratory that facilitates the implementation of practical activities? If not, please describe your alternative for conducting practical work!*" The participants' responses were categorized into groups such as having a fully equipped and adequate laboratory, having a laboratory but lacking complete and sufficient facilities, and alternative methods for conducting practical activities if a laboratory is unavailable. The analysis results are shown in Table 5.

Table 5. Answers to the Q4

Categories	Participants	Frequency	Percentage (%)
Fully equipped and adequate	T1, T2, T3, T5	4	66,67
Lacking complete and sufficient facilities	T4, T6	2	33,33

Hereafter, the Q5 was intended to determine the frequency of practical activities conducted in one semester. The question in Q5 was, "*How often do you conduct chemistry practical activities in one semester?*" Participants' responses were categorized into several groups based on a range of 1 to 3 practical sessions and depending on the chemistry material being taught. The results of the analysis of participants' responses are presented in Table 6.

Table 6. Answers to Q5

Categories	Participants	Frequency	Percentage (%)
Range of 1 to 5 session	T1, T2, T5, T6	4	50
Depending on chemistry topic	T1, T3, T4, T6	4	50

The Q6 was intended to assess the management of waste during practical activities. The question in Q6 was, "*How is the management of chemistry practical waste in your school's laboratory?*" Participants responded regarding the condition of waste management in their school laboratories according to the provided categories. The categories in Q6 included the availability of acid cabinets or fume hoods, the presence of solid and liquid waste containment systems, the existence of waste treatment before disposal into the environment, waste being disposed of directly into the environment without treatment, and waste being disposed of directly because the materials used are easily decomposable or not harmful to the environment. Participants' responses are presented in Table 7.

Table 7. Answers to the Q6

Categories	Participants	Frequency	Percentage (%)
Availability of acids cabinets or fume hoods	T1, T2, T3, T4, T5	5	50
The presence of solid and liquid waste containment systems	T1, T2	2	20

Categories	Participants	Frequency	Percentage (%)
The existence of waste treatment before disposal into the environment	T6	1	10
Waste being disposed of directly because the materials used are easily decomposable or not harmful to the environment	T2, T4	2	20

Table 5. above shows a positive indicator that most schools have basic infrastructure that supports the implementation of chemistry practicum activities. The availability of a complete laboratory is crucial to ensure an optimal and safe learning experience for students (Hendratno et al., 2023). Furthermore, the frequency of practicum activities carried out in one semester is shown in Table 6 where this frequency is related to the potential for more practicums, the more waste is produced (de Raad et al., 2024). The reliance on the material taught reflects a more flexible and thematic approach, where practicums are integrated when certain topics do require experimental exploration for better understanding. See some original response of the participants towards Q5 below

"*In the Merdeka curriculum, practical sessions are becoming less frequent due to time constraints from the P5 project, resulting in only 1-3 practical sessions per semester*" (T2)

"*Adjusting learning objectives for certain concepts*" (T3)

"*3-5 times, depending on the material being discussed*" (T5)

Then, in Table 7. shows waste management with the following details the presence of fume hoods is very important to ensure adequate ventilation and handling of hazardous vapors or gases, thus increasing the safety of the practicum. However, there are still not many who have liquid and solid waste storage installations. This shows that although there are basic facilities, a more comprehensive waste management system and waste separation has not been implemented in all schools. There are participants who state that waste is directly disposed of into the environment and conversely there are participants who state that waste is disposed of directly because the materials used are easily decomposed or are not harmful to the environment (A'yuniah et al., 2022). Overall, these data highlight the need for increased awareness and facilities in the management of laboratory waste. Despite the existence of basic facilities such as fume hoods, systematic waste collection and treatment practices are far from ideal. This is a critical area that requires further attention to align with the principles of green chemistry and sustainability.

Topics of practical activities

After assessing the implementation of chemistry practical work in schools, four questions (Q7, Q8, Q9, Q10) were used to explore the topics of the practical activities. In this aspect, there are three main topics addressed: redox, green chemistry, and the incorporation of local wisdom in chemistry practical work. The Q7 aimed to determine the organization of practical activities related to redox materials. The question in Q7 was, "*Have you ever conducted chemistry practical activities on the topic of redox? If so, please select from the following themes of practical work that you have conducted*." The themes provided included metal corrosion, metal plating, redox reactions in combustion, redox reaction in batteries, redox reactions in photosynthesis, and others. Based on the participants' responses, it was found that T2 had never conducted redox practical work. The participants' answers regarding the themes of practical work they have organized are presented in Table 8.

Table 8. Answer to the Q7

Categories	Participants	Frequency	Percentage (%)
Metal corrosion	T1, T3, T4, T5, T6	5	29,41
Metal plating	T1, T3, T4, T5	4	23,53
Redox reaction in combustion	T5	1	5,88
Redox reaction in batteries	T1, T3, T4, T5	4	23,53
Electrolysis	T1	1	5,88
Dissolved metal	T5	1	5,88
Redox reaction in iodine and vit C	T5	1	5,88

Based on Table 8, the topic of metal corrosion is the most frequently conducted redox practicum theme by participants. This high frequency may be due to the relevance of corrosion topics in everyday life, the availability of easily obtained materials, and clear visualization of changes that are easy for students to observe. Corrosion practicums provide a good opportunity to discuss the concepts of oxidation, reduction, and the factors that influence them (Roberge, 2019). Then, the concept of electrochemistry, both in the context of metal plating and energy sources such as batteries, is also considered important and relevant to be taught through practical work. This practical work allows students to understand the application of redox principles in modern technology and how chemical energy can be converted into electrical energy or vice versa (Marohn et al., 2007). Some other redox lab themes show much lower frequencies, one of which is redox reaction in combustion. Although combustion is a very common example of a redox reaction in life, its lab may be less explored due to challenges in detailed observation or control of experimental conditions. As for the redox reaction in iodine and Vit C lab used in redox titration for quantitative analysis, which may require higher skills and precision.

The Q8 and Q9 were designed to investigate the topic of practical work concerning the principles of green chemistry. The Q8 specifically aimed to evaluate participants' understanding of green chemistry by examining the application of its principles, which include the use of safe chemicals, renewable resources, designs that are easily degradable, and waste prevention in chemistry practical activities. The question posed in Q8 was, "*Do you believe that the use of safe chemicals, renewable resources, easily degradable designs, and waste prevention should be implemented in school chemistry practical activities? Please explain your reasoning!*" All participants indicated that it is essential to apply green chemistry principles in chemistry practical work. The reasons given by participants were analyzed and categorized, as shown in Table 9.

Table 9. Answers to the Q8

Categories	Participants	Frequency	Percentage (%)
Supports green chemistry	T1	1	16,67
Safe for living things and the environment	T2, T4, T5, T6	4	66,66
Reduce costs	T5	1	16,67

The Q9 consisted of the question, "*Do you have experience using safe chemicals, renewable resources, easily degradable designs, and waste prevention in chemistry practical activities? If so, please describe that experience*!". This question aimed to gather information about participants' experiences in applying green chemistry principles during their chemistry practical work. According to the responses, all participants reported having experience in implementing green chemistry principles in their chemistry instruction. The practical experiences provided by the participants were analyzed and categorized, as shown in Table 10.

Table 10. Answers to the Q9

Categories	Participants	Frequency	Percentage (%)
Natural acid-base indicator	T1, T3, T4, T5	4	28,58
Reaction rate using natural materials	T1, T2, T3, T5	4	28,58
Voltaic cells using fruits	T1, T3	2	14,28
Utilization of biodegradable polymers	T6	1	7,14
Waste disposal according procedures	T6	1	7,14
Use of low levels of chemicals	T6	1	7,14
Use of water as a common solvent	T6	1	7,14

Overall, data from Q8 and Q9 indicate that secondary school chemistry teachers have a high awareness of the importance of green chemistry and have begun to integrate its principles into their labs. Based on Table 9, participants explained the importance of the principles in the questions related to laboratory activities, namely supporting the principles of green chemistry, being safe for living beings and the environment, and reducing costs. Green chemistry has a total of 12 principles, some of which are mentioned in question Q8. These principles of green chemistry include: prevention waste, atom economy, less hazard chemical syntheses, designing safer chemicals, safer solvent and auxiliaries, energy efficiency, use renewable feedstocks, reduce derivatives, catalysis, design for degradation, real-time analysis for pollution prevention, and inherently safer chemistry for accident prevention (Anastas & Eghbali, 2010). The next reason provided by participants in response to Q8 is that it is safe for living beings and the environment. This aligns with green chemistry, which focuses on designing chemical products and processes to reduce or eliminate the use and generation of hazardous substances (Anastas

& Warner, 1998). In addition to being safe for living beings and the environment, participants also provided the reason that the application of green chemistry helps in reducing costs. Green chemistry can help save expenses at the industrial, research, and educational levels, such as in schools (Adam et al., 2020). Moving to the Q9, the majority of teachers understand that green chemistry is important for safety and the environment. Their practical experiences, especially in the use of natural indicators and natural materials for reaction rates, indicate positive initiatives. However, there is still room for further development, especially in exploring other themes such as green synthesis, safer solvent use, and more comprehensive waste prevention strategies (Ain, 2024; Grossmann & Sora, 2013; Tomar & Jain Deepali, 2023). These efforts should be supported by innovative lab guidelines and ongoing training to strengthen the implementation of green chemistry in chemistry education in Indonesia.

The Q10 aimed to explore the incorporation of local wisdom into chemistry teaching. The question posed was, "*Do you believe that elements of local wisdom, such as the tradition of caring for heirloom metal objects (jamasan), batik dyeing, the tradition of chewing betel (menginang), and the process of silver craftsmanship, can be included in chemistry education? If yes, please explain your views on how this can be implemented*." All participants indicated that local wisdom, including the tradition of caring for heirloom metal objects (*jamasan*), batik dyeing, the tradition of chewing betel (*menginang*), and the process of silver craftsmanship, could indeed be integrated into chemistry education. The participants' opinions on the application of this local wisdom are presented in Table 11.

Table 11. Answers to the Q10

Categories	**Participants**	**Frequency**	**Percentage (%)**
Depending on the context of the material	T2, T4, T6	3	75
Using project learning model	T3	1	25

The results of the analysis in Table 11. show two main categories in integrating local wisdom. The category depending on the context of the material highlights the importance of the relevance and suitability between the chemistry concepts taught and the selected aspects of local wisdom. For example, the *jamasan* tradition (treatment of metal heirlooms) is very relevant to the topic of redox and corrosion, where students can learn the chemical reactions that occur during cleaning or re-coating of metals, as well as the principles of protection from corrosion (Swastikawati et al., 2012). Likewise, batik colouring can be linked to the concepts of organic chemistry, the properties of dyes, hydrogen bonds, and adsorption (Alamsyah, 2018; Handayani & Mualimin, 2013; Hidayat & Fatmawahty, 2014; Nuriana, 2021). While the betel nut tradition involves the acid-base and antioxidant reactions of betel and areca nut components (Nilamsari, 2021; Novianti & Khusniati, 2022). The silver craft process is closely related to the concepts of electrochemistry, metal properties, and oxidation-reduction reactions in the purification or formation of silver (Orlik & Galus, 2007). This contextual approach ensures that local wisdom is not only inserted artificially, but becomes an integral part that enriches students' conceptual understanding. Furthermore, the using project learning model categorie offers greater flexibility for students to explore local wisdom independently and in depth. In the context of PjBL, students can conduct research, experiments, and presentations on the chemical aspects behind local traditions (Arfida et al., 2024; Lubis et al., 2022). See some original participants' response toward the Q10 below

"*Yes, using the PjBL (Project-based Learning) method*" (T3)

"*Yes, its implementation is adjusted to the subject matter related to local wisdom*" (T4)

Challenges faced during practical sessions

The challenges of practical were asked in Q11, Q12, and Q13. The questions include obstacles when carrying out practicums at schools, when carrying out redox practicum, and when carrying out green chemistry practicums. The Q11 is *"What obstacles did you encounter when carrying out chemistry practical activities at school?*". Participants' answers are presented in the following Table 12.

Table 12. Answers to the Q11

Categories	**Participants**	**Frequency**	**Percentage (%)**
Limited practicum time	T2, T5	2	33,33
Limited tools and material	T3, T4, T6	3	50
Don't have laboratory assistant	T3	1	16,67

The participants' answers regarding Q12, namely "*What obstacles do you face when carrying out chemical practicums on redox material*?" are presented in Table 13 below.

Table 13. Answer to the Q12

Categories	Participants	Frequency	Percentage (%)
Limited practicum time	T2,	1	20
Limited tools and material	T3, T4	2	40
Students' understanding of material concepts	T5	1	20
Choosing a topic to be practiced	T6	1	20

Finally, the Q13 question is "*What obstacles do you face when implementing green chemistry principles such as the use of safe chemicals, renewable resources, easily degradable designs, and waste prevention in chemical practicum activities*?". Based on this question, there are several categories related to obstacles in implementing green chemistry-based practicums which are presented in Table 14 below.

Table 14. Answer to the Q13

Categories	Participants	Frequency	Percentage (%)
Haven't found a safer substitute chemical	T2, T4	2	40
Less varied	T5	1	20
Limited tools and material	T6	1	20
Relating practical material to the principles of green chemistry	T6	1	20

Overall, this analysis underlines that the main challenges in implementing chemistry labs in schools, including those based on green chemistry, are rooted in resource constraints: equipment, materials, time and difficulties in adapting curricula and teaching practices to more innovative and sustainable ones. Especially for green chemistry, the main issues are the identification and availability of safe substitute materials, as well as the development of a wider variety of labs.

Guidelines for conducting practical work

Questions Q14 to Q17 are aimed at understanding the use of lab instructions by in-service chemistry teachers. In Q14, there is the question, "*Have you ever used practical guidelines/lab instructions in the chemistry learning process? If so, did the instructions help in the lab activities*?" All participants have used lab instructions in their practical activities. Furthermore, number of 5 participants agreed that the presence of lab instructions can assist students during practical activities. This finding indicates that lab instructions are a standard and integral element in the implementation of laboratory activities in their schools. Additionally, all participants also agreed that lab instructions are very helpful for students during practical activities. See some original expression of the participants below.

"*Yes, lab instructions must be available during practical activities as a guide for students to conduct the experiments*" (T1)

"*Yes, lab instructions are very helpful and guide students in conducting practical activities*" (T2)

"*Yes, the presence of lab instructions makes it easier for students to work efficiently in terms of time*" (T6)

Next, in the Q15, the question is, "*What do you think are the criteria and characteristics of quality green chemistry-based lab instructions that meet the needs of students*?" This question aims to identify the criteria and characteristics of green chemistry-based lab instructions that are suitable for the needs of students. The responses from the participants can be seen in Table 15 below.

Table 15. Answer to the Q15

Categories	Participants	Frequency	Percentage (%)
Using environmentally friendly materials	T1, T2, T5	3	33,33
There were waste preventions	T1	1	11,11
Easy for students to access	T2	1	11,11
Simple	T3	1	11,11
Easy for students to understand	T4, T6	2	22,22
Can train students' collaboration and independence skills	T6	1	11,11

The most significant criteria highlighted by the majority of participants with a frequency is using environmentally friendly materials. It's embodies the essence of green chemistry principles, which aim to minimize the use and creation of hazardous substances (Anastas & Warner, 1998). Educators acknowledge that high-quality laboratory instructions should clearly guide the choice of reagents that are non-toxic, biodegradable, or sourced from renewable materials. This aligns with the belief that laboratory activities must be safe for both students and the environment, as previously mentioned in Q8. Additionally, the second criteria "there were waste prevention" noted by T1, emphasizes the importance of sustainability. Effective laboratory instructions not only prioritize safe materials but also instruct students on how to minimize waste, such as through micro-scale experiments or efficient experimental designs (Ratnani et al., 2019). Preventing waste at the source is a fundamental principle of green chemistry that reflects the comprehensive quality of the instructions. Two other crucial criteria pertain to pedagogical considerations and the student experience. The criteria "easy for students to understand" mentioned by T4 and T6 suggests that laboratory instructions should be articulated in clear and direct language appropriate for the students' cognitive levels. Complex or unclear instructions can impede learning and result in mistakes. Similarly, the criteria "easy for students to access" from T2 is vital, indicating that the instructions should be available in a practical format, whether printed or digital, allowing students to refer to them easily when necessary. The criteria "simple" mentioned by T3 further supports this idea, reflecting a preference for straightforward yet effective procedures. Ensuring that laboratory instructions are easy to understand and accessible is essential for fostering independent learning and decreasing students' dependence on teacher support during experiment. See some original expression towards Q15 below

"*Using environmentally friendly materials, efforts to reduce waste, procedures for disposing of practical waste, and instructions for using equipment or materials that support work safety*" (T1)

"*Using materials/equipment that apply green chemistry principles, paperless, accessible and easy for all students to use, including digitalization of experiment results and reports*" (T2)

"*An attractive design that is clear, easy to understand and practice, fosters collaboration and independent learning among students, aligns with the material being discussed, and results in meaningful learning experiences*" (T6)

Then, question Q16 is intended to gather participants' opinions regarding the inclusion of theoretical foundations in the lab instruction book. Q16 asks, "*Do you think it is necessary to include the theoretical basis of chemistry in the lab instructions?*" The opinions expressed by the participants are subsequently categorized in Table 16 below.

Table 16. Answer to the Q16

Categories	Participants	Frequency	Percentage (%)
Students can formulate hypotheses	T1	1	12,5
Helping students understand the material and practical work that will be carried out	T1, T2, T4, T5	4	50
So that there are no misconceptions	T3	1	12,5
As a scientific basis for material development	T5, T6	2	25

The most dominant category, chosen by 4 out of 6 participants is that the theoretical foundation is important for "helping students understand the material and practical work that will be carried out." This indicates that the majority of teachers view the theoretical foundation as an essential basis that enables students to connect abstract concepts with concrete activities in the laboratory. An initial understanding of the chemical principles behind an experiment will make the laboratory work more meaningful, rather than just following procedures without comprehension (Emda, 2014). With a theoretical foundation, students can anticipate outcomes, understand the reasoning behind each step, and interpret the data obtained more effectively. See some original participants response toward Q16 below.

"*Students can accurately formulate hypotheses and understand the concepts of the practical material*" (T1)

"*To avoid misconceptions*" (T3)

"*The theoretical foundation serves as the necessary knowledge base to understand and carry out laboratory work correctly and purposefully*" (T5)

Q17 is aimed at understanding the participants' beliefs regarding whether green chemistry-based lab instructions that incorporate local wisdom can enhance students' understanding. The question in Q17 is, "*Do you believe that green chemistry-based lab instructions that incorporate local wisdom can improve students'* *understanding of chemistry content, environmental sustainability, and local culture? Please explain your reasons*." From this question, all participants believe that green chemistry-based lab instructions can enhance students' understanding of chemistry content, environmental sustainability, and local culture. The reasons provided by the participants are categorized and presented in Table 17 below.

Table 17. Answer to the Q17

Categories	Participants	Frequency	Percentage (%)
Supports contextual chemistry	T1, T3, T4, T5	4	66,66
Engaging students in studying chemistry	T2	1	16,67
Facilitate the learning process	T6	1	16,67

The most dominant category expressed by for out of six participants is that the laboratory instructions support contextual chemistry. This perspective indicates the teachers' understanding that linking chemistry concepts to real-world contexts, whether through green chemistry principles or local wisdom, makes learning more relevant and easier to comprehend. Laboratory work that combines local traditions such as cleansing rituals or batik dyeing with green chemistry principles for example, the use of natural materials and waste prevention allows students to see the application of chemistry in their daily lives and their own culture (Arifin et al., 2024; Hidayat & Fatmawahty, 2014; Sarwono, 2020). This contextual approach not only deepens the understanding of chemistry concepts but also simultaneously instills awareness of environmental sustainability and appreciation for cultural heritage. The other two categories focus on involving students in the study of chemistry. Student engagement is essential for effective learning. Interactive laboratory experiences, particularly those that incorporate familiar materials from the local environment or traditional knowledge, can ignite students' curiosity and motivation (Haw et al., 2022). When students feel engaged, they are more inclined to participate actively and grasp the material more effectively. Furthermore, well-crafted laboratory instructions that blend green chemistry with local wisdom can enhance the learning experience. This indicates that such instructions help clarify complex concepts, offer a more tangible learning experience, and enable students to build their own understanding through hands-on exploration. This creative approach can render chemistry education more accessible and meaningful for students, aligning with the principles of constructivist learning.

The overall need for practical guidance

Questions Q18 and Q19 are aimed at understanding the overall needs for green chemistry-based lab instructions that incorporate local wisdom to be developed. Question Q18 is a closed question regarding the participants' needs, which asks, "*Do you believe that green chemistry-based lab instructions on redox chemistry that incorporate local wisdom are needed in schools*?" All participants responded that they need these lab instructions, and the percentage of their responses is presented in Table 18 below.

Table 18. Answer to the Q18

Categories	Participants	Frequency	Percentage (%)
Very needed	T1, T2, T6	3	50
Needed	T3, T4, T5	3	50

Question Q19 is aimed at soliciting suggestions and recommendations from participants regarding the development of green chemistry-based lab instructions that incorporate local wisdom on the topic of redox. The question is phrased as, "*What are your suggestions and recommendations for the development of green chemistry-based lab instructions on redox chemistry that incorporate local wisdom?*" The suggestions and recommendations provided by the participants are categorized and presented in Table 19 below.

Table 19. Answers to the Q19

Categories	Participants	Frequency	Percentage (%)
Clear and easy to understand	T1, T2, T4, T6	4	30,78
Meets green chemistry criteria	T1, T6	2	15,38
Digital based	T2, T3	2	15,38
Systematic and structured	T2, T5	2	15,38
Easy to implement	T3, T5, T6	3	23,08

In summary, the findings from Q18 and Q19 establish a solid basis for creating green chemistry laboratory instructions focused on the redox topic that incorporate local wisdom. The significant demand from teachers necessitates the development of guidelines that not only comply with green chemistry principles but are also straightforward, adaptable to different school environments, systematically organized, and suitable for digital formats. These types of instructions hold significant promise for transforming chemistry education into a more relevant, safe, effective, and meaningful experience for students, all while preserving cultural heritage and promoting environmental sustainability.

CONCLUSION AND SUGGESTIONS

The results of this research underscore the urgent necessity for creating laboratory instructions based on green chemistry that also incorporate local wisdom, especially regarding redox topics. The information gathered from in-service chemistry teachers shows a strong agreement on the significance of merging green chemistry principles with local wisdom in practical activities. Educators acknowledge that this integration not only improves students' comprehension of chemistry concepts but also promotes environmental sustainability and appreciation of cultural heritage. The study indicates that, despite the considerable demand for these guidelines, challenges remain, including limited resources, time constraints, and the need for appropriate materials. Creating practical guidelines based on green chemistry should focus on ensuring clarity, accessibility, and adherence to green chemistry principles to improve comprehension and implementation for both teachers and students. However, this research is constrained by a small sample size, comprising just six in-service chemistry teachers from four national high schools in Bantul Regency, Indonesia, which may not adequately reflect the varied perspectives and experiences of all chemistry educators in different areas.

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