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THE DEVELOPMENT OF GREEN CHEMISTRY TEACHING MATERIAL BASED ON ORGANIC COMPOUND SYNTHESIS

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Abstract: Green chemistry is currently included in 10th-grade chemistry in Indonesia's Merdeka curriculum. However, the learning implementation is still limited to the knowledge of approximately 12 principles of green chemistry, but its relevance to real-world applications is less discussed. The process of organic compound synthesis is a problem that is closely related to the application of green chemistry. This research aims to produce context-based green chemistry teaching materials for senior high school students on the basis of experiments using an ionic liquid and microwave-assisted organic synthesis (MAOS) method in the synthesis of an organic compound named dehydrozingerone (DHZ) from vanillin and acetone. The instructional material development method follows the Research & Development (RnD) method via a 4D model and includes the Define, Design, Develop, and Deliver stages. The guided-inquiry student worksheets developed in this research were tested in a classroom setting with 31 10th grade students from Al Ma'soem Senior High School in Bandung, West Java, Indonesia. The evaluation of the teaching materials received a positive response from the students, with a score of 78.29%, indicating a "good" classification. The findings of this study highlight the potential of these contextual teaching materials to enhance students' engagement and understanding in learning green chemistry concepts and applications.

Keywords: *Green Chemistry, Merdeka Curriculum, Ionic Liquid, Microwave Synthesis*

Abstrak: Kimia Hijau saat ini termasuk salah satu materi dalam mata pelajaran Kimia kelas 10 pada Kurikulum Merdeka di Indonesia. Namun pelaksanaan pembelajarannya saat ini masih terbatas pada pengetahuan tentang 12 prinsip kimia hijau sedangkan keterkaitannya dengan aplikasi di dunia nyata kurang dibahas. Dalam hal ini, proses sintesis senyawa organik merupakan permasalahan yang erat kaitannya dengan penerapan prinsip kimia hijau. Penelitian ini bertujuan untuk menghasilkan bahan ajar kimia hijau berbasis kontekstual untuk siswa SMA berdasarkan eksperimen menggunakan cairan ion dan metode *Microwave Assisted Organic Synthesis (MAOS)* dalam sintesis senyawa organik bernama Dehydrozingerone (DHZ) dari vanillin dan aseton. Metode pengembangan bahan ajar mengikuti metode *Research & Development (RnD)* dengan menggunakan model 4D meliputi tahap *Define, Design, Develop,* dan *Deliver*. Lembar kerja siswa inkuiri terbimbing dihasilkan pada penelitian ini kemudian diuji coba dalam proses pembelajaran di kelas dengan 31 responden siswa kelas 10

SMA Al-Ma'soem, Bandung Jawa Barat. Bahan ajar yang dikembangkan memperoleh respon penilaian siswa sebesar 78,29% yang tergolong baik. Umpan balik siswa dikumpulkan untuk perbaikan bahan ajar selanjutnya. Temuan dari studi ini menunjukkan potensi bahan ajar berbasis kontekstual yang dikembangkan pada penelitian ini untuk meningkatkan partisipasi peserta didik dan pemahamannya dalam pembelajaran konsep dan aplikasi kimia hijau.

Kata kunci: *Kimia Hijau, Kurikulum Merdeka, Cairan Ion, Sintesis Gelombang Mikro*

INTRODUCTION

In recent years, there has been a global shift toward incorporating sustainable practices into education, particularly in the sciences (Yildiz et. al., 2024). In Indonesia, this movement is reflected in the inclusion of green chemistry in the 10th grade chemistry curriculum under the Merdeka curriculum. Green chemistry, which focuses on designing products and processes that minimize environmental impact and enhance sustainability, is crucial in preparing students to address global challenges (Mamluaturrahmatika et. al., 2024). The current Indonesian curriculum aims to create a more dynamic and adaptable educational framework, equipping students with the skills to solve real-world problems and contributing to the Sustainable Development Goals (SDGs) by 2030 (Kemdikbud RI, 2022).

Green chemistry, also known as sustainable chemistry or environmentally benign chemistry, is a discipline that focuses on the design and development of chemical processes and products that minimize environmental impacts. It encompasses principles and practices that promote the efficient use of resources, reduce or eliminate hazardous substances, and prioritize the overall well-being of human health and the environment. The guiding frameworks for the design of new chemical products and processes are covered in 12 principles of green chemistry, including (1) prevention, (2) atom economy, (3) less hazardous chemical synthesis, (4) designing safer chemicals, (5) safe solvents and auxiliaries, (6) design for energy efficiency, (7) use of renewable feedstocks, (8) reducing derivatives, (9) catalysis, (10) design for degradation, (11) real-time analysis for pollution prevention, and (12) inherently safer chemistry for accident prevention (P. Anastas & Eghbali, 2010). The incorporation of the 12 principles of green chemistry into class materials and curricula is important for teaching sustainability and "green" approaches that work in real-life situations. Students will learn about problems with how industries currently work and be motivated to create solutions using green chemistry methods. Green chemistry education can provide knowledge and awareness to achieve the ultimate goal of a sustainable world (Anastas and Warner, 1998; Braun et al., 2006).

However, the implementation of green chemistry education in Indonesian schools has been limited. The existing curriculum's focus on theoretical knowledge without sufficient emphasis on practical applications presents a challenge for both teachers and students. Teachers often lack the resources and training to effectively integrate green chemistry principles into classroom instruction (Auliah et al., 2018). Consequently, students struggle to see the connection between green chemistry concepts and their practical implications, limiting their engagement and critical thinking skills (Mulyanti & Kadarohman, 2021). This disconnect can hinder students' ability to understand the relevance and importance of green chemistry in solving environmental issues.

This research addresses these challenges by developing innovative context-based green chemistry teaching materials on the basis of real-life organic synthesis problem-solving cases. The development of context-based teaching materials is crucial and is expected to enhance learning quality and meet curriculum needs(Mu'aziyah & Isnawati, 2023). Contextual-based teaching approaches aim to help teachers connect academic content with real-world situations and motivate students to link their knowledge with practical applications in real life (Muchtar, 2017). This study seeks to fill the gap in current green chemistry educational resources by offering a comprehensive practical and engaging approach to teaching green chemistry. This research aims to provide evidence of its potential to improve students' understanding and engagement.

The use of ionic liquids and the microwave assisted organic synthesis (MAOS) method has gained significant recognition in chemical research in both academia and industry. The utilization of ionic liquids and MAOS methods in organic synthesis has been recognized as a novel, green synthesis method (Rajak & Mishra, 2004; Ravichandran & Karthikeyan, 2011) with better results than traditional methods do (Hakala et al., 2009). Ionic liquids are referred to as green solvents because of their biodegradability, low vapor pressure and toxicity. It can also accelerate kinetic reactions and influence reaction pathways to increase reaction selectivity so that the formation of side products can be reduced (Singh & Savoy, 2020). microwave-assisted organic synthesis (MAOS) method is a synthesis method that utilizes microwave radiation. Microwaves have energy that can affect the rotational energy of molecules. When the rotational energy of a molecule is stronger, the molecule can move faster, and the activation energy is more easily achieved. As a result, the reaction time of MAOS can be faster than that of conventional synthesis methods (Nayak et al., 2016). The combination of ionic liquids and the MAOS method was then employed in the synthesis of dehydrozingerone (Pertiwi and Wahyuningrum, 2023).

Dehydrozingerone (DHZ), 4-(4-hydroxy-3-methoxyphenyl)-3-buten-2-one, is a natural compound that can be isolated from the rhizome of ginger (Zingiber officinale) and has attracted the attention of many researchers, especially in the field of medicinal chemistry due to its wide range of bioactivities, including antioxidant, anticancer, antimalarial, antidepressant, antifungal, and many others (Hampannavar et al., 2016; Mapoung et al., 2020). DHZ can be synthesized in the laboratory via the Claisen–Schmidt condensation of vanillin and acetone. However, the synthesis of DHZ can be challenging. At room temperature, the synthesis of DHZ requires 24–48 hours of reaction but only results in a low yield of the product (Abdelrahman, 2017; Hayun et al., 2018). Other experiments have utilized metal halides and reflux methods to accelerate the reaction, but these methods generate impurities after the reaction , necessitating the use of organic solvents for further purification steps (Ruiz et al., 2020) which results in more waste, is time-consuming, is inefficient, and tends to be unsafe for human health and the environment. Based on this issue, ionic liquids have become materials that offer solutions to current DHZ synthesis problems. Previously, ILs have been shown to function as both catalysts and solvents for the synthesis of chalcone resulting from the same type of reaction with DHZ, which is the Claisen–Schmidt reaction (Yadav & Wagh, 2020). The cross-aldol condensation synthesis can be optimized via the MAOS method to make it more efficient and eco-friendly (Handayani, Budimarwanti and Haryadi, 2017).

METHOD

Participants

The study involved 31 10th-grade students (15 males and 16 females) from Al-Ma'soem senior high school in Bandung, West Java, Indonesia.

Research Design

The research utilized the 4D Research & Development (RnD) model, developed by Thiagarajan (1974), which consists of four stages: define, design, develop, and disseminate. For this study, the process was limited to the development stage. The define stage involved identifying the need for green chemistry education and establishing the objective of the teaching materials. The design stage focused on creating a guided-inquiry student worksheet and supporting PowerPoint materials. The general concept design of the learning materials is illustrated in Figure 1. The development stage included the implementation of these materials in a classroom setting.

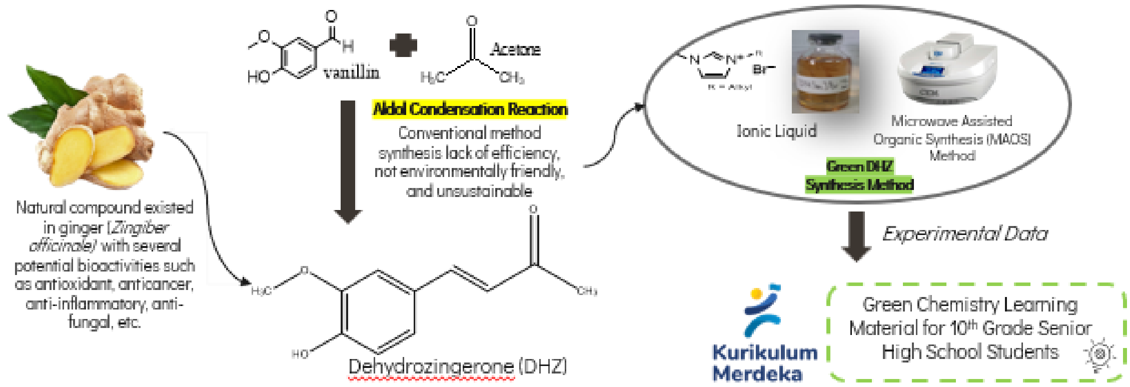

Figure 1. General Concept Design of Green Chemistry Teaching Material Development

Table 1. Questionnaire statements of the students' responses to the teaching materials

No	Statements
Material Aspects	
1	I find it difficult to understand the material
2	The problems presented are interesting to study
3	The presented material provides an overview of the application of green chemistry
4	The presented material motivates me to learn chemistry
5	The problems presented do not make me want to determine more
Language Aspects	
6	The language used in the modules is simple and easy to understand
7	The language used does not motivate me to learn
8	Materials and information conveyed in an interesting language
9	The teacher's explanation as facilitator helps me understand the text well
Constuction/graphic Aspects	
10	The overall appearance of the learning materials and media is attractive
11	The media presented cannot clarify the material
12	The modules and learning media displayed are boring

Instruments

The primary instruments used in this study were guided-inquiry student worksheets and a PowerPoint presentation, which served as supporting media during a 90-minute chemistry lesson. To assess students' attitudes and opinions regarding the teaching materials, a questionnaire consisted of statements designed to collect various aspects of students' engagement and understanding, which were measured via a Likert scale. The questionnaire statements are presented in Table 1.

Data Analysis

Data collected from the questionnaires were analyzed to determine the effectiveness of the teaching materials. The responses were quantified and classified according to a Likert scale to evaluate the students' attitudes and opinions. The results were then used to assess the overall responses of the materials, with particular attention given to their potential to enhance students' engagement with and understanding of green chemistry concepts.

The aspects in question are material aspects, language aspects, and construction/graphic aspects. There are 5 criteria, strongly agree (SA), agree (S), doubtful (D), disagree (D), and strongly disagree (SD) which are scored on the basis of the form statement. If the statement is a positive sentence, the score ranges from 5 to 1. Conversely, if the statement is negative, the score ranges from 1 to 5.

$$\%\ \text{response} = \frac{\text{observed score}}{\text{expected score}} \times 100\%$$

The questionnaire data were then processed quantitatively and interpreted on the basis of several response criteria in Table 2 (Riduwan & Anwar, 2008).

Table 2. Interpretation of student response questionnaire criteria

Response percentage	Criteria
0-20%	Very Less
21-40%	Not Enough
41-60%	Enough
61-80%	Very Good
81-100%	Excellence

RESULTS AND DISCUSSION

In this study, we developed a set of context-based green chemistry teaching materials designed for high school students, with a focus on the synthesis of organic compounds. The teaching materials are presented in Figure 2. The materials included guided-inquiry student worksheets and PowerPoint presentations, which were designed to introduce the principles of green chemistry and demonstrate their application through the synthesis of DHZ via ionic liquids and the microwave-assisted organic synthesis (MAOS) method.

Figure 2. The developed green chemistry teaching materials for 10th grade high school students

The introduction of green chemistry and the development of innovative teaching materials are necessary to meet curriculum requirements. Green chemistry teaching materials were previously developed for reduction and oxidation reactions and improved high school students' learning outcomes (Redhana et al., 2021).

The process of organic compound synthesis is a real-world example that requires the implementation of 12 green chemistry principles. Green chemistry principles help chemists overcome the problems of conventional synthesis such as slow reaction rates, unhealthy solvents, low yields of products, catalysts, long durations of reaction completion by developing green solvents, the use of microwave and ultrasonic radiations, the use of solvent-freecatalysts, the use of environmentally benign catalysts, etc. (Rubab et al., 2022).

The use of an ionic liquid and the MAOS method as an effort to solve problems found in the DHZ synthesis process can be used as a concrete example that can be introduced to senior high school students regarding the application of green chemistry principles. Ionic liquids, as multifunctional materials, can be studied by students as a context for the development of teaching materials at the senior high school level (Yulianti et al., 2020) and have the potential to increase students' chemical literacy (Hernani et al., 2017). The design of green chemistry teaching materials encourages students to have a higher level of awareness and practice of green chemistry applications. Therefore, teachers should empower students with appropriate coping mechanisms for sustainable environmental issues in the classroom or laboratory instruction to provide them with a better understanding of green chemistry applications (Taha et al., 2019). To support this, guided-inquiry can be used as learning models that involve student-centered interactive learning that can empower students' problem-solving (Palajukan et al., 2021) and critical thinking abilities (Nisa et al., 2018).

The use of an ionic liquid and the MAOS method in dehydrozingerone (DHZ) synthesis experiments improved the product results. The addition of 5% 1-decyl-3-methylimidazolium bromide ([DMIM]Br) ionic liquids and 3 hours of synthesis via microwave radiation affect the purity of the DHZ product compared with its traditional reaction, which takes 24–48 hours at room temperature with low yield products (Pertiwi & Wahyuningrum, 2023). DHZ itself is an interesting compound that can be synthesized from two relatively simple ingredients: vanillin and acetone. These two basic ingredients are two compounds that are familiar to students, so they are most likely interested learning.

Table 3. Detailed guided-inquiry learning steps and activities conducted during the lesson

Guided-Inquiry Model Learning Step
Opening (apperception and motivation)
▪ The teacher initiates the lesson and inquires about the students' prior knowledge regarding the 12 principles of green chemistry they have learned before. ▪ The teacher divide the students into 6 group and every group will be equipped with student worksheet and gadget or laptop with internet access to find information. ▪ Powerpoint as the supporting media will be presented by the teacher to guided the learning flow. ▪ To motivate the students, they played role as the Research & Development team that work in a pharmacy company that are trying to develop chemical drug that is DHZ. However, the current synthesis method is inefficient and relatively unsafe for their worker and the environment so they need to find a greener and safer synthesis method.
Orientation
▪ The teacher introduces the topic to be studied Students are asked to read the "orientation" section about the Dehydrozingerone Synthesis and background study in the student worksheet
Questioning
▪ The teacher assist students in formulating research questions related to the DHZ Synthesis phenomena. The expected problem formulation is closely to "how's the effect of using ionic liquid and MAOS method in DHZ synthesis process?" and "what principles of green chemistry fulfilled by the DHZ synthesis method utilized with ionic liquid and MAOS method?"
Data Collection (Investigation)
▪ Students are shown two videos of DHZ synthesis using different methods. Method A is DHZ conventional synthesis method video conducted by the Chemistry Lab, Eastern Kentucky University. Method B is the novel DHZ synthesis method utilizes [DMIM]Br ionic liquid and MAOS method conducted by the researchers in Bioorganic Laboratory Chemistry, Bandung Institute of Technology. ▪ Students gather information by comparing the two methods based on its reaction temperature, reaction time, yield product percentage, the quantity and ingredients hazards. ▪ Students are provided with DHZ synthesis experimental data. Students expected to observe the synthesis product results and write what they observed from the results. ▪ Students learn about simple analysis method, Thin Layer Chromatography (TLC), then observed the TLC results of DHZ synthesized product samples mediated by [DMIM]Br ionic liquid in various concentration.
Data Analysis (Investigation)
▪ Students analyze TLC spot in 7 different DHZ product that synthesized in various [DMIM]Br ionic liquid concentration. ▪ Students are introduced to the instruments used to analyze the structure of the samples. Students are expected to learn how scientists are able to determine the structure of any chemical compounds. ▪ Regarding their previous knowledge about the 12 principles of green chemistry, students are expected to analyze what green chemistry principles criteria fulfilled with the novel DHZ synthesis method and desribe the reason.
Conclusion
▪ The students draw conclusions related to the previous problem question regarding the influence of using ionic liquid and MAOS method on DHZ synthesis results and the Green Chemistry principles fulfilled by these methods.

The guided-inquiry learning model is used in this research as student-centered interactive learning (Llewellyn, 2014). The detailed inquiry-based learning and lesson plans are further described in Table 3. In guided-inquiry learning, students engage in experiments adhering to the steps of scientific discovery, collect and analyze data, and draw conclusions. This process allows them to acquire fresh knowledge and skills while addressing questions or solving problems (Pedaste et al., 2015). Previous research has shown that guided-inquiry based learning materials are effective in enhancing students' scientific literacy skills (Auliah, Muharram and Mulyadi, 2018).

The teaching simulation began with students' role-playing as a research and development (RnD) team in a pharmaceutical company to motivate and attract students' interest and engagement in learning green chemistry. This is confirmed by the results of questionnaire assessments (2), (3), and (4), which received "very good" score. In general students believe that the problems and cases presented concerning the utilization of ionic liquids and the MAOS method in DHZ synthesis are interesting to study (2), motivate them to study chemistry (3), and provide an overview of the application of green chemistry in real life (4). The use of ionic liquid materials in DHZ synthesis actually involves many potential chemical concepts that can be explored such as chemical bonds, chemical structure, chemical compound nomenclature, functional groups, stoichiometry, etc. (Hernani et al., 2016; Yulianti et al., 2020). However, the chemistry material topics for 10th-grade high school students with the Merdeka curriculum are still too basic. The general chemistry topics in the 10th-grade Merdeka curriculum are the atomic structure and its applications in nanotechnology, basic chemical laws, scientific work in explaining chemical concepts in everyday life, and the application of chemical concepts in environmental management (including green chemistry and Sustainable Development Goals 2030) (Kemendikbud RI, 2022). Thus, the developed teaching materials focus on highlighting the principles of green chemistry which are fulfilled by the synthesis of DHZ using an ionic liquid and the MAOS method.

In the learning process, students are asked to compare two synthesis methods from two different videos on the basis of the reaction temperature, time of reaction, yield percentage, and materials used in the synthesis process. The comparisons are presented in Table 4. The first video was the traditional DHZ synthesis method performed by the students in Chemistry Lab Eastern Kentucky University (2020) and the second video was the DHZ synthesis experimental video using an ionic liquid and the MAOS method. By comparing these two methods, students are expected to assess which methods are 'greener'. They are required to explore the material safety data sheets (MSDSs) and hazard labels of each material used to examine the safer chemical used in the synthesis process.

After students collect information and data related to the process of DHZ synthesis via the ionic liquid and MAOS methods compared with conventional methods, they are asked to analyze which green chemistry principles are fulfilled if DHZ synthesis is carried out via ionic liquids and the MAOS method. In general, the developed DHZ synthesis method fulfilled 9 of the 12 green chemistry principles. The 9 principles are prevention, atom economy, less hazardous chemical synthesis, designing safer chemicals, safer solvents and auxiliaries, energy efficiency, reducing derivatives, catalysis, and inherently safer chemistry. The reasons are included in the students' answers in the worksheet. A summary of the students' answers is presented in Table 6.

The developed green chemistry teaching material was tested on 31 10th-grade students in Al-Ma'soem senior high school. After the learning process is complete, the students are asked for feedback regarding the learning session simulation and the developed green chemistry student worksheet presented. An overview of the quantitative scores of the students' responses is presented in Table 5.

Table 4. Comparison of traditional and utilized DHZ synthesis methods with the MAOS method

Comparation	Traditional Method	Ionic Liquid + MAOS method
Temperature	Room temperature (25 ºC)	50 ºC
Time reaction	2 weeks	3 hours
Yield percentage	31%	50 – 75%
Materials	Vanillin, acetone, sodium hydroxide, hydrochloric acid, dichloromethane, water, sodium sulphate anhydrate	Vanillin, acetone, sodium hydroxide, hydrochloric acid, aquades, [DMIM]Br ionic liquid

Table 5. Results of questionnaire assessments of the green chemistry student worksheets and the learning trial

Number of Statement	Score	Criteria
Material Aspects		
1	65,16%	Good
2	92,25%	Very Good
3	87,74%	Very Good
4	81,93%	Very Good
5	64,51%	Good
Average	78,32%	Good
Language Aspects		
6	75,48%	Good
7	67,74%	Good
8	80,64%	Good
9	80%	Good
Average	78,71%	Good
Construction/Graphic Aspects		
10	80%	Good
11	80%	Good
12	72%	Good
Average	77,84%	Good

Table 6. Green chemistry principles fulfilled by the DHZ synthesis method with an ionic liquid and the MAOS method

No.	Green Chemistry Principles	Fulfilled Criteria		Reasons
		Yes	No	
1	Prevention	√		Synthesis DHZ using ionic liquid and MAOS method has shorter steps, does not require further purification processes, prevents organic solvent waste
2	Atom economy	√		Higher product yield percentage than the conventional method
3	Less hazardous chemical synthesis	√		Do not use the organic solvents for purification method
4	Designing safer chemical	√		Using nonvolatile solvents and catalyst (ionic liquid)
5	Safer solvents and auxiliaries	√		Using ionic liquid as its solvents
6	Energy efficiency	√		Shorter time reactions with only 3 hours of reactions in 50°C with MAOS method
7	Renewable feedstocks		√	
8	Reduce derivatives	√		Synthesized DHZ using ionic liquid generates pure product without impurities
9	Catalysis	√		Ionic liquid acted as catalyst
10	Design for degradation		√	
11	Real-time analysis for pollution prevention		√	
12	Inherently safer chemistry	√		Do not use volatile organic solvent

The questionnaire assessment conducted among 31 respondents revealed that the developed green chemistry student worksheets and the learning trial received scores of 78.20%, which were classified as ‘good’. Overall, the questionnaire assessment of the developed green chemistry teaching materials received 78.32% scores for material aspects, 78.71% for language aspects, and 77.84% for construction/graphic aspects, which were classified as good.

However, students still find the material presented to be difficult to understand, as shown by the 65.15% score in statement (1). This can be caused by several factors; although guided inquiry learning offers several benefits, there are few challenges following the implementation of this learning model, such as lack of time, lack of effective inquiry activities, pedagogical difficulties, management difficulties, large classes, the risk of student misconceptions, assessment issues, and material demands (Orosz et al., 2023). The challenges faced in this research include the many new vocabularies that students have never read or known before, the limited amount of chemistry concept material that has been studied by 10^{th}-grade students as respondents who use the Merdeka curriculum, and the limited time session lessons provided in the simulation learning process. These responses can be important for researchers to improve the teaching materials so that they can be easier for beginners to understand. Adjustments such as reducing the content can also be considered so that the students do not feel overwhelmed by receiving much information at once in a short time.

The development of green chemistry teaching materials utilizing ionic liquids and microwave synthesis as the topic has the potential for further development as an enrichment book for 10th-grade students. Connecting chemistry concepts to real-world applications of green chemistry has the potential to enhance students' chemical literacy skills (Hernani, Mudzakir and Sumarna, 2017). Using DHZ synthesis in ionic liquid media and the MAOS method can also be utilized for similar teaching material development for higher-level students or university students by integrating fundamental chemistry concept questions. The expected outcomes of this research are increased student engagement and motivation in learning chemistry due to the contextualized and practical approach to teaching materials, enhanced comprehension and application of chemistry concepts through real-world examples and the introduction of environmentally friendly synthesis methods, such as the use of ionic liquid media and the MAOS method, to foster awareness of sustainable practices within the chemical industry and their positive impact on both the environment and human health.

CONCLUSION

The use of ionic liquids and MAOS methods in the synthesis of dehydrozingerone (DHZ) has been effectively integrated into our green chemistry teaching materials. This integration provides students with a practical understanding of green chemistry principles and their application to real-world problems. The developed green chemistry teaching materials received a positive response from the students, with a score of 78.29%, indicating a "good" classification. These findings suggest that the materials successfully engaged students and enhanced their comprehension of green chemistry concepts. Additionally, the context provided by the DHZ synthesis offers many opportunities for exploring various chemistry concepts, making it suitable for senior high-school students.

The implications of this research are significant for chemistry education, particularly within the framework of the current Merdeka curriculum. The organic compound synthesis process developed in these teaching materials offers an alternative approach that can be adapted, modified, and applied by chemistry teachers to enrich the perspective of teaching green chemistry materials. However, one limitation of this research is that the teaching materials were tested on a small scale. Future research could explore similar green chemistry teaching materials that are more accessible anytime and anywhere.

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