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Micro-Scale Approach in Organic Chemistry Learning as An Innovative Strategy to Support Sustainable Development Goals (SDGs)

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ABSTRACT

The micro-scale approach in organic chemistry learning offers an innovative solution to enhance the effectiveness of the teaching and learning process while supporting the Sustainable Development Goals (SDGs). This study aims to describe the implementation of the micro-scale approach in the curriculum of an organic chemistry course at a higher education institution. This approach emphasizes the use of small quantities of chemicals, simple laboratory equipment, and eco-friendly techniques to minimize laboratory waste, operational costs, and negative environmental impacts. The research method involves qualitative analysis to evaluate the effectiveness of this approach in terms of learning outcomes and its relevance to the SDGs, particularly those related to quality education. The results reveal that the micro-scale approach has not yet been implemented in organic chemistry learning. However, organic chemistry lecturers and students have a general understanding of the concept of the micro-scale approach. Moreover, both lecturers and students recognize that the micro-scale concept aligns with the objectives of sustainable development. This study concludes that the micro-scale approach is an innovative and effective strategy to support sustainability-oriented organic chemistry learning. The implementation of this approach is expected to serve as a replicable learning model across various educational institutions, contributing to broader SDGs achievements.

Keywords: Micro-Scale Approach, Organic Chemistry, SDGs

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1. INTRODUCTION

Curriculum innovation in education serves as a strategic step to enhance learning quality and address contemporary challenges. In higher education, developing a relevant and adaptive curriculum is particularly crucial for complex subjects such as organic chemistry. Curriculum innovation aims not only to improve students' theoretical understanding but also to encourage practical, efficient, and globally relevant learning, particularly in addressing environmental sustainability. This aligns with the Sustainable Development Goals (SDGs), particularly those related to quality education and responsible production. Organic chemistry, as a major branch of chemistry, plays a vital role in various aspects of life. However, its learning process often encounters challenges, such as the extensive use of chemicals, high operational laboratory costs, and hazardous waste generated from practical activities. Research data indicate that chemical laboratories in Indonesia produce a significant portion of the total hazardous waste (Hamidah et al., 2017; Auliah, 2018; Wirodimurti et al., 2022). This highlights the inefficiency and environmental impact of conventional laboratory practices.

The micro-scale approach has emerged as an innovative solution to these issues. This approach involves using small amounts of chemicals and simple laboratory equipment, significantly reducing waste, lowering costs, and enhancing efficiency without compromising learning quality. Micro-scale methods can reduce laboratory waste by up to 70% compared to conventional methods. Furthermore, this approach contributes significantly to achieving responsible consumption and production goals (Tesfamariam et al., 2014; Mayo et al., 2023). In Indonesia, the primary challenges in implementing organic chemistry learning include limited laboratory infrastructure, high chemical costs, and a lack of student awareness of sustainability issues. Most students feel less engaged in organic chemistry practicals due to conventional and less contextual teaching methods (Hume et al., 2013; Situmorang et al., 2020). This underscores the urgent need for adopting more innovative and sustainability-oriented approaches. The micro-scale approach also holds potential for increasing student engagement and understanding of organic chemistry concepts. Students exposed to micro-scale practicals exhibit improved conceptual understanding compared to traditional methods. Additionally, these students demonstrate greater awareness of environmental and sustainability issues (Nurbaity et al., 2015; Ratnasari et al., 2019; Khoirunnisa et al., 2024). Despite the identified benefits of the micro-scale approach, its implementation across institutions still faces several barriers. These include insufficient faculty training, concerns about the validity of experimental results, and resistance to curriculum changes (Plomp, 2013; Akuma et al., 2016; Balaz et al., 2017). This study aims to analyze the implementation of the micro-scale approach in organic chemistry education as an innovative strategy to support SDGs. The primary objectives are: (1) to describe the effectiveness of the micro-scale approach in improving learning quality; (2) to analyze its impact on students' awareness of sustainability issues; (3) to identify challenges and opportunities in adopting the micro-scale approach in organic chemistry education. The findings are expected to contribute significantly to curriculum development, particularly in fostering more sustainability-oriented organic chemistry education.

2. METHODS

This study employs a descriptive research method to analyze the micro-scale approach in organic chemistry education as an innovative strategy supporting the achievement of the Sustainable Development Goals (SDGs). Descriptive research focuses on systematically and accurately portraying phenomena based on collected data. Unlike experimental studies, it does not aim to test hypotheses or determine causal relationships but provides a comprehensive depiction of specific phenomena. As such, descriptive research serves as a crucial initial step in understanding a problem or phenomenon before advancing to more complex investigations (Cohen et al., 2002; Cresswell, 2009). The descriptive method is chosen for its rational, empirical, and systematic approach, enabling an in-depth understanding of the micro-scale approach implementation. This type of non-inferential research aims to describe phenomena factually. The research design encompasses planning, implementation, and evaluation stages of the micro-scale approach in organic chemistry learning.

The subjects of this study include organic chemistry instructors and students enrolled in organic chemistry courses at a purposively selected higher education institution. Research instruments: (1) Observation sheets: to assess the implementation of the learning process; (2) Student learning outcomes analysis: to evaluate conceptual understanding; (3) Questionnaires: to gauge students' perceptions of sustainability. Data collection techniques: (1) video observation of learning activities: to capture the teaching and learning process; (2) interviews with Lecturers and Students: to gain qualitative insights into their experiences and perspectives; (3) questionnaires: to collect quantitative data on students' perceptions. Data analysis consist of: (1) quantitative data: learning outcomes portfolios and questionnaire responses are analyzed using descriptive statistics to identify patterns in learning outcomes and student perceptions; (2) qualitative data: observation sheets are analyzed using content analysis techniques to identify key patterns in the implementation of the micro-scale approach. The research process is illustrated in figure 1. This methodological framework ensures a comprehensive depiction of the micro-scale approach's application, effectiveness, and potential for broader adoption in organic chemistry education.

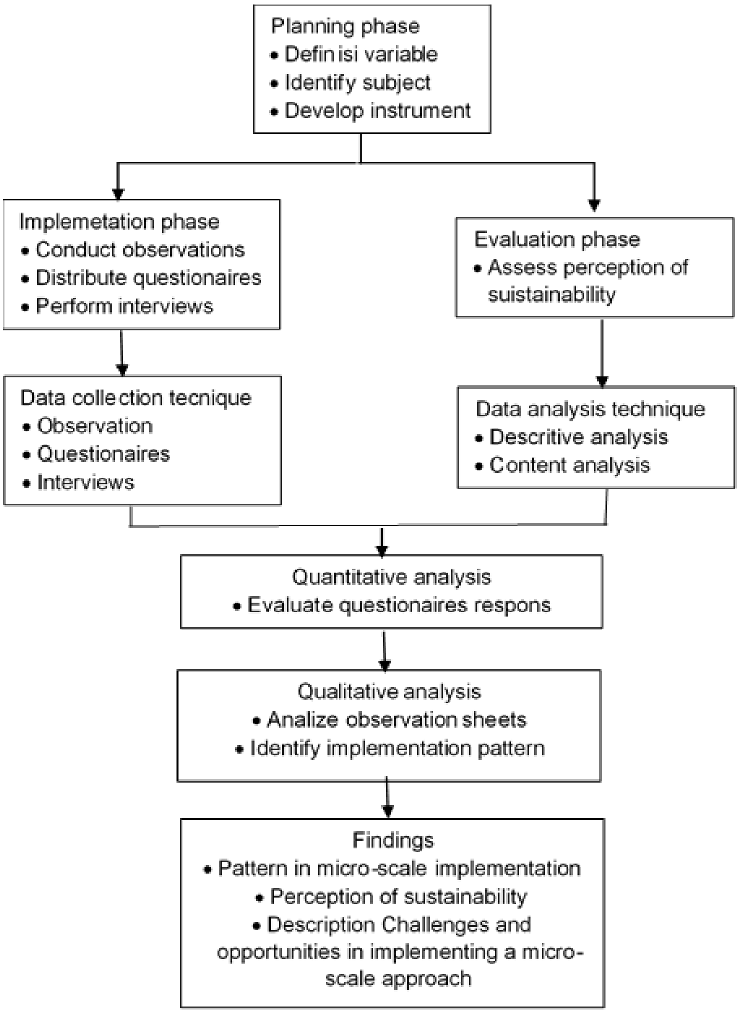

Figure 1. Flow of research methods

3. RESULTS AND DISCUSSION

RESULTS

The effectiveness of micro-scale approaches in improving the quality of organic chemistry learning

The research findings indicate that the micro-scale approach has not yet been intensively utilized in organic chemistry education. Qualitative analysis from in-depth interviews reveals that students feel more engaged and better able to understand organic chemistry concepts through experiments. However, some students also mentioned experiencing anxiety when faced with complex experiments in organic chemistry learning. In terms of resource efficiency, the absence of micro-scale approach implementation has resulted in no significant efforts to reduce chemical usage, and there has been no noticeable decrease in laboratory waste. Although the benefits have yet to materialize due to the lack of micro-scale approach implementation, the study also identifies several challenges, such as the need for additional training for lecturers to master micro-scale tools and methods, as well as initial resistance from students to changes in teaching methods.

The impact of student awareness of sustainability issues

The interviews revealed that students' awareness of sustainability issues ranges from moderate to high, with 72% of respondents reporting a basic understanding of topics such as climate change, energy conservation, and waste management. However, only 35% of students were able to connect these concepts to practical applications in their daily lives or academic fields. In-depth interviews highlighted that students with higher awareness of sustainability issues tend to have a more comprehensive understanding of the interconnectedness of environmental aspects. Those actively engaged in campus environmental activities demonstrated the ability to integrate sustainability principles into solving academic problems, such as designing sustainable solution-based projects for group assignments. Conversely, students with lower awareness showed a narrower understanding, often limited to environmental aspects without considering social or economic implications. Document analysis of student assignments supported these findings. Students with high sustainability awareness produced more innovative works, such as projects integrating sustainability solutions into organic chemistry coursework, including submissions for student creativity programs. In contrast, assignments from students with lower awareness tended to be descriptive and lacked practical solutions. The study also found that social media plays a significant role in increasing students' sustainability awareness. Digital campaigns, online discussions, and educational platforms contributed significantly to enhancing their understanding of sustainability issues. However, limited digital literacy was identified as a barrier for some students in filtering valid information.

Challenges and opportunities in implementing a micro-scale approach in organic chemistry learning

The results of the study showed that the perception of lecturers teaching organic chemistry courses stated that the micro-scale approach provides a number of significant opportunities in learning organic chemistry. From a pedagogical perspective, this approach has been shown to increase student engagement in practicums. Experiments designed on a micro-scale allow students to focus better on the details of chemical processes because of the use of simpler and more controlled chemicals and tools. Most of the lecturers interviewed also acknowledged that this approach strengthens the understanding of basic organic chemistry concepts, because students can do more repetitions of experiments in the same time. However, the implementation of the micro-scale approach has not been realized so that the good perception has not shown results in the learning process. However, this study also identified various challenges in its implementation. One of the main challenges is the initial resistance from lecturers and students. Some lecturers feel the need to adapt to new methods that require additional training to understand and use micro-scale tools effectively. Students, especially those who are accustomed to conventional methods, initially showed discomfort and lack of confidence in using smaller equipment. The challenge that arises is that in-depth understanding is still needed from lecturers to manage organic chemistry learning based on the micro-scale approach. Another challenge is the limited availability of micro-scale equipment in the laboratory, especially in institutions that do not yet fully support this infrastructure. The relatively high price of micro-scale equipment in the initial purchase is also an obstacle for institutions that are in the transition stage. In addition, redesigning the practicum learning module to adapt to the micro-scale approach requires time and collaboration between teaching staff, which is not always easy to do. However, the opportunity to overcome this challenge is quite large. Institutions that have implemented the micro-scale approach have succeeded in overcoming initial resistance through regular training and group discussions to share experiences. Policy support from the institution, such as special budget allocation and integration of the micro-scale approach into the curriculum, is also an important factor in the success of implementation.

DISCUSSION

The effectiveness of micro-scale approaches in improving the quality of organic chemistry learning

The results of this study indicate that the micro-scale approach has not been used intensively in organic chemistry learning, although this approach has great potential to improve the quality of learning. Pedagogically, micro-scale experiments allow students to better understand organic chemistry concepts through a more controlled and in-depth learning process. This finding is consistent with previous studies showing that small-scale experiments can increase student engagement by providing a safe, material-saving, and more accessible laboratory experience (Muller et al., 2023). However, interview results showed that students often experience anxiety when facing complex experiments in organic chemistry learning. This indicates the need for learning strategies that not only focus on conceptual understanding but also on efforts to reduce psychological stress during the learning process. The micro-scale approach can be a solution to this problem because small-scale experiments are more controlled, allowing students to experiment without fear of major failure. On the other hand, in terms of resource efficiency, the lack of implementation of the micro-scale approach has resulted in no significant reduction in the use of chemicals and laboratory waste. The micro-scale approach is able to reduce the use of chemicals, thereby creating a more environmentally friendly and cost-effective laboratory (Tyagi et al., 2015; Hanson, 2022). This indicates that the implementation of the micro-scale approach is not only pedagogically relevant but also supports sustainability in educational institutions. This study also highlights the main challenges in implementing the micro-scale approach, such as the need for additional training for lecturers and initial student resistance to changes in learning methods. These challenges are in line with research findings stating that adaptation to new technologies or methods often requires ongoing training for lecturers and deeper integration efforts into the curriculum (Barab et al., 2003; Zhao et al., 2023). To overcome these challenges, educational institutions need to invest in lecturer training and the provision of micro-scale laboratory equipment. In addition, student resistance to change can be minimized through a gradual approach, such as introducing the method in one or two initial laboratory sessions before being fully implemented. This will give students time to adapt to the workings and advantages of the micro-scale approach. Overall, although the micro-scale approach has not been widely implemented, this study shows that this method has the potential to improve the quality of organic chemistry learning and resource efficiency. With effective challenge management, this approach can be an innovative and sustainable learning model in higher education institutions.

The impact of student awareness on sustainability issues

The results of this study indicate that students' awareness of sustainability issues has a significant relationship with their comprehensive understanding of sustainability. The majority of students have moderate to high levels of awareness, with 72% stating that they understand basic sustainability concepts such as climate change, energy conservation, and waste management. Basic understanding of sustainability has increased among students, especially in universities that integrate sustainability into the curriculum. However, only 35% of students are able to connect sustainability concepts with practical applications in their daily lives or fields of study. This indicates a gap between conceptual understanding and implementation skills. Although many students understand the importance of sustainability, they often have difficulty translating this knowledge into real actions (Jickling et al., 2008; Winter et al., 2012). Students with high sustainability awareness demonstrate a deeper and more integrative understanding, such as the ability to connect environmental aspects with social and economic dimensions. They also produce more innovative work, such as sustainable solution-based projects in organic chemistry courses. In contrast, students with low awareness tend to limit their understanding to environmental aspects without considering other dimensions. This emphasizes the importance of a multidimensional approach in sustainability education to produce holistic problem solving (Zsoka et al., 2013; Munkebye et al., 2022). This study also highlights the role of social media as a significant source of information in increasing students' awareness of sustainability issues. Digital campaigns, online discussions, and educational platforms have contributed greatly to expanding students' knowledge. However, limited digital literacy is an obstacle for some students in filtering valid information. Thus, there is a need to improve digital literacy to ensure that students can access and use information critically. Thus, this study shows that the level of students' awareness of sustainability plays an important role in determining their understanding. Higher education institutions have a responsibility to bridge the gap between conceptual understanding and practical application, one of which is by integrating sustainability issues into the curriculum and providing facilities that encourage project-based learning. In addition, digital literacy needs to be strengthened to ensure that students can use information sources effectively.

Challenges and opportunities in implementing a micro-scale approach in organic chemistry learning

The results of the study indicate that the microscale approach has great potential in improving the quality of organic chemistry learning in higher education institutions. The perceptions of organic chemistry lecturers indicate that this approach provides significant opportunities, especially from a pedagogical perspective. Microscale experiments allow students to be more actively involved in the practicum, by focusing attention on the details of the chemical process. The microscale approach can improve students' conceptual understanding through more frequent repetition of experiments in the same time (Hanson et al., 2011; Ardestani et al., 2014; Tesfamariam et al., 2014). However, despite its great potential benefits, the implementation of the microscale approach still faces various challenges. One of the main obstacles is the initial resistance from lecturers and students. Lecturers feel the need to adapt to new methods, especially since this approach requires additional training to understand the use of microscale equipment effectively. Students, especially those who are accustomed to conventional methods, show initial discomfort in using smaller laboratory equipment. These obstacles also include changes in learning methods that often require ongoing support to overcome resistance and ensure sustainability of implementation. In addition to resistance, limited infrastructure is a major challenge. The relatively high initial cost of microscale equipment, coupled with the need for redesigned learning modules, is a barrier for institutions with limited resources. The initial investment in microscale laboratory equipment can be a burden, but in the long run it provides significant economic benefits through reduced chemical use and laboratory waste (Hilson, 2002; Gavrilescu, 2004; Busin et al., 2016). Despite these challenges, there is a significant opportunity to overcome these barriers. Institutional support, such as dedicated budget allocation for equipment and training, and integration of microscale approaches into the curriculum are important. Institutions that have successfully implemented this approach have found that regular training for faculty and group discussions are key to overcoming initial resistance. Training and collaboration among faculty are essential in implementing educational innovations (Blouin et al., 2009; Zhu et al., 2014; Kovacs, 2017). Overall, microscale approaches have the potential to revolutionize the learning of organic chemistry by providing more efficient and immersive laboratory experiences for students. To realize this potential, educational institutions need to address infrastructure challenges, resistance, and training needs with a planned strategy. Strong institutional policy support and collaboration among stakeholders will be key to the successful implementation of the micro-scale approach.

4. CONCLUSION

This study reveals that the microscale approach in organic chemistry learning has great potential as an innovative strategy that supports the achievement of the Sustainable Development Goals (SDGs). From a pedagogical perspective, this approach is able to increase student engagement in the teaching and learning process through safer, more efficient, and more affordable laboratory experiments. Microscale experiments allow students to focus more on the details of chemical processes, improve their understanding of basic organic chemistry concepts, and facilitate the repetition of experiments without sacrificing resources. Thus, this approach is in line with the SDGs (Quality Education) goals by creating inclusive and effective learning. In addition to pedagogical benefits, the microscale approach also has a positive impact on resource efficiency. The use of fewer chemicals and reduction of laboratory waste support the SDGs (Responsible Consumption and Production) goals. Although the implementation of this approach is not yet evenly distributed in higher education institutions, this study shows that its use can make a significant contribution to environmental and economic sustainability in educational laboratory practices. However, this study also identified a number of challenges in implementing the microscale approach, including initial resistance from lecturers and students, the need for additional training, limited laboratory infrastructure, and relatively high equipment procurement costs. To overcome these barriers, strong institutional support is needed, such as special budget allocation, provision of continuous training, and integration of microscale approaches into the curriculum. Overall, the microscale approach is an innovation that not only improves the quality of organic chemistry learning but also contributes to sustainable development goals. With adequate planning and support, this approach can be widely adopted in higher education institutions to create a more sustainable and relevant education to today's global challenges.

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