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Green Chemistry Microscale Practicums on High School Students' Learning Outcomes and Motivation: Systematic Literature Review

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Abstract
Microscale practicums are a practicum design that utilizes small amounts of materials and tools as a solution to the limitations of school laboratories, while integrating the application of green chemistry principles in education. A number of empirical studies have reported the positive impact of implementing green chemistry-based microscale practicums. However, studies that specifically integrate green chemistry principles and analyze their integrated impact on learning outcomes and motivation among high school students are still limited and scattered. The purpose of this study is to systematically examine how the application of green chemistry-based microscale practicums can improve learning outcomes and motivation among high school students. This study uses the Systematic Literature Review (SLR) method with the PRISMA model through searching for articles on Google Scholar, GARUDA, DOAJ, and SCOPUS. The articles analyzed were adjusted to the inclusion criteria, namely empirical studies published between 2005 and 2025 with high school/MA students as subjects and focusing on the effect of green chemistry-based microscale practicums on student learning outcomes and motivation. A total of 10 articles met the inclusion criteria and were analyzed in this study. The synthesis results show that this approach consistently improves student learning outcomes in terms of concept understanding, achievement, science process skills, and student memory retention, as well as learning motivation through increased interest and enthusiasm for learning. These findings provide evidence-based guidance for chemistry teachers and curriculum developers in designing environmentally friendly laboratory learning that is effective in improving students' cognitive and affective achievements.

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INTRODUCTION

Chemistry exsamines the composition, structure, properties of matter, and changes in matter, as well as the energy involved (Dewi et al., 2019; Supatmi, 2022). At the high school level, the abstract and multirepresentational nature of chemistry often causes conceptual and procedural difficulties for students (Priliyanti et al., 2021). Empirical data shows that approximately 48.99% of students have difficulty explaining terms in chemistry learning, 41.32% of students have difficulty understanding chemistry concepts, and 70.97% of students have difficulty completing chemistry calculations (Yakina et al., 2017). These findings confirm that learning strategies are needed that are able to bridge theoretical concepts with empirical experiences in a contextual manner. In line with what was stated by (Suardana et al., 2018) that chemistry learning leads to active student involvement through meaningful and contextual learning activities so that the knowledge construction process runs optimally.

A practicums is a pedagogical tool that allows students to observe macroscopic phenomena as a starting point for learning so that the material is understood contextually and bridges the process of forming chemical knowledge (Subagia & Wiratma, 2020; Wong & Sim, 2022). On the other hand, conducting laboratory work also requires mastery of basic laboratory skills so that experiments can be carried out safely, orderly, and in a manner that supports chemistry learning (Sudria et al., 2020).

The connection between these concepts and experiences will later influence the improvement of student learning outcomes (BalRam, 2017; Setianingsih, 2023). However, in practice, most chemistry practicums conducted in high schools are still conventional, using chemicals that are harmful to living things and the environment (Redhana, 2017). This situation creates a need to reconstruct chemistry practicums to be safer, more efficient, and sustainable.

In line with the principles of sustainable education, a green chemistry-based microscale practicum approach is a relevant alternative (Zuin et al., 2020). This practicum approach uses small amounts of chemicals, thereby reducing risks, costs, and environmental impact without compromising the essence of the chemistry concepts being studied (Al Idrus et al., 2021; Mashami, 2025; Supatmi, 2022).

Various empirical studies in Indonesia show that the application of green chemistry-based microscale practicum can improve learning outcomes through increased conceptual understanding, learning achievement, and scientific process skills (Ali et al., 2023; Setianingsih, 2023; Supatmi, 2022) as well as increasing student motivation to learn (Redhana, 2017; Rocios et al., 2024). Theoretically and empirically, these findings indicate that this approach has the potential to optimize cognitive and affective outcomes simultaneously.

However, these studies are generally still partial in nature. Some studies focus only on learning outcomes, while others focus on motivation separately. In addition, not all studies explicitly integrate green chemistry principles into the design of microscale practicums, resulting in varying implementation orientations. On the other hand, there is an imbalance in reporting effectiveness, whereby some studies only report learning outcomes in quantitative form, while motivation is only presented descriptively. This conceptual and methodological fragmentation has resulted in a lack of comprehensive understanding of the effectiveness of implementing green chemistry-based microscale practicums in simultaneously improving learning outcomes and motivation at the high school level.

Although a number of empirical studies have reported the positive impact of green chemistry-based microscale practicum approaches, to date there has been no systematic study that simultaneously and integrally synthesizes their influence on student learning outcomes and motivation at the high school level. The absence of this comprehensive synthesis has hampered the development of an evidence-based foundation for the development of effective sustainable chemistry practices at the high school level. Based on this research gap, this study aims to conduct a Systematic Literature Review (SLR) to analyze and synthesize evidence and previous research results related to the application of green chemistry-based microscale practicum to simultaneously improve learning outcomes and student motivation in high school.

METHOD

The method of information collection in this study used structured analysis techniques with Preferred Reporting Items for Systematic Review and Meta-Analyses, known as the PRISMA method. The SLR method provides researchers with the opportunity to review and identify journals systematically by following certain stages in each process involved (Suantara et al., 2019). The preparation of this article also involved exploratory questions, so that the purpose of the research question that had been formulated could be more focused on the literature review and facilitate the discovery of relevant data units. The research questions in this study are presented in Table 1.

Table 1. Research Question

No.	Research Question	The analysis sought
1.	What chemical materials were used in previous studies in the application of green chemistry-based microscale practicums to improve high school students' learning outcomes and motivation?	Analyzing articles on any material or topic that has been applied in green chemistry-based microscale practicum activities to improve learning outcomes and motivation among high school students.

No.	Research Question	The analysis sought
2.	What types/methods of research were used by previous researchers in studies related to the application of green chemistry-based microscale practicum on high school students' learning outcomes and motivation?	Analyzing articles on the types of research used in studies related to the application of green chemistry-based microscale practicums to improve learning outcomes and motivation among high school students.
3.	How effective is implementing green chemistry-based microscale practicum in improving high school students' learning outcomes and motivation?	Analyzing research results related to the effectiveness of implementing green chemistry-based microscale practicums to improve learning outcomes and motivation among high school students through previous articles.

The articles used in this literature review were obtained through searches of the Google Scholar, GARUDA, DOAJ, and SCOPUS databases. The literature review on the research topic used the keywords "microscale practicum," "green chemistry," "senior high school (SMA)," "improvement of learning outcomes," and "motivation." The search strategy was carried out using a combination of relevant keywords and Boolean operators (AND, OR) to ensure specific results. The search string used was as follows: ("microscale practicum" OR "microscale laboratory") AND "green chemistry" AND ("high school" OR "senior high school") AND ("learning outcomes" OR 'achievement') AND "motivation". Articles obtained from the search will be selected based on the exclusion and inclusion criteria that have been established. The exclusion and inclusion criteria for this literature are shown in Table 2.

Table 2. Exclusion and Inclusion Criteria

Exclusion Criteria	1)	Research articles published before 2005.
	2)	The research does not focus on applying microscale green chemistry-based practicum to improve learning outcomes and motivation among high school students.
	3)	The research subjects are not high school students.
	4)	The article is not available in full text.
Inclusion Criteria	1)	Research articles published between 2005 and 2025.
	2)	The research focuses on applying green chemistry-based microscale practicum to improve learning outcomes and motivation among high school students.
	3)	The research subjects are high school students.
	4)	Articles are from published journals, proceedings, and theses.
	5)	Articles are peer-reviewed.

Articles will be reviewed and selected once the inclusion and exclusion criteria have been determined. The PRISMA selection method was used to obtain the final articles related to the implementation of green chemistry-based microscale practicums to improve learning outcomes and motivation among high school students, which consisted of four stages, namely:

1. Identification. At this stage, researchers collected article data from four databases using Google Scholar, GARUDA, DOAJ, ERIC and Scopus resulting in n=435 articles.
2. Screening. Records After Duplicates Removed, or the total number of articles with the same title from the four sources obtained, will be removed. This resulted in Records Exclude with Reasons with a result of n=102 articles.
3. Eligibility. From the screening results, 30 articles were obtained, which were then read in full to assess their eligibility based on the exclusion and inclusion criteria that had been compiled. As a result, 20 articles were excluded because they did not meet the criteria. In addition to selection based on inclusion and exclusion criteria, articles that passed were also assessed for methodological quality. The aspects assessed included: (1) clarity of research design, (2) suitability of methods to research objectives, (3) validity and reliability of data collection instruments, (4) data analysis techniques used, and (5) completeness of research result reporting. Articles that did not meet methodological eligibility standards were not included in the final analysis.
4. Inclusion. At this stage, n=10 articles met the exclusion and inclusion criteria in the SLR analysis of the effect of green chemistry-based microscale practicums on high school students' learning outcomes and motivation.

Although the number of articles obtained was relatively small and limited (n=10), this number was the result of systematic selection from a total of 435 initial articles through the stages of the PRISMA selection method. Research topics that specifically integrate microscale practicums, green chemistry approaches, and measurements of learning outcomes and learning motivation of high school students are still limited in empirical publications. Therefore, the ten articles that met the inclusion criteria and underwent method-logical quality assessment were deemed re-presentative and suitable for analysis in this systematic literature review.

In systematic reviews, the suitability for analysis is not solely determined by the quantity of studies, but by the relevance, methodological quality, and consisten-cy of the research findings included.

RESULTS AND DISCUSSION

Overview of Articles Reviewed

Based on the results of a systematic literature review of relevant articles, 10 articles were found to meet the exclusion and inclusion criteria and were suitable for systematic analysis. The results of the analysis are presented in the form of percentages that represent the proportion of studies reporting specific findings from all articles reviewed, rather than statistical effect sizes from each study. The results of the analysis of the 10 articles are presented in Table 3.

Table 3. Results of the analysis of articles on applying green chemistry-based microscale practicum to improve learning outcomes and motivation among secondary school students.

No.	Author (Year)	Article Title	Method	Learning Topic	Samples	Effectiveness/Findings
1	Supatmi (2022)	Improving Science Process Skills Through Microscale Chemistry Practicals on Stoichiometry	Quasi-experiment	Stoichiometry	40 students in a senior high school	This study shows an improvement in science process skills, but does not yet provide empirical evidence of an increase in student learning motivation.
2	Mafumiko (2008)	The Potential of Microscale Chemistry Experimentation in Enhancing Teaching and Learning of Secondary Chemistry: Experiences from Tanzania Classrooms	R&D	Solubility & Precipitation	40 students in a senior high school	This study shows an improvement in science process skills as well as an increase in student learning motivation.
3	Utmeemang & Buaraphan (2024)	Effects of Small-Scale Chemistry STEM Integrated with Local Contexts for Enhancing Grade 11 Students' Learning Achievement and Learning and Innovation Skills	Quasi-experiment	Reaction rate	296 grade XI high school students	This study shows an improvement in science process skills, but does not yet provide empirical evidence of an increase in student learning motivation.
4	Setianingsih (2023)	Penerapan Pembelajaran Berbasis Praktikum untuk	Classroom Action Research	Green Chemistry	27 grade X high school students	This study shows an increase in learning achievement as well as

No.	Author (Year)	Article Title	Method	Learning Topic	Samples	Effectiveness/Findings
		Meningkatkan Motivasi dan Hasil Belajar Peserta Didik pada Materi Kimia Hijau				an increase in student learning motivation.
5	Allanas et al. (2024)	Pengembangan Praktikum Microscale untuk Menganalisis Pemahaman Prinsip Green Chemistry	R&D	Acid-Base	36 grade XI high school students	This study shows an increase in students' understanding of chemistry concepts, but does not yet provide empirical evidence of an increase in student learning motivation.
6	Merta (2020)	Model Pembelajaran Penemuan Menggunakan Praktikum Kimia Hijau untuk Meningkatkan Hasil Belajar Siswa	Classroom Action Research	Thermochemistry & Reaction Rate	39 grade XI high school students	This study shows an increase in learning achievement as well as an increase in student learning motivation.
7	Redhan (2017)	Green Chemistry Practicum to Improve Student Learning Outcomes of Reaction Rate Topic	Quasi-experiment	Reaction rate	80 grade XI high school students	This study shows an increase in learning achievement as well as an increase in student learning motivation.
8	Abdullah et al. (2009)	The Effect of an Individualized Laboratory Approach through Microscale Chemistry Experimentation on Students' Understanding of Chemistry Concepts, Motivation and Attitudes	Quasi-experiment	Acid–Base & Electrochemistry	170 grade X high school students)	This study shows an increase in students' understanding of chemistry concepts, but does not yet provide empirical evidence of an increase in student learning motivation.
9	Rocios et al. (2024)	Investigating the Impact of Small-Scale Chemistry Experiments on Student Engagement and Concept Retention	Quasi-experiment	Various topics in secondary school chemistry	98 grade XI- XII high school students	This study shows an increase in concept retention, but does not yet present empirical evidence of an increase in student learning motivation.
10	Ali et al. (2023)	Examining the Effects of Supervised Laboratory Instruction on Students' Motivation and	Quasi-experiment	Acid-Base & Solutions	160 grade XII high school students	This study shows an increase in understanding of chemistry concepts as well as an increase in student learning motivation.

No.	Author (Year)	Article Title	Method	Learning Topic	Samples	Effectiveness/Findings
		Their Understanding of Chemistry				

Discussion of Findings

Based on the analysis of ten articles that met the inclusion criteria, information was obtained regarding the chemical materials that had been integrated into green chemistry-based microscale practicum activities to improve high school students' learning outcomes and motivation. It should be emphasized that the data presented below shows the proportion of studies that highlight certain phenomena and does not represent empirical effects. Thus, the interpretation of the findings in this section is descriptive-comparative in nature and cannot be equated with the strength of the intervention effect as in quantitative meta-analyses.

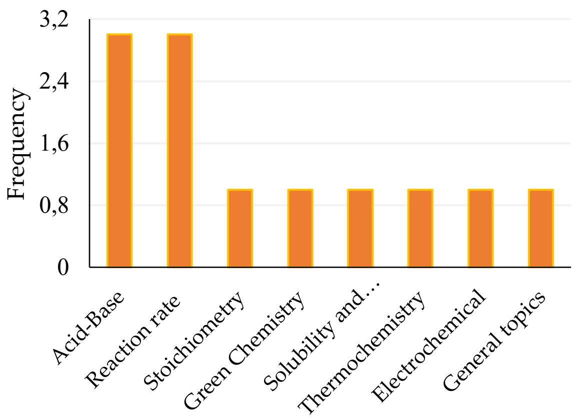

Figure 1. Percentage of Chemistry Learning Materials

Based on Figure 1, the percentage of chemistry learning materials, acid-base materials, and reaction rates are the topics most frequently used compared to other topics in previous studies. The selection of acid-base topics was reported in three studies (Ali et al., 2023; Allanas et al., 2024), while reaction rate material appeared in three other studies (Merta, 2020; Redhana, 2017; Utmeemang & Buaraphan, 2024). These findings indicate that both topics are relatively more frequently chosen in the implementation of green chemistry-based microscale practicums. The results of the analysis of studies that chose the topic of acids and bases are associated with the potential use of natural materials that can be used as natural indicators, such as plant extracts that are capable of showing color changes in acidic and basic conditions (Allanas et al., 2024; Lestari, 2016). In addition, it was found that many students considered the topic of acids and bases difficult to understand in a submicroscopic form (Ali et al., 2023). Thus, the selection of this topic was not only based on the ease of integrating green chemistry principles but also on the pedagogical need to help students visualize abstract concepts through direct experimental experience.

The analysis also found that reaction rate material was also widely chosen because the curriculum guidelines provide a wide variety of practical activities that have the potential to produce more waste if carried out conventionally (Redhana & Suardana, 2021). This condition shows that the integration of microscale practicum and green chemistry principles is an alternative to reducing the use of materials while maintaining students' experimental experience. Synthetically, both topics share similar characteristics, namely relatively high conceptual complexity and the potential for large amounts of chemicals to be used in conventional practical work. These similar characteristics indicate that the selection of material in green chemistry-based microscale practicum is not random, but rather a strategy for topics that are both urgent and ecological.

Other topics such as stoichiometry appear less frequently than topics such as acids and bases and reaction rates. The selection of topics is based on the difficulty students have in combining the three levels of representation, namely the microscopic, macroscopic, and symbolic levels found in chemistry learning (Supatmi, 2022). On the other hand, it was found that stoichiometry material has quantitative properties and involves chemical calculations, which means it involves quite a lot of mathematical concepts. This allows the application of microscale practicums on stoichiometry topics to emphasize the strengthening of symbolic and quantitative representations rather than significant waste reduction, so that its frequency of appearance is more limited in previous studies.

In addition to these three popular topics, other materials were also found, such as green chemistry, thermochemistry, solubility and precipitation, as well as several general chemistry materials that were combined into a single research unit. The results of the analysis of the selection of these topics were not explicitly explained in most studies, but in general they were oriented towards efforts to use small amounts of materials and tools to reduce waste and laboratory facility limitations. Although less frequent, these findings indicate that green chemistry-based micro-laboratory approaches have the flexibility to be implemented in various chemistry topics, as long as there are opportunities for material reduction and optimization of experimental safety.

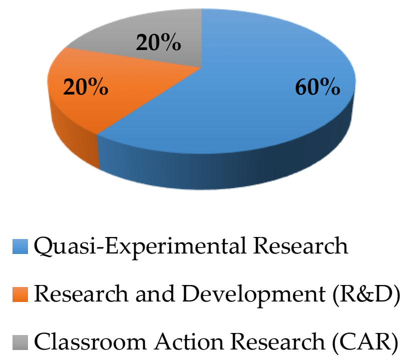

Figure 2. Percentage of the Research Method

Based on **Figure 2,** which shows the percentage of research methods in ten articles that meet the inclusion criteria, it is emphasized that the percentage figures presented represent the proportion of studies that use research designs and are not a measure of the empirical effect of the interventions carried out. The percentage data shows that 60% of the studies used quasi-experimental research methods. The percentage value for quasi-experimental methods in the proportion of studies reviewed indicates that most studies were oriented towards testing the effectiveness of implementing green chemistry-based microscale practicums in a real classroom context.

This research method provides the possibility to test the effectiveness of the practicum implementation by comparing the experimental group with the control group to find out and see how significant changes occur after the implementation of the practicum model (Redhana, 2017; Supatmi, 2022; Utmeemang & Buaraphan, 2024). In addition, Ali (2023) argues that quasi-experimental methods allow learning activities to take place in natural conditions (without manipulating conditions), while still providing control over dependent variables. However, the use of quasi-experimental designs also shows that most studies have not used pure experimental designs with full randomization, so control over external variables is still limited. Interpretation of this distribution shows that research tends to choose designs that maintain natural learning conditions, but still allow for limited cause-and-effect testing. This indicates an effort to obtain contextual empirical evidence, even though control over external variables is not yet fully optimal as in pure experiments.

In addition to quasi-experimental methods, 20% of previous researchers used R&D methods. The selection of this method was based on the type of research that focused on the development of existing learning products or tools, such as modules, green chemistry-based practicum guides, or small-scale practical kits (Sari et al., 2024; Yuniar et al., 2019). The selection and application of this method is expected to demonstrate the feasibility of the learning products that have been created or developed (Okpatrioka, 2023; Waruwu, 2024). Thus, efforts to improve student learning outcomes and motivation can be determined using actual data.

The last method, used in 20% of previous studies, was classroom action research (CAR). The results of the analysis show that the choice of this method was based on the characteristics of the research design, which focuses on the gradual improvement of the learning process through cycles of action and reflection. This approach confirms that some adaptive processes require continuous evaluation in a specific classroom context. Overall, the distribution of research methods shows that microscale green chemistry-based practicum studies are still dominated by quasi-experimental designs with a moderate level of control.

The condition indicates that the available empirical evidence generally comes from non-randomized class research contexts, so that the generalization of findings still needs to be strengthened through pure experimental designs and more comprehensive mixed approaches. In addition, the proportion of classroom development and action methods indicates that this field is still in the stage of strengthening innovation and contextual implementation, not merely testing large-scale effects.

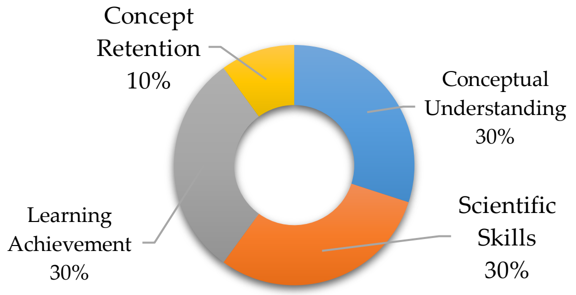

Figure 3. Percentage of Learning Outcomes

Based on **Figure 3,** the application of gree chemistry-based microscale practicums research shows an increase in high scho students' learning outcomes. The proportion improvement in learning outcome indicators reported as follows: concept understanding wi a presentation of 30%, learning achievement wi a percentage of 30%, science process skills of 30' and finally concept retention of 10%.

The percentages represent the proportion studies that reported improvements in eac indicator and are not empirical measures of tl intervention. Based on the proportion of studies reviewed, the findings indicate that the application of green chemistry-based microscale practicums shows a tendency to improve student learning outcomes in three aspects simultaneously. The similarity in proportions for the indicators of concept understanding, learning achievement, and science process skills shows that the impact of the practicum is not only limited to improving academic scores but also to strengthening more comprehensive scientific competencies.

Pedagogically, this improvement can be understood through the characteristics of practical activities that provide direct learning experiences by facilitating students' limitations in understanding chemical concepts that are considered abstract to become more concrete (Ali et al., 2023; Merta, 2020; Redhana, 2017; Rocios et al., 2024; Yuniar et al., 2019). In addition, activities involving observation, hypothesis formulation, data processing, and conclusion drawing in practical activities also strengthen students' scientific process skills and conceptual understanding (Supatmi, 2022).

Thus, the improvement in learning outcomes does not only occur in the cognitive domain but also reflects students' active involvement in the scientific process. The final improvement in learning outcomes is also reflected in students' ability to retain chemistry concepts over a certain period of time (Rocios et al., 2024). However, the low proportion of studies measuring concept retention (10%) indicates that most research still focuses on short-term effects. The lack of delayed post-test measurements limits our understanding of the sustainability of learning effects, so longitudinal studies are still needed to ensure the stability of learning outcome improvements in the long term.

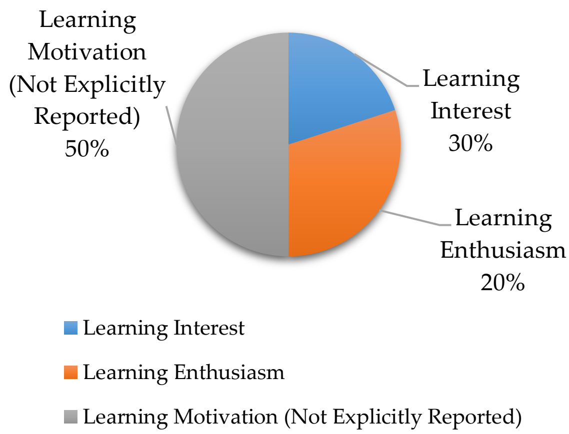

Figure 4. Percentage of Student Motivation and Interest in Learning

Based on Figure 4, the application of green chemistry-based microscale practicums in research shows an increase in student learning motivation. The proportion of increase in student motivation is reported as follows: 30% showed an increase in learning interest, 20% showed an increase in learning enthusiasm or enjoyment, while 50% did not report quantitative data related to motivation. This percentage reflects the proportion of studies reporting specific findings, not the empirical effect size of the intervention. Based on the proportion of studies reviewed, the implementation of microscale practicums shows a tendency to increase student learning motivation, particularly in terms of interest and enjoyment (Merta, 2020; Redhana et al., 2021; Setianingsih, 2023).

Pedagogically, this increase can be understood because microscale practicums provide safe, simple, and environmentally friendly direct learning experiences. Contextual and environmentally relevant experimental activities allow students to experience the meaning of learning in a real way, thereby encouraging intrinsic motivation (Maulidiningsih & Kusumaningrum, 2023).

Conceptually, the integration of green chemistry principles not only impacts cognitive aspects but also has the potential to shape sustainability awareness (Sunday et al., 2025). This is in line with the objectives of the independent curriculum and the Education for Sustainable Development (ESD) approach, which emphasizes the integration of cognitive, affective, and sustainability awareness competencies (Riess et al., 2022; Widyawati et al., 2024). However, the results of the analysis also show significant limitations. Half of the studies did not report quantitative data related to increases in student learning motivation, so the generalization of motivation increases is still limited. The lack of quantitative data in half of the studies opens up the possibility that the reported increases in motivation are situational and influenced by the novelty effect, which is temporary enthusiasm due to new learning experiences.

Several studies present qualitative data in the form of observations or student responses, without using standard motivational instruments. In fact, learning motivation is an important element because it encourages students to actively engage and strive to achieve the expected results (Boro et al., 2021). Differences in measurement methods between studies show that motivation is often positioned as a secondary effect compared to cognitive learning outcomes. This condition emphasizes the need to use valid and reliable quantitative instruments so that motivation can be analyzed more comprehensively. Overall, although some studies show positive results, empirical evidence related to increased motivation still requires methodological reinforcement. Further research is needed with better experimental designs, systematic reporting, and more in-depth analysis of supporting factors and implementation limitations to strengthen the empirical data on the application of green chemistry-based microscale practicums in chemistry learning in schools.

CONCLUSION

Based on the analysis of ten scientific articles that met the inclusion criteria, it was found that a consistent pattern of findings indicated that green chemistry-based microscale practicum tended to contribute to improving high school students' learning outcomes, particularly in terms of conceptual understanding, academic achievement, and scientific process skills. This approach is widely implemented in chemistry topics with high conceptual complexity and the potential for significant use of chemicals in conventional practicum, such as acids and bases and reaction rates.

Conceptually, this approach not only emphasizes the efficient use of materials and waste reduction, but also provides a more contextual and meaningful learning experience. The integration of green chemistry principles in laboratory activities is in line with the objectives of the independent curriculum and the Education for Sustainable Development (ESD) approach, which emphasizes the integration of cognitive and affective competencies and sustainability awareness. Several studies have also reported an increase in student learning motivation in the form of increased interest and enthusiasm for learning, although variations in measurement and reporting methods limit the strength of empirical evidence and the generalization of findings.

RECOMMENDATION

Further research should use a larger number of articles with a more homogeneous research design and consistent motivation measurement methodology to strengthen the generalization of findings and empirical evidence related to the measurement of green chemistry-based microscale practicums.

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