International Journal of Scientific Multidisciplinary Research (IJSMR)
Vol. 4, No. 5, 2026: 633 - 648

Analysis of Trends, Effectiveness, and Gaps in the Integration of Green Chemistry within Project-Based Reaction Rate Micro-Modules: A Systematic Literature Review

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ARTICLEINFO

Keywords: green chemistry, micro-modules, reaction rates, project-based learning, environmental character

Received : 07, March
Revised : 17, April
Accepted: 29, May

ABSTRACT

This study aims to analyze trends, effectiveness, and research gaps in the integration of green chemistry within chemistry education, particularly in the development of project-oriented micro-modules on reaction rates. The study employed a Systematic Literature Review (SLR) method using the PRISMA approach to ensure a transparent and rigorous selection process. The results indicate that the integration of green chemistry has shown a significant upward trend over the past five years, with implementations occurring through curriculum design, active learning approaches, and the development of instructional materials. Approaches such as Project-Based Learning (PjBL), Problem-Based Learning (PBL), and contextual approaches including socio-scientific issues and ethnoscience demonstrate positive contributions to improving students' conceptual understanding of chemistry and fostering environmental character. In conclusion, this study highlights the need to develop project-oriented micro-modules on reaction rates integrated with green chemistry as a more comprehensive and sustainable instructional innovation.

INTRODUCTION

The evolution of chemistry education in the modern era reflects a significant paradigm shift, moving from a concept-oriented approach toward learning that is more contextual, sustainable, and relevant to real-world challenges. This transformation is characterized by an increasing emphasis on the integration of green chemistry as a foundational framework within chemistry education. Green chemistry is no longer viewed merely as a technical approach for designing safer chemical processes, but rather as a paradigm that emphasizes ethical responsibility toward environmental sustainability and human health (Etzkorn & Ferguson, 2022). Within the educational context, the integration of green chemistry is essential for enabling students to understand the interconnections between chemical science and global sustainability issues, including climate change and environmental degradation. Furthermore, this integration aligns with the objectives of the Sustainable Development Goals (SDGs), particularly those related to responsible consumption and production (Mitarlis et al., 2023). The adoption of systems thinking approaches further supports students in comprehending the complex interrelationships among chemical systems, environmental dynamics, and societal impacts in a holistic manner (Hurst, 2020). Consequently, contemporary chemistry education extends beyond cognitive development, encompassing the cultivation of environmental awareness and responsible character formation. This highlights the strategic role of chemistry education in shaping future generations who are not only academically competent but also environmentally responsible. Therefore, innovative instructional strategies are required to effectively integrate green chemistry concepts across various chemistry topics.

In line with these developments, numerous studies have explored the implementation of green chemistry through active learning approaches. One widely adopted method is Problem-Based Learning (PBL), which facilitates students' understanding of chemical concepts through the analysis of real-world environmental issues. Empirical findings indicate that PBL enhances students' comprehension of green chemistry principles and their ability to connect theoretical knowledge with practical contexts (Vaz et al., 2025). Similarly, Project-Based Learning (PjBL) has been shown to significantly improve students' critical thinking skills, creativity, and conservation-oriented character (Sudarmin et al., 2023). Socioscientific Issues (SSI)-based approaches also demonstrate strong potential in increasing the relevance of chemistry learning by linking concepts to real-world challenges, such as pesticide use (Zowada et al., 2019). Additionally, ethnoscience approaches enable the incorporation of local knowledge as a contextual learning resource, thereby enhancing both conceptual understanding and environmental awareness (Zidny & Eilks, 2022). Despite the demonstrated effectiveness of these approaches, their implementation still faces several challenges, including conceptual complexity, limited instructional time, and the lack of structured learning media that support systematic integration. Moreover, certain green chemistry concepts, particularly those involving technical aspects such as atom economy and catalysis, are often perceived as difficult by students (Vaz et al., 2025). These challenges underscore the need for more structured instructional strategies supported by innovative learning media. In this regard, the development of instructional media emerges as a critical factor in enhancing the effectiveness of these pedagogical approaches.

Within the domain of instructional media development, learning modules have been widely recognized as effective tools for supporting independent and flexible learning. Prior research indicates that modules integrating science process skills and chemical representations can significantly improve students' conceptual understanding (Apriwanda et al., 2021). However, most existing modules predominantly focus on cognitive aspects and rarely incorporate explicit integration of green chemistry principles or the development of environmental character. Furthermore, current innovations in instructional media have yet to fully accommodate the simultaneous integration of active learning approaches and sustainability contexts. Previous studies also reveal that the implementation of green chemistry within higher education curricula remains limited and is often positioned as an elective component rather than a core element (Vaz et al., 2024). This indicates that the integration of green chemistry has not been systematically embedded within chemistry education. Additionally, safety considerations in chemistry education require a paradigm shift from rule-based instruction toward risk analysis and the cultivation of a safety culture (Goode et al., 2021), which is inherently aligned with the preventive principles of green chemistry. Thus, there is a pressing need to develop instructional media that not only enhance conceptual understanding but also integrate safety and sustainability dimensions. This necessity reinforces the urgency of developing innovative learning media capable of addressing these multidimensional educational demands.

A further analysis of the literature reveals a substantial research gap within the field of chemistry education. Although numerous studies have investigated green chemistry integration, active learning approaches, and instructional media development, these efforts are often conducted in isolation and lack integration within a cohesive instructional system. Systematic review studies in science education highlight that research fields frequently exhibit fragmentation, with diverse methodologies and limited alignment across pedagogical innovations, thereby hindering comprehensive implementation . Moreover, evidence suggests that the effectiveness of educational interventions is often evaluated based on self-reported perceptions rather than robust experimental designs, limiting the strength of empirical conclusions . In addition, abstract chemistry topics such as reaction rates are rarely contextualized within sustainability frameworks, despite the need for contextualized approaches to facilitate deeper understanding. The integration of contextual approaches such as SSI and ethnoscience also remains limited to specific cases and has not been widely generalized across chemistry topics. These findings indicate a critical need for the development of instructional media that integrate conceptual content, pedagogical approaches, and sustainability perspectives within a unified framework. Therefore, the primary research gap lies in the lack of comprehensive integration among content, pedagogy, and instructional media in chemistry education.

Based on this background, this study is both relevant and necessary, as it seeks to address the need for more integrative and sustainable innovations in chemistry education. The primary objective of this research is to analyze trends, effectiveness, and research gaps in the integration of green chemistry within chemistry learning, particularly in the development of project-oriented micro-modules on reaction rates through a systematic literature review approach. Systematic reviews have been recognized as rigorous methodologies for synthesizing existing knowledge, identifying patterns, and uncovering research limitations across studies. Additionally, this study aims to examine how active learning approaches such as PjBL and PBL, as well as contextual approaches such as SSI and ethnoscience, contribute to improving students' conceptual understanding and environmental character. Furthermore, this research seeks to identify gaps that may inform the development of more innovative instructional media. By adopting a systematic literature review approach, this study not only summarizes prior findings but also analyzes emerging trends and patterns within the field. This approach enables a comprehensive understanding of current developments in chemistry education while providing a strong theoretical foundation for the design of innovative micro-modules.

Based on these objectives, this study is guided by three primary research questions. First, what are the trends, characteristics, and forms of implementation of green chemistry integration in chemistry education based on previous research? Second, how effective are active learning approaches such as PjBL and PBL, as well as contextual approaches such as SSI and ethnoscience, in improving students' conceptual understanding and environmental character? Third, what research gaps can be identified in the development of instructional media that integrate green chemistry, project-based learning, and environmental character formation? These research questions are designed to provide a comprehensive overview of the current state of research in chemistry education while identifying opportunities for future development. By addressing these questions, this study is expected to contribute significantly to the advancement of innovative and sustainability-oriented chemistry education. Furthermore, the findings of this study are anticipated to serve as a foundational basis for the development of project-based micro-modules on reaction rates that are integrated with green chemistry principles. Consequently, this research offers not only theoretical contributions but also practical implications for improving chemistry education practices.

THEORETICAL REVIEW

The theoretical framework of this study emphasizes the integration of green chemistry, active learning approaches, and instructional media development within the context of sustainability-oriented chemistry education. In general, the evolution of theories in chemistry education reflects a paradigm shift from content-based instruction toward contextual and sustainability-based learning. Green chemistry emerges as a central foundation in this transformation, as it emphasizes the design of chemical processes that are safe, efficient, and environmentally benign (Etzkorn & Ferguson, 2022). Moreover, green chemistry plays a significant role in supporting the achievement of the Sustainable Development Goals (SDGs), particularly in promoting responsible consumption and production (Mitarlis et al., 2023). In educational settings, this approach extends beyond cognitive aspects to include the development of environmental awareness and character. Therefore, the integration of green chemistry is essential for fostering multidimensional competencies encompassing knowledge, attitudes, and skills. This perspective highlights the necessity of designing chemistry learning in a holistic and contextual manner. Accordingly, this theoretical review positions green chemistry as the primary foundation for developing sustainable chemistry education.

Green Chemistry Theory in Education

Green chemistry is defined as an approach aimed at reducing or eliminating the use and generation of hazardous substances in chemical processes. Within the educational context, green chemistry is not only understood as scientific content but also as a conceptual framework that emphasizes environmental and societal responsibility (Etzkorn & Ferguson, 2022). Its integration into learning aims to enhance students' awareness of the environmental impact of chemical practices while encouraging the development of innovative solutions to environmental challenges. Previous studies indicate that integrating green chemistry into education can foster environmentally responsible behavior and sustainability awareness (Mitarlis et al., 2023). However, its implementation in higher education curricula remains limited and is often confined to specific courses rather than being systematically embedded (Vaz et al., 2024). This highlights the need for more structured strategies to integrate green chemistry into chemistry education. Thus, green chemistry theory serves as a foundational basis for developing learning that is relevant to global challenges.

Systems Thinking in Chemistry Learning

Systems thinking is an approach that emphasizes understanding the complex relationships among components within a system. In chemistry education, it is applied to help students comprehend the interconnections between chemical processes, environmental systems, and societal impacts (Hurst, 2020). This approach enables learners to analyze cause-and-effect relationships holistically rather than in a fragmented manner. Additionally, systems thinking supports students in evaluating the long-term consequences of chemical activities on the environment. Within the framework of green chemistry, systems thinking is particularly important as it facilitates the integration of multiple concepts into a unified understanding. Research indicates that systems thinking enhances higher-order thinking skills; however, its application in chemistry education remains limited and requires appropriate instructional design. Therefore, systems thinking is a crucial theoretical component in supporting sustainability-oriented chemistry learning.

Problem-Based Learning (PBL) Theory

Problem-Based Learning (PBL) is a student-centered instructional approach that uses problem-solving as a means to facilitate conceptual understanding. In chemistry education, PBL is employed to connect theoretical concepts with real-world problems relevant to students' daily lives. Studies have shown that PBL improves students' understanding of green chemistry concepts and their ability to apply knowledge in real contexts (Vaz et al., 2025). Furthermore, PBL promotes the development of critical thinking and analytical skills. However, some research indicates that students may encounter difficulties when dealing with complex concepts through this approach. This suggests that PBL should be supported by effective instructional media to optimize learning outcomes. Consequently, PBL represents a relevant theoretical framework for problem-oriented chemistry learning.

Project-Based Learning (PjBL) Theory

Project-Based Learning (PjBL) emphasizes active student engagement in completing projects that are meaningful and relevant to real-life situations. In chemistry education, PjBL enhances critical thinking, creativity, and collaboration skills. Empirical evidence suggests that PjBL contributes to the development of conservation-oriented and entrepreneurial character among students (Sudarmin et al., 2023). Additionally, it enables learners to apply chemical concepts in authentic contexts, thereby increasing the relevance of learning. Within green chemistry education, PjBL provides opportunities for students to design solutions to environmental problems. However, its successful implementation requires careful planning and the support of appropriate instructional media. Therefore, PjBL is considered an effective approach for project-oriented and sustainability-focused chemistry learning.

Socio-Scientific Issues (SSI) Approach

The Socio-Scientific Issues (SSI) approach integrates real-world social issues related to science into the learning process. In chemistry education, SSI connects chemical concepts with societal and environmental challenges. Research indicates that SSI enhances students' understanding of chemistry concepts while increasing awareness of the social implications of chemical use (Zowada et al., 2019). Moreover, SSI fosters critical thinking and informed decision-making based on scientific and ethical considerations. However, its implementation requires careful selection of relevant contexts and well-designed instructional materials. Thus, SSI serves as an essential approach for contextual and meaningful chemistry learning.

Ethnoscience Approach in Chemistry Learning

Ethnoscience refers to the integration of local and cultural knowledge into science education. In chemistry learning, this approach enhances contextual relevance by linking scientific concepts with students' everyday experiences. Studies show that ethnoscience integration improves conceptual understanding and promotes environmental sustainability awareness (Zidny & Eilks, 2022). Additionally, it enables students to recognize the relationship between chemical knowledge and local cultural practices. Despite its potential, the implementation of ethnoscience remains limited and requires further development of appropriate instructional tools. Therefore, ethnoscience represents an important approach for culturally responsive and contextual chemistry education.

Instructional Media Development (Modules and Micro-Modules)

Instructional media play a crucial role in enhancing the effectiveness of chemistry learning. Learning modules are among the most widely used media, as they support independent and flexible learning. Research demonstrates that well-designed modules can improve students' conceptual understanding, particularly in representing chemical concepts (Apriwanda et al., 2021). However, most existing modules focus primarily on cognitive aspects and do not explicitly integrate green chemistry or environmental character development. Recently, micro-modules have emerged as an innovative format for presenting content in concise and structured units. Micro-modules allow for the integration of multiple learning approaches within a flexible medium, making them particularly suitable for complex topics such as reaction rates. Therefore, the development of micro-modules represents a promising strategy for improving chemistry learning quality.

Chemical Safety Education as Part of Green Chemistry

Chemical safety education is an essential component of sustainable chemistry learning. This approach extends beyond the use of personal protective equipment to include risk assessment and hazard management (Goode et al., 2021). A risk-based perspective aligns with green chemistry principles, which emphasize the prevention of hazards at the source. In educational contexts, integrating chemical safety enhances students' awareness of safety and sustainability. However, its implementation remains limited and is often theoretical rather than practice-oriented. Thus, integrating chemical safety with green chemistry is essential for developing comprehensive and responsible chemistry education.

METHODOLOGY

This study employed a Systematic Literature Review (SLR) approach, following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency, reproducibility, and methodological rigor in the literature selection process. The research design was descriptive-analytical in nature, aiming to identify research trends, evaluate the effectiveness of pedagogical approaches, and examine existing gaps related to the integration of green chemistry within project-oriented micro-modules on reaction rates. The application of systematic review methodologies has been widely recognized as an effective strategy for synthesizing fragmented research findings and generating structured insights across educational studies.

The sample of this study consisted of peer-reviewed journal articles retrieved from the Scopus database using the keywords "Green Chemistry Education", "Project-Based Learning in Chemistry", and "Environmental Character Development". The initial identification stage yielded 124 articles, which were subsequently filtered through a multi-stage selection process based on predefined inclusion and exclusion criteria. These criteria included publication years (2020–2025), topical relevance, availability of abstracts, and journal quality indexed within quartiles Q1–Q4. The selection process followed four sequential stages—identification, screening, eligibility, and inclusion—resulting in a final corpus of 10 articles deemed suitable for in-depth analysis. This structured filtering process aligns with established systematic review practices aimed at enhancing the validity and reliability of synthesized findings.

The research instrument utilized in this study was a data extraction sheet developed based on key indicators relevant to the analysis of the selected literature. These indicators included research trends, instructional approaches, integration of green chemistry principles, types of learning media, and reported learning outcomes related to effectiveness. Additionally, the extraction framework incorporated theoretical dimensions underpinning each study, such as green chemistry, Project-Based Learning (PjBL), Problem-Based Learning (PBL), socioscientific issues (SSI), ethnoscience, and systems thinking (Etzkorn & Ferguson, 2022; Hurst, 2020; Sudarmin et al., 2023; Zowada et al., 2019; Zidny & Eilks, 2022). The instrument also facilitated the identification of research limitations and their relevance to the development of micro-modules as the focal point of this study. Data collection procedures involved systematic searching, article selection, and coding based on predetermined categories. Each selected article was analyzed comprehensively to identify patterns, similarities, and discrepancies in research findings. This process was conducted iteratively to ensure data consistency and analytical validity.

The data analysis method applied in this study was qualitative descriptive analysis using a thematic synthesis approach. The analysis was structured around three main dimensions: (1) trends and characteristics of green chemistry integration, (2) the effectiveness of active learning approaches, and (3) existing research gaps. Extracted data were systematically categorized and examined to identify relationships between instructional approaches and learning outcomes, particularly in terms of students' conceptual understanding and environmental character development (Mitarlis et al., 2023; Vaz et al., 2025). Furthermore, the analysis evaluated the extent to which existing instructional media simultaneously integrate green chemistry principles and project-based learning. The findings were then synthesized to generate comprehensive conclusions regarding the current state of research in this field. By adopting this methodological approach, the study not only provides a descriptive overview but also offers an in-depth interpretation of existing literature. The entire analytical process was conducted systematically and transparently to ensure replicability and methodological robustness, in line with best practices in systematic review research.

RESULTS

Trends in the Integration of Green Chemistry in Chemistry Education

The synthesis results indicate that research on the integration of green chemistry in chemistry education has increased significantly in recent years, particularly during the 2020–2025 period. This trend reflects a broader shift in science education toward sustainability-oriented learning, where chemistry is positioned not only as a body of knowledge but also as a discipline closely connected to environmental and societal challenges. Several studies emphasize green chemistry as a central framework to support the achievement of Sustainable Development Goals (SDGs), particularly those related to environmental sustainability and responsible resource management (Mitarlis et al., 2023; Etzkorn & Ferguson, 2022).

Furthermore, the adoption of systems thinking approaches has emerged as a key trend, enabling students to understand the complex interrelationships between chemical processes and their environmental impacts (Hurst, 2020). The analyzed studies reveal that green chemistry integration is implemented through multiple pathways, including curriculum design, instructional material development, and project-based learning activities. However, despite this growing interest, the implementation remains limited and not yet systematically embedded within higher education curricula (Vaz et al., 2024). In addition, a considerable proportion of studies are still conceptual rather than empirical, indicating a lack of robust experimental validation. These findings suggest that although research attention is increasing, practical implementation requires further development and standardization.

Table 1. Trends in Green Chemistry Integration

Trend Aspect	Key Findings
Research focus	Integration of green chemistry and sustainability
Approaches	Systems thinking, SDGs alignment
Implementation	Curriculum, instructional materials, learning activities
Limitations	Lack of systematic integration, predominantly conceptual
Dominant period	2020–2025

Characteristics of Instructional Approaches

The analysis demonstrates that a variety of active learning approaches are employed in the reviewed studies, with a predominance of Project-Based Learning (PjBL), Problem-Based Learning (PBL), and contextual approaches such as Socioscientific Issues (SSI) and ethnoscience. PjBL is widely used to enhance student engagement through authentic, real-world projects, fostering meaningful learning experiences (Sudarmin et al., 2023). Meanwhile, PBL facilitates conceptual understanding by encouraging students to analyze real-life problems, particularly those related to environmental and green chemistry contexts (Vaz et al., 2025).

SSI-based approaches contribute to the relevance of chemistry learning by linking scientific concepts with societal and environmental issues, such as pesticide use and its implications (Zowada et al., 2019). Similarly, ethnoscience approaches integrate local knowledge systems into chemistry education, promoting contextual understanding and environmental awareness (Zidny & Eilks, 2022). Although some studies combine multiple approaches, most implementations remain partial and lack a fully integrated instructional design. This indicates that while pedagogical diversity is evident, comprehensive integration across approaches is still limited.

Table 2. Characteristics of Instructional Approaches

Approach	Description
PjBL	Project-based learning
PBL	Problem-based learning
SSI	Socioscientific issues-based learning
Ethnoscience	Integration of local knowledge
Systems Thinking	Holistic understanding

Effectiveness of Instructional Approaches on Conceptual Understanding and Environmental Character

The findings reveal that active learning approaches contribute positively to both students' conceptual understanding of chemistry and the development of environmental character. PjBL has been shown to enhance critical thinking skills, creativity, and conservation-oriented attitudes among students (Sudarmin et al., 2023). Similarly, PBL improves students' understanding of green chemistry concepts and their ability to relate theoretical knowledge to real-world situations (Vaz et al., 2025).

SSI-based approaches increase students' awareness of the social and environmental implications of chemical practices, while ethnoscience approaches strengthen conceptual understanding by contextualizing learning within local cultural knowledge (Zowada et al., 2019; Zidny & Eilks, 2022). In addition, project-based learning modules demonstrate high validity and effectiveness in improving conceptual mastery (Apriwanda et al., 2021). Nevertheless, some studies report difficulties in understanding complex chemical concepts, indicating that the effectiveness of these approaches is context-dependent. Therefore, while overall learning outcomes show improvement, variations in effectiveness highlight the importance of instructional design and implementation quality.

Table 3. Effectiveness of Instructional Approaches

Approach	Key Outcomes
PjBL	Enhances conservation character
PBL	Improves conceptual understanding
SSI	Increases environmental awareness
Ethnoscience	Enhances contextual relevance
Modules	High validity and effectiveness

Use of Instructional Media in Green Chemistry Integration

The synthesis indicates that the use of instructional media in green chemistry integration remains limited and underdeveloped. Several studies focus on the development of learning modules, which have proven effective in enhancing students' conceptual understanding, particularly in representing chemical concepts (Wimbi et al., 2021). However, most existing modules do not explicitly integrate green chemistry principles or environmental character development.

Moreover, many studies emphasize pedagogical approaches without being supported by structured instructional media, suggesting a lack of alignment between teaching strategies and learning resources. Although some research highlights the potential of integrating instructional media with active learning approaches, such integration is still context-specific and not widely implemented. These findings indicate a need for more innovative and systematically designed instructional media that incorporate sustainability principles.

Table 4. Instructional Media

Media Type	Findings
Modules	Effective in improving understanding
Micro-modules	Rarely developed
Digital media	Limited usage
Green chemistry integration	Not yet optimal
Environmental character	Not integrated

Research Gaps in Green Chemistry Integration

The analysis identifies several significant research gaps in the field of green chemistry integration in chemistry education. First, most studies focus on instructional approaches without systematically integrating instructional media. Second, the incorporation of green chemistry into curricula remains limited and lacks comprehensive implementation (Vaz et al., 2024). Third, the development of students' environmental character is not consistently addressed as a primary research focus.

Fourth, active learning approaches such as PjBL, PBL, SSI, and ethnoscience are often applied independently rather than within an integrated instructional framework. Fifth, specific chemistry topics, such as reaction rates, are rarely contextualized within green chemistry perspectives. Additionally, several studies report limitations related to small-scale implementation and lack of empirical validation, which restricts generalizability.

These gaps indicate substantial opportunities for future research, particularly in developing integrative instructional models that combine content, pedagogy, and media within a sustainability framework. Such efforts are essential to advance chemistry education toward a more holistic, contextual, and environmentally responsible paradigm.

Table 5. Research Gaps

Aspect	Identified Gaps
Green chemistry integration	Not systematic
Instructional media	Not structured
Instructional approaches	Fragmented
Content topics	Not specific
Environmental character	Underexplored

DISCUSSION

Trends, Characteristics, and Forms of Green Chemistry Integration

The findings of this study indicate a significant increase in the integration of green chemistry within chemistry education, particularly over the past five years. This trend reflects a paradigm shift in which green chemistry is no longer positioned as supplementary content but rather as a central conceptual framework in modern chemistry education. These findings are consistent with prior studies emphasizing that green chemistry serves as a strategic approach to linking chemical knowledge with global sustainability challenges (Etzkorn & Ferguson, 2023; Mitarlis et al., 2023). Furthermore, the synthesis reveals that green chemistry integration occurs through multiple forms, including curriculum incorporation, development of instructional materials, and implementation within project-based learning environments. However, such implementation remains uneven and tends to be partial, as green chemistry is often still positioned as an elective component rather than a core curricular element (Vaz et al., 2024).

A key characteristic identified in this study is the growing adoption of systemic approaches to understanding the interconnections among chemistry, environmental systems, and society. This is particularly evident in the increasing use of systems thinking, which facilitates students' comprehension of complex sustainability-related issues (Hurst, 2020). In addition, the integration of green chemistry is closely associated with the development of environmental awareness and social responsibility among students. Nevertheless, the findings also reveal that most existing studies remain conceptual in nature, with limited empirical validation. This indicates a persistent gap between theoretical development and practical implementation. Thus, while research trends demonstrate substantial growth, systematic and comprehensive implementation remains limited.

The significance of these findings lies in their ability to provide a comprehensive overview of the evolution of green chemistry integration in chemistry education. They highlight a shift toward more contextual and sustainability-oriented learning paradigms. Moreover, the study contributes to the field by synthesizing diverse approaches into a unified analytical framework, thereby offering a foundation for future instructional innovations, such as the development of project-oriented micro-modules. The implications of these findings underscore the need for curriculum reform and the development of instructional media that systematically integrate green chemistry principles. However, a limitation of this study is that most of the analyzed literature remains conceptual, necessitating further empirical investigations.

Effectiveness of Active Learning Approaches

The results demonstrate that active learning approaches, including Project-Based Learning (PjBL), Problem-Based Learning (PBL), and contextual approaches such as Socioscientific Issues (SSI) and ethnoscience, contribute significantly to improving both students' conceptual understanding and environmental character. These findings are consistent with previous research indicating that PjBL enhances critical thinking skills, creativity, and conservation-oriented attitudes (Sudarmin et al., 2023). Similarly, PBL has been shown to effectively improve students' understanding of green chemistry concepts and their ability to connect theoretical knowledge with real-world contexts (Vaz et al., 2025).

SSI-based approaches further strengthen students' awareness of the social and environmental implications of chemical applications (Zowada et al., 2019), while ethnoscience approaches enhance learning relevance by integrating local knowledge systems (Zidny & Eilks, 2022). Despite these positive outcomes, the effectiveness of these approaches is not always consistent and is influenced by several factors, including content complexity, instructional design, and students' prior knowledge. In particular, some green chemistry concepts—especially those involving technical aspects—remain challenging for students (Vaz et al., 2025).

The significance of these findings lies in demonstrating that chemistry learning can simultaneously address cognitive and affective domains, reinforcing the importance of integrating environmental character development into instructional practices. The contribution of this study is its comprehensive synthesis of multiple pedagogical approaches within a single analytical framework. The implications suggest that future instructional designs should integrate these approaches simultaneously rather than applying them in isolation. However, a limitation is that most studies were conducted on a small scale, limiting the generalizability of their findings.

Research Gaps

The study identifies several critical research gaps in the integration of green chemistry within chemistry education. One of the primary gaps is the lack of systematic integration among green chemistry concepts, active learning approaches, and environmental character development within a unified instructional design. This finding aligns with existing literature indicating that most studies examine these aspects independently rather than holistically. Additionally, the integration of green chemistry within higher education curricula remains limited and has not yet achieved widespread impact (Vaz et al., 2025).

Another significant gap is the limited development of instructional media specifically designed to integrate green chemistry with particular chemistry topics, such as reaction rates. Existing learning modules, while effective in improving conceptual understanding, often do not explicitly incorporate green chemistry principles or environmental character development (Wimbi et al., 2021). Furthermore, contextual approaches such as SSI and ethnoscience are still applied within specific contexts and have not been broadly generalized across different chemistry topics (Zidny & Eilks, 2022; (Zowada et al., 2020).

The importance of these findings lies in their ability to map research gaps that can guide future innovations in chemistry education. This study contributes by providing a comprehensive overview of these gaps, offering a clear direction for subsequent research. The implications highlight the need to develop innovative instructional media, such as project-based micro-modules, that integrate content, pedagogy, and sustainability dimensions. However, a limitation of this study is that the identified gaps are dependent on the available literature, which may not fully represent all existing research areas.

Overall Significance and Contribution of the Study

Overall, this study holds substantial significance for the advancement of chemistry education. It not only provides insights into current research trends and the effectiveness of instructional approaches but also identifies critical research gaps that can inform future innovations. The primary contribution of this study lies in integrating multiple pedagogical approaches within a comprehensive analytical framework. Additionally, it establishes a strong theoretical foundation for the development of project-oriented micro-modules on reaction rates integrated with green chemistry principles.

From a practical perspective, the findings can serve as a reference for educators in designing more contextual and sustainability-oriented learning experiences. The study also offers recommendations for the development of innovative instructional media that align with contemporary educational needs. From a theoretical standpoint, this research enriches the literature by providing a systematic and comprehensive synthesis of existing studies.

Nevertheless, this study has certain limitations, including the relatively small number of analyzed articles and its exclusive reliance on literature review without empirical validation. Therefore, future research should focus on implementing and testing the proposed frameworks in real classroom settings. In conclusion, this study contributes significantly to the development of more relevant, contextual, and sustainability-oriented chemistry education.

CONCLUSIONS AND RECOMMENDATIONS

The findings of this study indicate that the integration of green chemistry in chemistry education has experienced significant development, particularly within learning contexts oriented toward sustainability and real-life relevance. The main findings reveal that current research trends are shifting toward the integration of green chemistry concepts with active learning approaches such as Project-Based Learning (PjBL), Problem-Based Learning (PBL), as well as contextual approaches including socio-scientific issues (SSI) and ethnoscience. Furthermore, the results demonstrate that these approaches contribute positively to improving students' conceptual understanding of chemistry and fostering environmental character, although their effectiveness varies depending on instructional design and implementation context.

At the same time, this study identifies substantial research gaps, particularly regarding the lack of systematic integration among green chemistry concepts, instructional media, and active learning approaches within a unified instructional design. In addition, the development of instructional mediaespecially micro-modules that explicitly integrate green chemistry and environmental character development remains limited. Therefore, this study provides a significant contribution by offering a comprehensive synthesis that not only describes the current state of research but also identifies future research directions. This contribution strengthens the position of this study within the field of chemistry education, particularly in advancing sustainability-oriented and 21st-century competency-based learning.

Based on these findings, future research is recommended to focus on the development and empirical validation of innovative instructional media capable of simultaneously integrating green chemistry, project-based learning, and environmental character development. Further studies should also emphasize the design of more systematic and contextual instructional models, particularly for abstract chemistry topics such as reaction rates, in order to enhance students' deep conceptual understanding. Additionally, future research should involve larger and more diverse samples to examine the effectiveness of instructional approaches across various educational contexts. The integration of digital technologies in the development of micro-modules should also be explored to improve learning flexibility and accessibility. Moreover, contextual approaches such as SSI and ethnoscience need to be expanded to be applicable across a wider range of chemistry topics, rather than being limited to specific contexts. In conclusion, future research is expected to generate more comprehensive, applicable, and impactful instructional innovations that contribute to the advancement of sustainable chemistry education.

FURTHER STUDY

This study is subject to several limitations, as it relies solely on a Systematic Literature Review (SLR) with a relatively limited number of analyzed articles, most of which are conceptual or conducted on a small scale, thereby restricting the generalizability and empirical strength of the findings. In addition, variations in research design, context, and participant characteristics across the selected studies may influence the consistency of the results. Therefore, future research is recommended to conduct empirical investigations using experimental or quasi-experimental designs to validate the effectiveness of integrating green chemistry, project-based learning, and environmental character development within micro-module frameworks in real classroom settings. Further studies should also involve larger and more diverse samples to enhance generalizability, as well as explore the development of innovative digital micro-modules that integrate sustainability principles with active learning approaches. Moreover, future research is encouraged to expand the application of this integrated framework to other abstract chemistry topics and to examine its long-term impact on students' conceptual understanding, environmental awareness, and behavioral change.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to colleagues and academic peers who have provided valuable insights, constructive feedback, and thoughtful suggestions throughout the development of this study. Their contributions have significantly enhanced the quality and clarity of this paper.

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