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A Project-Based Learning Student Worksheet Based on STEM and Green Chemistry to Improve Students' Conceptual Understanding and 21st Century Competencies

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ABSTRAK

Artikel ini menggunakan metode narrative review yang membahas pengembangan dan implementasi lembar kerja peserta didik berbasis Project-Based Learning yang terintegrasi dengan pendekatan STEM dan prinsip Green Chemistry untuk meningkatkan pemahaman konsep dan keterampilan abad ke-21 peserta didik. Pendidikan saat ini menghadapi tantangan untuk tidak hanya menekankan penguasaan materi, tetapi juga membekali peserta didik dengan keterampilan berpikir kritis, pemecahan masalah, kolaborasi, komunikasi, kreativitas, serta kesadaran terhadap isu lingkungan global. Integrasi model PjBL dengan pendekatan STEM dan Green Chemistry diyakini mampu menjadi solusi yang relevan dan kontekstual dalam pembelajaran kimia yang bermakna. Tinjauan ini mengulas hasil-hasil penelitian nasional dan internasional yang dipublikasikan dalam rentang waktu 2020–2025, dan menunjukkan bahwa penggunaan LKPD berbasis pendekatan tersebut dapat meningkatkan keaktifan belajar, pemahaman konsep secara mendalam, serta mendorong peserta didik untuk mengembangkan keterampilan abad ke-21. Selain itu, integrasi prinsip Green Chemistry dalam pembelajaran memberikan kontribusi penting dalam menanamkan nilai-nilai keberlanjutan dan tanggung jawab lingkungan sejak dini. Artikel ini juga merekomendasikan perlunya pengembangan lebih lanjut dan penelitian empiris untuk menguji efektivitas LKPD ini dalam berbagai konteks pendidikan, khususnya pada pembelajaran kimia tingkat sekolah menengah.

ABSTRACK

This article is a narrative review that discusses the development and implementation of a student worksheet based on Project-Based Learning *(PjBL) integrated with the STEM (Science, Technology, Engineering, and Mathematics) approach and the principles of* Green Chemistry *to enhance students' conceptual understanding and 21st century competencies. Today's education faces the challenge of not only focusing on content mastery but also equipping students with critical thinking, problem-solving, collaboration, communication, creativity, and awareness of global environmental issues. The integration of PjBL with STEM and Green Chemistry offers a relevant and contextual solution for meaningful chemistry learning. This review analyzes national and international studies published between 2020 and 2025, showing that the use of worksheets based on this integrated approach can improve students' learning engagement, deepen conceptual understanding, and foster 21st century skills. Moreover, incorporating Green Chemistry principles into learning contributes significantly to instilling values of sustainability and environmental responsibility from an early age. This article also recommends further development and empirical research to test the effectiveness of such worksheets in various educational contexts, particularly in secondary school chemistry instruction.*

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INTRODUCTION

The demands of 21st-century education emphasize the importance of developing student competencies that extend beyond content mastery, encompassing critical thinking, creativity, collaboration, communication, and awareness of environmental and sustainability issues. In line with the increasing complexity of global challenges, science education—particularly chemistry—is expected to foster meaningful, contextual, and transformative learning experiences (Trilling & Fadel, 2021). One approach considered effective in addressing these challenges is the integration of the Project-Based Learning (PjBL) model with the STEM (Science, Technology, Engineering, and Mathematics) approach and the principles of Green Chemistry.

The PjBL model encourages students to actively construct knowledge through authentic projects that are relevant to everyday life, which has been shown to enhance conceptual understanding and 21st-century skills (Yuliati et al., 2021; Sahal et al., 2022). The STEM approach has proven to strengthen students' scientific literacy and problem-solving abilities in real-world contexts (Fitriani et al., 2023). Integrating Green Chemistry principles into learning is essential for cultivating environmental awareness and sustainability values from an early age (Anastas & Warner, 2020; Putri & Wulandari, 2023).

Several studies have indicated that the development of learning tools, such as student worksheets, that combine these three approaches can improve learning outcomes, student engagement, and higher-order thinking skills (Hidayati et al., 2021; Nugraheni & Azizah, 2024). However, comprehensive studies examining the integration of PjBL, STEM, and Green Chemistry into a single learning tool—such as worksheets—remain limited, particularly in the context of secondary school chemistry education.

This article aims to narratively review various studies that develop or implement student worksheets based on Project-Based Learning integrated with the STEM approach and Green Chemistry principles, and to analyze their contributions to improving students' conceptual understanding and 21st-century competencies.

METHODS

This study employs a narrative review method aimed at summarizing and analyzing a variety of scholarly literature related to the development of Student Worksheets using the Project-Based Learning (PjBL) model based on STEM and the principles of green chemistry. The objective is to improve students' conceptual understanding and 21st-century skills. The narrative review method was chosen because it enables an in-depth exploration of information from various primary sources without the rigid procedures of a systematic review, while still maintaining analytical quality by considering the validity and relevance of the sources used (Ferrari, 2015).

The data sources in this review were obtained from indexed national and international journals such as Sinta, DOAJ, and Scopus, with inclusion criteria: (1) articles published between 2020 and 2025, (2) discussing topics related to worksheets, PjBL, STEM, green chemistry, conceptual understanding, or 21st-century skills, and (3) relevant to the context of chemistry education at the secondary level. The selected literature was then analyzed thematically to identify research trends, approaches to worksheet development, and their impact on student learning outcomes, particularly in terms of conceptual understanding and 21st-century competencies such as critical thinking, communication, collaboration, and creativity (Trilling & Fadel, 2021).

During the analysis process, key themes were classified, such as the integration of STEM in LKPD design, the role of green chemistry principles in sustainable learning, and the effectiveness of the PjBL model in supporting students' mastery of chemistry content. In addition, the methodologies used in the previous studies were reviewed to identify their strengths and limitations as a basis for future development. The review also considered the pedagogical approaches applied, the types of assessment instruments used, and the research findings that demonstrate improvements in conceptual understanding or 21st-century skills among students. This article is expected to provide a comprehensive scientific synthesis to serve as a reference for the future development of PjBL-based LKPD that integrates STEM and green chemistry.

RESULT AND DISCUSSION

Result

Based on the review results, it was found that students who learned using LKPD (Student Worksheets) based on Project-Based Learning (PjBL), STEM, and Green Chemistry showed an increase in conceptual understanding scores across various chemistry topics. This improvement was measurable through comparisons of pretest and posttest results and was also reflected in indicators of conceptual performance, such as the ability to explain concepts, establish relationships between variables, and relate the material to real-life contexts.

Table 1 presents a summary of research findings that highlight the impact of using Student Worksheets (LKPD) based on the integration of Project-Based Learning (PjBL), STEM approaches, and Green Chemistry principles on students' conceptual understanding in chemistry. Each study demonstrates how the implementation of such instructional materials positively influenced students' comprehension of specific chemistry topics. The interventions varied in focus—ranging from PjBL-STEM combinations to STEM-Green Chemistry integrations—and consistently led to improvements in

students' ability to grasp core chemical concepts, as evidenced by pretest-posttest score gains and enhanced performance in interpreting and applying scientific knowledge.

Table 1. The Impact of PjBL–STEM–Green Chemistry Student Worksheets on Conceptual Understanding

Researcher & Year	Learning Materials	Types of Intervention	Main Findings
Hidayati et al. (2021)	Electrolyte Solution	PjBL-STEM Student Worksheet	Concept understanding scores increased from 63 to 84 (gain 0,66)
Sari & Hadi (2024)	Acid – Base Reaction	STEM Student Worksheet	Post test scores increased by 27% over pre test
Nugraheni & Azizah (2024)	Reduction – Oxidation Reaction	STEM-Green Chemistry Student Worksheet	Significant improvement (gain 0,71) in understanding of redox reactions
Yuliati et al. (2021)	Reaction Rate	PjBL Student Worksheet	Students are able to explain the concept of reaction rate factors accurately
Aini & Nasrudin (2023)	Stoichiometry	PjBL-Green Chemistry Student Worksheet	Improve conceptual understanding in calculating mole ratios through projects

The use of this type of student worksheet (LKPD) is effective in developing 21st-century skills, particularly the 4C skills: critical thinking, communication, collaboration, and creativity. This is evident from project activities that encourage students to work in teams, formulate solutions, engage in scientific communication, and create products or ideas using environmentally friendly materials.

Table 2. The Impact of PjBL–STEM–Green Chemistry Student Worksheets on 21st – Century Skills

21st – Century Skills	Achievement Indicators	Research Sources	Hasil Temuan
Critical Thinking	Analyzing data, constructing arguments, and evaluating experimental results	Hidayati et al. (2021); Sari & Hadi (2024)	Students demonstrated argumentative and reflective skills in chemistry projects
Creativity	Designing solutions or products using local or environmentally friendly materials	Aini & Nasrudin (2023); Nugraheni & Azizah (2024)	Students produced innovations such as natural indicators and simple prototypes
Collaboration	Working in groups, sharing roles, and completing projects	Yuliati et al. (2021); Sahal et al. (2022)	Increased social interaction and teamwork effectiveness
Communication	Presenting project results orally and in writing	Fitriani et al. (2023)	Students' presentation and scientific report writing skills improved significantly

Table 2 outlines the influence of Project-Based Learning (PjBL)–STEM–Green Chemistry-based Student Worksheets (LKPD) on the development of students' 21st-century skills, particularly the 4Cs: critical thinking, creativity, collaboration, and communication. The table summarizes how various studies have demonstrated the role of these worksheets in fostering essential competencies through

contextual and inquiry-driven learning activities. The integration of project work, environmental awareness, and interdisciplinary approaches not only supports students' conceptual understanding but also enhances their ability to analyze, innovate, work collaboratively, and communicate scientific ideas effectively. These outcomes affirm the relevance of using such integrated instructional tools to prepare students for the demands of 21st-century education and beyond.

The integrated approach of Project-Based Learning (PjBL), STEM, and green chemistry in the development of student worksheets (LKPD) has made a significant contribution to improving the quality of chemistry learning, both in cognitive aspects and essential 21st-century skills. Overall, these findings indicate that LKPD with a PjBL–STEM approach oriented toward green chemistry is a potential learning medium for enhancing the quality of the chemistry learning process and outcomes by contributing to conceptual mastery and the development of essential skills required in 21st-century education.

Discussion

Based on a review of various literature sources, it can be concluded that the development of PjBL-based LKPD integrated with STEM and oriented toward green chemistry consistently addresses the main challenges in chemistry education—namely, the low level of conceptual understanding and the limited mastery of 21st-century skills among students. These findings directly respond to the research focus, indicating that this integrative approach holds great potential for enhancing the quality of both the process and outcomes of chemistry learning.

The improvement in conceptual understanding found in several studies (Hidayati et al., 2021; Nugraheni & Azizah, 2024; Sari & Hadi, 2024) indicates that project-based learning provides students with the opportunity to learn actively and construct their own knowledge through concrete experiences and scientific investigation. This aligns with the principles of constructivism, which emphasize that knowledge is actively constructed by learners through direct engagement with their environment and authentic tasks (Thomas, 2000). Student worksheets (LKPD) designed with PjBL syntax and STEM elements encourage higher-order thinking processes such as analyzing, evaluating, and creating—core components of the cognitive domain in Bloom's revised taxonomy.

The integration of STEM in the development of student worksheets (LKPD) has been proven to strengthen interdisciplinary connections and support a holistic learning approach. STEM encourages students to understand chemical concepts and relate them to technology, engineering, and mathematics within real-world contexts (Fitriani et al., 2023). This enhances students' ability to solve complex problems, think critically, and generate innovative solutions—competencies that are essential for addressing the challenges of the 21st century (Trilling & Fadel, 2021).

From the perspective of values and character, the integration of green chemistry principles into student worksheets (LKPD) has shown a significant contribution to fostering environmental awareness and sustainable attitudes. Several studies (Putri & Wulandari, 2023; Aini & Nasrudin, 2023) have demonstrated that students involved in experiments using environmentally friendly materials not only gain an understanding of the taught chemical concepts but also develop an awareness of the importance of environmental preservation in scientific practice. This aligns with the views of Anastas & Warner (2020), who emphasize that green chemistry serves not only as a laboratory principle but also as an educational approach to shaping ethical and responsible scientists.

The development of 21st-century skills through this type of student worksheet (LKPD) is supported not only by complex project activities but also by a collaborative structure that facilitates teamwork, scientific communication, and creativity. Sahal et al. (2022), in their meta-analysis, found that Project-Based Learning (PjBL) significantly enhances students' collaborative and communication skills across various educational levels. This strengthens the argument that project-based learning improves not only cognitive outcomes but also affective and social outcomes.

Theoretically, the findings of this review support and simultaneously expand the conceptual framework of 21st-century chemistry education. By combining a pedagogical approach (PjBL), a multidisciplinary approach (STEM), and a values-based approach (Green Chemistry), an integrative and holistic model can be constructed—one that focuses on knowledge transfer as well as the development of skills and character. This model can be referred to as the integrative PjBL–STEM–Green Chemistry model, which holds potential to serve as a new theoretical foundation for the development of sustainable chemistry teaching materials.

By integrating the PjBL approach, STEM, and the principles of Green Chemistry in the development of student worksheets (LKPD), this article presents a synthesis of empirical findings and offers a new framework for chemistry education that is contextual, collaborative, and sustainable. The Integrative PjBL–STEM–Green Chemistry Model developed through this review can serve as a foundation for the development of chemistry learning theories that are aligned with the demands of 21st-century competencies and global sustainability issues.

CONCLUSION

PjBL-based student worksheets (LKPD) integrated with the STEM approach and Green Chemistry principles have been proven effective in enhancing students' conceptual understanding and 21st-century skills in chemistry learning. The use of PjBL–STEM–Green Chemistry-based LKPD has been shown to develop essential 21st-century skills, including critical thinking, collaboration, communication, and

creativity. Project-based activities encourage students to actively participate in learning, work in teams, express ideas both orally and in writing, and design products using environmentally friendly materials. Chemistry learning that is designed in an integrative and contextual manner can strengthen academic achievement while also shaping character and competencies relevant to future challenges.

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