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A Systematic Review: Strategies in Chemistry Learning

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Abstract

This study aims to synthesize research related to learning strategies focusing on chemistry learning research in the last ten years from various reputable journals and proceedings focusing on the last ten years, grounded in the theoretical framework of conceptual change and the challenges posed by chemistry's multiple representational levels (macroscopic, submicroscopic, and symbolic). After searching national and international reputable databases using key patterns of relevance (Pattern 1: "chemistry learning strategies" "Merdeka Curriculum"; Pattern 2: "learning strategies" 'chemistry education'; Pattern 3: 'chemistry learning strategies' 'effective'), the 19 relevant articles were systematically reviewed. Inclusion criteria required publication in reputable journals (Q1–Q4) or proceedings, english language, and explicit discussion of strategy effectiveness in secondary or higher chemistry education. The results showed that cooperative learning and inquiry learning dominated from several articles used as learning that is often applied in the learning process to see its effect on learner achievement, cognitive development, laboratory skills, science process skills, and understanding of science knowledge. The implementation of the Merdeka Curriculum requires educators to provide innovations to the learning strategies applied. Technology-based learning is one form of innovation that is in accordance with the curriculum and the development of the current era. Learning strategies by utilizing ICT create enthusiasm and meaningfulness for students to learn independently. This review contributes a refined theoretical understanding of chemistry specific learning strategies, identifies research gaps, and suggests future directions in chemistry education.

Keywords: chemistry learning, strategy learning, systematic literature review 3

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1. Introduction

The natural sciences, including chemistry, play a crucial role in developing students' scientific knowledge and competencies. Chemistry contributes significantly to scientific and economic development by examining the properties of matter, the composition of substances, and the transformations they undergo under various conditions (Adauyah & Aznam, 2024). Beyond factual knowledge, chemistry involves scientific processes and inquiry practices. A defining characteristic of chemistry learning is its multilevel nature, encompassing macroscopic phenomena, submicroscopic particle interactions, and symbolic representations, commonly conceptualized as Johnstone's Triangle (Rahmadhani et al., 2021). Difficulties in navigating these representational levels often lead to misconceptions and increased cognitive load among learners.

The process of teaching and learning chemistry requires careful consideration so that the chemistry knowledge conveyed can be accepted and understood by students. Learning is an educational process aimed at achieving educational goals. Learning seeks to transform uneducated students into educated ones and those who do not know into those who know (Ernawati et al., 2022). Effective learning objectives aim to develop knowledge, attitudes, and skills, including critical 21st century skills (4Cs) such as critical thinking and collaboration. The learning process is a determining factor in student success, and educators are a vital component in implementing educational standards. Other key factors include learning strategies, instructional media, and student characteristics (Ismono et al., 2018). Learning objectives are best achieved when paired with appropriate and well-formulated strategies (Fatkhurrokhman et al., 2018). The quality of education is influenced by the strategies applied, necessitating their effective management (Sulaiman et al., 2023). To improve learning quality and student engagement, educators must identify learner needs and plan active, appropriate learning strategies (Wiguna et al., 2020), drawing on frameworks like Pedagogical Content Knowledge (PCK).

A learning strategy is a practical way for teachers to plan lessons so students can reach learning goals. Granström et al. (2023) found that teachers use various strategies flexibly to organize instruction based on lesson demands and student understanding. Similarly, Sun et al. (2022) showed that direct instruction and collaborative learning are effective strategies that engage students differently, and teachers may choose or combine them depending on content and needs. The success of a strategy depends on how well it is applied. Proper use allows teachers to plan, evaluate, and reflect on their teaching. As Sulaiman et al. (2023) note, this strategic planning is key to helping students understand chemistry concepts.

Based on this discussion, this systematic review aims to examine the prevailing learning strategies reported in recent chemistry education research and to analyze their theoretical grounding within chemistry-specific frameworks. Furthermore, this review investigates how these strategies are effectively implemented within contemporary curricula to foster students' conceptual understanding, representational competence, and broader learning potential.

2. Research Method

This study employs a Systematic Literature Review (SLR) with a bibliometric analysis component, focused on research conducted over the past ten years (January 2014–December 2024). A systematic literature review is a literature review aimed at identifying and synthesizing all relevant research to determine strategies for chemistry education by establishing themes and templates. Bibliometric analysis is conducted to obtain an overview of the literature across various fields of study. Two methods were used in this study: the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) procedure for data collection (Page et al., 2021) and bibliometric analysis using VOSviewer software. The research steps are shown in Figure 1.

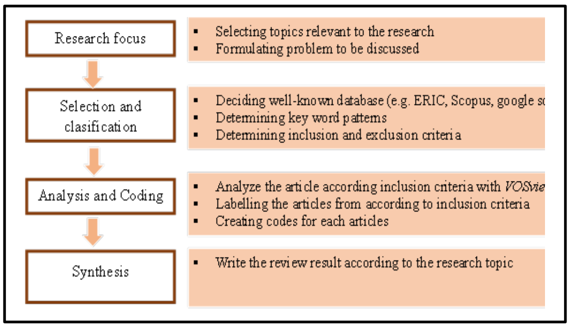

Figure 1. Stages of Systematic Review Research

2.1. Search Strategy & Selection Process

The initial stage in conducting a systematic literature review, where researchers determine the research topic, namely chemistry learning strategie, the research topic: chemistry learning strategies. A comprehensive and reproducible search was performed across multiple databases to ensure breadth and scholarly rigor. The selected databases were:

- Google Scholar: For broad coverage and grey literature.
- Scopus: For its comprehensive coverage of peer-reviewed journals and robust indexing.

- ERIC (Education Resources Information Center): As the primary database for educational research.
- ACS Publications: For disciplinespecific research in chemistry education.

Researchers using relevant keyword patterns (Pattern 1: “chemistry learning strategies” “Merdeka Curriculum”; Pattern 2: “learning strategies” “chemistry education”; Pattern 3: “chemistry learning strategies” “effective”). The topic of learning strategies in chemistry education or chemistry learning in articles is sufficiently familiar to be discussed, as evidenced by the number of articles found in Google Scholar (n = 2,700), Scopus Link (n = 13), ERIC (n = 34), and ACS Publishing (n = 142). The researcher read the abstracts to determine what types of learning strategies were commonly applied in chemistry classrooms and which strategies were considered effective for understanding chemistry material. Not all of the articles found met the criteria relevant to the desired topic.

2.2. Inclusion/Exclusion Criteria and Screening

The criteria used in the study are referred to as inclusion criteria and are outlined in Table 1.

Table 1. The Inclusion Criteria

Criteria	Description
Inclusion	Publication in reputable/Scopus journals such as Q1, Q2, Q3, Q4 journals or proceedings Research written in English Research published in the last 10 years (2013-2023) Research conducted in an educational setting (secondary and higher education) Research related to the subject of chemistry The study in the article includes an explanation of effective teaching strategies for teaching chemistry
Exclusion	Non-chemistry studies, duplicate publications, conceptual papers without data, and studies lacking methodological clarity. Full text not accessible

There are articles after review that can be used in systematic literature reviews. Selected articles are then coded based on seven groups: research objectives, research methods, samples, learning strategies, solutions/suggestions. Next, code analysis within and/or across all included studies is followed in the narrative synthesis process of this study.

2.3. Synthesis

The final stage is to write the results of a systematic literature review.

3. Result and Discussion

3.1. Bibliometric Results

The results of the bibliometric analysis will be interpreted to explore the implications of the findings for chemistry learning strategies. This interpretation involves a deep understanding of trends, research focus, and research objectives, as well as the relationships between key concepts in the analyzed literature. The results of the bibliometric visualization can be seen in Figure 1, which shows that there is a relationship between various concepts and keywords related to chemistry learning strategies.

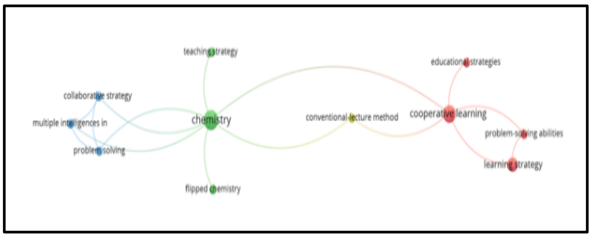

Figure 2. Bibliometric Visualization of Chemistry Learning Strategies

Conclusions can be both specific and general conclusions. Specific conclusions are the results of data analysis or the results of hypothesis testing about the phenomenon of the study. General conclusion must be as a result of generalization or association with similar phenomena in other areas of previous publications. The writers must notice about the consistency triangle (the problem-goal-conclusion must be consistent).

The bibliometric visualization above shows that keywords and concepts are interconnected by lines representing the strength and/or frequency of relationships between those keywords in the literature or data analyzed. Based on Figure 1, the following can be identified.

Cluster 1: Chemistry, Flipped Learning, Teaching Strategy, Collaborative Strategy, Multiple Intelligences, Conventional Lecture Method, Cooperative Learning, Problem Solving
This cluster provides information related to several strategies, including flipped learning, teaching strategy, collaborative strategy, multiple intelligences, conventional lecture method, cooperative learning, and problem solving, which can be applied in the learning process, particularly in chemistry lessons. This cluster mapping indicates that the understanding and application of these learning strategies are the primary focus in efforts to provide information that there are many learning strategies that can be applied in the chemistry learning process. This cluster reflects research on the application of learning strategies aimed at achieving more meaningful chemistry learning. Several articles used in this vosviewer show that there are several strategies that educators can use in the learning process.

A critical synthesis of this cluster reveals a significant research gap: while these strategies are grouped, few studies comparatively analyze their specific efficacy in overcoming chemistry's unique challenges, such as navigating between macroscopic, submicroscopic, and symbolic representations. The strong link to 'problem solving' remains generic; a deeper, chemistry-specific analysis would investigate how collaborative and flipped strategies specifically support stoichiometric or equilibrium problem solving. Furthermore, the inclusion of 'conventional lecture method' within this innovative cluster suggests a body of literature focused on comparative effectiveness, yet methodological weaknesses in these comparisons such as short intervention periods or a lack of control for teacher effect are rarely critically addressed across the studies.

Cluster 2: Cooperative Learning, Educational Strategy, Conventional Lecture Method, Learning Strategy, Problem Solving Abilities
This cluster focuses on cooperative learning, which has been extensively discussed in several articles. Some of these articles explain cooperative learning in relation to conventional lecture methods, learning strategies, educational strategies, and problem-solving abilities. Further discussion of this cluster can provide knowledge and insights, particularly for educators, to learn more about learning strategies, especially cooperative learning.

The dominance of cooperative learning in the literature, as shown in this cluster, necessitates a critical comparison. While studies consistently report its benefits over conventional lectures for general achievement and engagement, its specific impact on remediating chemical misconceptions (e.g., regarding chemical bonding or thermodynamics) or on developing practical laboratory skills is less explored and sometimes yields contradictory findings depending on task structure. This cluster's focus underscores its recognized importance, but also highlights a trend where the strategy itself is often the variable of interest, rather than its detailed application to core, difficult chemical concepts.

Cluster 3: Collaborative Strategy, Multiple Intelligences, Problem Solving
This cluster shows the relationship between several types of learning strategies. The application of multiple intelligences is related to collaborative learning and problem solving. This shows that the application of multiple intelligences learning strategies will involve students in discussions with their groups as an effort to solve problems. The application of collaborative learning is related to multiple intelligences and problem solving. This indicates that the application of collaborative learning can integrate multiple intelligences to solve problems. The application of problem solving is related to multiple intelligences and

collaborative learning. This indicates that the application of problem solving involves good cooperation among students, which involves the multiple intelligences of the students.

This cluster points toward holistic, students centered approaches. However, its analysis remains superficial. A deeper interpretation, guided by theories like Johnstone's Triangle, would probe how collaborative problem-solving leveraging multiple intelligences aids students in integrating macroscopic observations with particulate-level explanations and symbolic notation. This presents a clear emergent research gap: there is minimal exploration of how digital tools (e.g., AI-generated visualizations or virtual labs) can scaffold this collaborative, multi-representational problem-solving process in chemistry, particularly for diverse learners.

3.2. Learning Strategies

Learning is an effort to guide students through the learning process so that they achieve learning objectives that are in line with expectations (Fatkhurrokhman et al., 2018). Learning objectives can be achieved if educators can apply appropriate learning strategies. Learning, as an educational process aimed at achieving specific objectives, cannot be separated from instructional implementation strategies. Instructional strategies must be managed effectively to enhance the quality of education (Sulaiman et al., 2023). Instructional strategies are systematic methods for transferring educators' knowledge to learners to achieve learning objectives (Fatkhurrokhman et al., 2018). There are several types of strategies that can be applied in the learning process, especially in chemistry lessons. Based on several analyses conducted, the article (n=12) provides information on the various types and explanations related to learning strategies. The types of learning strategies described in the article include inquiry learning, problem-based learning, cooperative learning, flipped learning, web-based learning, STEM, didactic, teacher-centered, student-centered, OE3R, game-based learning, and collaborative learning based on multiple intelligences. Based on the twelve articles used, inquiry learning and cooperative learning, as described in bibliometric cluster 2, are topics frequently tested to assess the effectiveness of implementing these strategies in the chemistry learning process.

Cooperative learning is a teaching strategy in which small teams are formed, with each member having different levels of ability, to improve students' understanding of a subject (AgwuUdu, 2018). Based on research conducted by AgwuUdu (2018), it is clear that the application of cooperative learning strategies is more effective in improving student achievement in organic chemistry than lecture methods. Cooperative learning is a teaching strategy that provides a learning environment where students can actively participate in the learning process. Cooperative learning is based on knowledge constructed together through interaction with others. Students exchange ideas with peers or educators, then collectively construct their knowledge (Doris & Ndu, 2018). Based on research conducted by Suryatin (2020), it is explained that learning with cooperative learning strategies can effectively improve students' problem-solving skills. Learning with cooperative learning strategies can also reduce students' anxiety during the chemistry learning process (Oludipe & Awokoy, 2010). In a cooperative learning environment, students can seek information and understanding through active searching (AgwuUdu, 2018). Based on the results of research conducted by Doris and Ndu (2018), educators are recommended to apply cooperative learning strategies to teach natural sciences such as physics, chemistry, and biology in secondary schools, taking into account both male and female students. This is because gender has an influence on the application of cooperative learning. The learning environment with cooperative learning assumes that students seek information and understanding through active minds in each group, reflecting the composition of the class in terms of ability, background, and gender (Oludipe & Awokoy, 2010).

To strengthen the connection to chemistry specific challenges, it is critical to analyze how cooperative learning structures (like jigsaw or think-pair-share) can be strategically used to tackle representational transitions. For instance, one group could focus on a symbolic equation, another on a particulate animation, and another on a macroscopic demonstration, then synthesize understanding. This addresses a key gap: most reviewed studies measure general achievement or attitude, not mastery of chemistry's triplet relationship. Furthermore, cross-study comparison reveals a contradiction: while some studies report uniform success, others note that the effectiveness of cooperative learning on conceptual understanding depends heavily on the design and chemistry content specificity of the group task, a methodological detail often under-reported.

Inquiry learning is learner-centered learning based on the process of investigation (Orosz et al., 2022). Inquiry learning is an approach that enables learners to obtain information and improve critical skills by discovering and investigating a phenomenon (Rahmadhani et al., 2021). This learning strategy is based on constructivist theory, where learners actively create understanding through the learning process. Learners can address problems by conducting experiments, collecting and analyzing data, and drawing conclusions, thereby gaining new knowledge and skills (Bell et al., 2010; Pedaste et al., 2015). Based on the theory of inquiry learning, there are five syntaxes, including engagement, assimilation-accommodation, collaboration, simulation, and implementation (Ismono et al., 2018). Chemistry can be learned through inquiry learning, which involves understanding, exploring, interpreting phenomena, problem-solving, scientific discussion, and critical thinking skills (Rahmadhani et al., 2021). Inquiry learning is an effective strategy to apply in the science learning process for students (Gibson & Chase, 2002). Scientific inquiry requires the use of evidence, logic, and strong imagination in developing explanations related to problems in the natural world (Caparoso & Orleans, 2024). Many studies conducted with secondary school students using inquiry-based learning activities have shown positive effects on student achievement, cognitive development, laboratory skills, scientific process skills, and scientific knowledge understanding (Gibson & Chase, 2002). Learning with inquiry learning strategies can improve high-order thinking skills (HOTS) (Ismono et al., 2018).

The discussion of inquiry learning, while noting its constructivist basis, would be deepened by explicitly linking it to chemistry education frameworks like the 5E model (Engage, Explore, Explain, Elaborate, Evaluate). This provides a clearer lens to analyze its effectiveness for laboratory skill development and combating misconceptions through direct investigation. A critical synthesis must acknowledge a key methodological limitation across many inquiry studies: they often demonstrate success in controlled settings but face significant implementation barriers in resource constrained classrooms, particularly for inquiry requiring sophisticated lab equipment or safety measures. This points directly to an emergent research gap: the potential and challenges of digital inquiry labs (simulations, VR) to provide equitable access to investigative experiences that develop process skills and conceptual understanding of unseen particulate phenomena.

3.3. Learning Strategies in the Merdeka Curriculum

Many studies have been conducted on innovation and strategies in the implementation of the Merdeka Curriculum by applying several strategies that can produce effective and efficient learning and strengthen character education (Rosa et al., 2024). The implementation of the Merdeka Curriculum focuses more on discussions between students and educators in a comfortable learning environment and outdoor classes. Educators do not only explain the material but also shape the character of students to be smart, brave, sociable, independent, competent, polite, not only relying on the ranking system, and adaptable. In today's rapidly evolving world, both students and educators must be able to adapt to technology. The Merdeka Curriculum's learning strategies are based on the use of Information and Communication Technology (ICT). Innovative educational strategies can integrate technologies such as virtual reality, gamification, and artificial intelligence (Rosa et al., 2024).

The connection between the reviewed strategies and the Merdeka Curriculum requires analytical justification beyond description. The curriculum's emphasis on student autonomy, critical thinking, and character development provides a theoretical rationale for why strategies like inquiry and cooperative learning are not just compatible but essential. Specifically, inquiry learning aligns with the curriculum's competency to "reason and process information" through investigation, while cooperative learning directly supports the "collaboration" competency. The integration of technology (e.g., flipped learning, DGBL) is justified by the curriculum's demand for relevance and its focus on leveraging technology for differentiation and independent learning, potentially addressing equity issues in access to diverse learning modalities.

The use of educational technology in teaching material to students can encourage students to be active during the learning process and make learning meaningful (Paristiowati et al., 2024). Research conducted by Caparoso and Orleans (2024) used digital game-based learning (DGBL) based on inquiry learning. Scientific inquiry requires the use of evidence, logic, and imagination in the development of the scientific world. Students are asked to ask questions, investigate, and find solutions to a problem and present evidence-based results. The learning media used in the implementation of this learning is a computer game that can cause changes in students' cognitive skills and motivation.

Technology-based learning in the reviewed article mostly explains the application of the flipped learning strategy in the learning process. Flipped learning facilitates student understanding significantly more than conventional classroom learning. The implementation of flipped learning can make students more prepared to participate in the learning process, and students have the opportunity to interact with peers and educators during classroom learning (Olakanmi, 2017). Flipped learning utilizes electronic learning media in the independent learning process before students enter the classroom. The main objective of the flipped learning strategy is to provide an independent learning environment for students in problem-solving skills. The application of technology to the flipped learning strategy can address time constraints in the classroom, enhance problem-solving skills, foster positive perceptions of learning outcomes among students, and improve interaction and communication among students (Syakdiyah et al., 2018). This aligns with the findings of a study conducted by Nadarajan et al. (2022), which indicates that the implementation of the flipped classroom learning strategy can have a positive effect on student learning outcomes and create an effective learning environment for enhancing students' higher-order thinking skills (HOTS). Educators who already possess the ability to use technology-based learning media can further enhance their competencies to foster student enthusiasm and the meaningfulness of independent learning. The millennial generation, which has grown up with technology, can effectively utilize ICT (Nadarajan et al., 2023).

This final section on technology-based learning hints at but does not critically explore major future research directions. The discussion of AI, VR, and gamification is nascent. An analytical synthesis would identify specific gaps: how can AI-supported representations (like adaptive molecular simulations) personalize learning during the flipped phase? What are the equity issues in ICT-dependent strategies like flipped learning where home internet access is uneven? Furthermore, the promise of these technologies must be tempered by a critical evaluation of the current literature's limitations, which often feature small-scale, short-term studies with technology-enthusiast teachers, raising questions about scalability and sustained impact on deep chemical understanding.

4. Conclusion

This systematic literature review provides a comprehensive overview of learning strategies that can be effectively implemented in chemistry education. The reviewed studies indicate that cooperative learning and inquiry-based learning dominate contemporary chemistry education research due to their positive impacts on student achievement, cognitive development, laboratory skills, science process skills, and conceptual understanding. These findings suggest that chemistry educators should prioritize mastering and integrating these strategies into instructional planning.

Furthermore, the implementation of the Merdeka Curriculum requires continuous innovation in learning strategies. Technology-based learning, particularly strategies that integrate information and communication technology (ICT), aligns well with the curriculum's emphasis on student autonomy, independent learning, and meaningful learning experiences. Theory-guided recommendations based on constructivist and social learning perspectives highlight the importance of blending cooperative, inquiry-based, and technology-supported strategies to foster authentic chemistry learning.

Despite these contributions, this review also reveals limitations in the existing literature, which predominantly focuses on short-term outcomes and small-scale implementations. Future research should therefore emphasize longitudinal studies to examine the sustained effects of learning strategies, as well as explore their application across diverse educational contexts and varying resource conditions.

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