



Systematic Literature Review: The Effectiveness of Flipped Classroom in Chemistry Education to Enhance Students' Competencies

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ABSTRACT

The Flipped Classroom (FC) model has gained increasing attention in chemistry education as an innovative approach to address challenges related to low conceptual understanding, limited student engagement, and the need to develop higher-order thinking skills. This study employs a Systematic Literature Review (SLR) guided by the PRISMA 2020 framework to systematically identify, screen, and synthesize relevant studies published between 2016 and 2026. A total of 31 peer-reviewed articles were selected and analyzed using thematic synthesis and cross-study comparative analysis to provide a comprehensive overview of FC implementation in chemistry education. The findings indicate that the FC model generally has a positive impact on students' competencies across cognitive, affective, and psychomotor domains. The cognitive domain shows the greatest improvement, particularly in conceptual understanding, problem-solving, and higher-order thinking skills. In the affective domain, FC enhances students' motivation, engagement, and self-confidence, while in the psychomotor domain, it supports the development of laboratory skills, experimental procedures, and inquiry-based practices. The implementation of FC is most prevalent in general and organic chemistry but has increasingly expanded into other sub-disciplines, including physical chemistry, biochemistry, environmental chemistry, and laboratory-based learning. However, the effectiveness of FC is highly context-dependent and influenced by factors such as instructional design quality, technological accessibility, and students' readiness for self-directed learning. Several studies also report inconsistent findings and highlight limitations, including the predominance of short-term research designs and the lack of evidence regarding long-term learning retention. Overall, the FC model demonstrates strong potential to enhance the quality of chemistry education. Nevertheless, its successful implementation requires careful alignment between pre-class materials, in-class activities, and assessment strategies. Future research should prioritize longitudinal studies and more inclusive educational contexts to strengthen the evidence base for sustainable and scalable FC practices.

Keywords: flipped Classroom, chemistry education, systematic literature review, student competencies.

INTRODUCTION

Chemistry education in the 21st century faces increasingly complex challenges arising from both the nature of its content and the competencies students are expected to develop. The abstract and multi-representational nature of chemistry concepts requires learners to simultaneously understand macroscopic phenomena, microscopic particle behavior, and symbolic representations (Johnstone, 2009). Numerous studies indicate that students' misconceptions are often rooted in traditional lecture-based approaches and an overemphasis on rote memorization. Consequently, educators are urged to adopt instructional models that promote higher-order thinking skills, foster active engagement, and support the development of broader scientific competencies. In this

context, evaluating the effectiveness of the Flipped Classroom (FC) is essential, as it represents a pedagogical innovation with the potential to create more meaningful, student-centered chemistry learning experiences.

Chemistry learning necessitates an understanding of concepts and concrete reasoning. Recent studies since 2020 have reported various benefits of FC—ranging from increased motivation and concept retention to enhanced scientific reasoning abilities. For instance, Chakawodza et al. (2024) found that the flipped classroom (FC) enhances student participation in 12th-grade organic chemistry material even after the COVID-19 pandemic, while Nsabayezu et al. (2025) demonstrated that multimedia-based FC models significantly improve concept mastery among students in Rwanda, particularly when combined with structured laboratory work.

Recent research indicates that many parties are testing new ideas in the design of flipped classrooms (FC) and the use of technology. (Arteaga et al., 2024), Theoretical insights, as articulated by scholars, increasingly emphasize the importance of self-directed learning prior to class, asserting that "pre-class self-directed learning is crucial for fostering a deeper understanding of chemical thinking."

Given these advancements, the literature review indicates that the research gap remains unaddressed. Findings regarding the impact of Flipped Classroom (FC) remain inconsistent. For instance, Rodríguez and Silva (2022) reported that improvements in thermodynamics learning outcomes are minimal, particularly when students lack experience in self-directed learning. Furthermore, many studies focus solely on short-term effects. This research has not extensively explored long-term retention or knowledge transfer.

Additionally, research tends to concentrate in developed countries, resulting in underrepresentation of regions in the Global South—such as Southeast Asia, East Africa, and Latin America. Further inconsistencies regarding video duration, classroom activities, assessments, and interaction intensity complicate generalizations. Additional issues, such as pre-class workload, unequal access to technology, and low digital literacy, continue to pose challenges to the effective implementation of FC, especially in contexts with limited resources. This reality underscores the necessity for a review that provides a comprehensive understanding of how the current FC model is utilized in chemistry education. Despite the growing number of studies reporting positive outcomes, the literature remains marked by significant inconsistencies. Some studies report substantial improvements in higher-order thinking skills, while others indicate minimal or no significant effects, particularly in mathematically intensive topics such as thermodynamics. These contradictions suggest that the effectiveness of the flipped classroom is highly context-dependent and influenced by instructional design quality, learner readiness, and technological access. Moreover, there is a lack of consensus regarding optimal video duration, assessment strategies, and the balance between pre-class and in-class activities. This inconsistency indicates a critical gap in the standardization and scalability of the FC model, particularly across different socio-economic and educational contexts.

This systematic review assesses the effectiveness of the FC model based on research evidence. It also identifies supporting and inhibiting factors for the FC model and demonstrates how various educational contexts can shape learning outcomes. This systematic literature review (SLR) is conducted to address three questions: (1) How does the FC approach influence student performance in the cognitive, affective, and psychomotor domains at both the secondary and higher education levels?; (2) How is the FC model applied across various branches of chemistry, including general chemistry, organic chemistry, physical chemistry, biochemistry, environmental chemistry, and inquiry-based laboratory practices?; (3) The third question is more exploratory in nature, aiming to identify recurring patterns or existing gaps in the application of FC, particularly concerning the use of technology, classroom environments, and learner characteristics.

The analysis in this systematic literature review (SLR) is based on empirical articles published between 2016 and 2026, encompassing both secondary and higher education, and specifically investigating the application of FC in chemistry education. This review adopts a global perspective, including studies from countries such as South Africa, Rwanda, Colombia, China, India, the United States, and Brazil, among others. The diversity of contexts enables a deeper understanding of how the FC model operates across various educational systems, accounting for factors such as infrastructure, learning culture, digital readiness, and curriculum design.

This SLR consists of five sections. The introduction outlines the significance of the topic, highlights previous research and identifies gaps, and presents the objectives and scope of the review. The methodology section explains how the PRISMA 2020 framework was utilized and details the literature search process, inclusion and exclusion criteria, and analytical steps. The results section presents themes and descriptive summaries of the reviewed studies. The discussion section connects the findings to existing theories and prior research, addresses the implications of the results for educational practice, and notes the limitations of the study. Finally, the conclusion summarizes the main findings and offers recommendations for future research and practical applications in chemistry education.

METHODOLOGY

Research Design

This study employed a Systematic Literature Review (SLR) approach to synthesize existing research on the effectiveness of the flipped classroom (FC) in chemistry education. The review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure a transparent, systematic, and replicable process in identifying, screening, and selecting relevant studies. The design of this SLR was guided by three research questions focusing on the impact of the flipped classroom on student performance across cognitive, affective, and psychomotor domains, its implementation across different branches of chemistry, and the identification of emerging trends and research gaps related to technology integration, classroom environments, and learner characteristics.

Data Sources/Database

The data for this study were collected from several reputable academic databases, including Scopus, ScienceDirect, SpringerLink, and Google Scholar. These databases were selected due to their extensive coverage of high-quality, peer-reviewed journals in science and education. The selection of multiple databases was intended to ensure comprehensive coverage of the literature and to minimize the risk of publication bias. The final dataset consisted of 31 articles that met all inclusion criteria and were deemed relevant to the research objectives.

Search Strategy

A systematic search strategy was developed using a combination of keywords and Boolean operators to retrieve relevant studies. The primary search terms included “flipped classroom” AND “chemistry education,” “flipped learning” AND “chemical learning,” and “flipped classroom” AND “organic chemistry.” Additional combinations were used to capture variations in terminology and broaden the search scope. The search was limited to articles published between 2016 and 2026 to ensure that the review reflects recent developments in the field. Furthermore, backward searching was conducted by examining the reference lists of selected articles to identify additional relevant studies that may not have been captured in the initial search.

Tabel 1. Article Used in SLR

Code	Article Title	Writer	Year	Journal	Indexed
A1	Impact of the Flipped Classroom on Student Performance and Retention	Ryan, M. D.; Reid, S. A.	2016	Journal of Chemical Education	Q2
A2	A Flipped Classroom Redesign in General Chemistry	Reid, S. A.	2016	Chemistry Education Research and Practice	Q1
A3	Examining the Effectiveness of a Semi-Self-Paced Flipped Learning Format	Hibbard, L., et al.	2016	Journal of Chemical Education	Q2
A4	Unpacking Active Learning: Flipped Classroom and Collaboration Support.	Rau, M., et al.	2017	Journal of Chemical Education	Q2
A5	Flipped Classroom in Organic Chemistry Has Significant Effect on Students' Grades	Cormier, C.; Voisard, B.	2018	Frontiers in ICT	Q2
A6	Flipped classroom use in chemistry education: results from a survey of postsecondary faculty members	Srinivasan, S., et al	2018	Chemistry Education Research and Practice	
A7	Implementation and evaluation of flipped learning for analytical chemistry topics	Ponikwer, F.; Patel, B. A.	2018	Analytical and Bioanalytical Chemistry	Q1
A8	Introductory Chemistry Using the 'Flipped' Environment: An Update	Pienta, N. J.	2019	Journal of Chemical Education	Q2
A9	Leveling the Field: Flipped Instruction as a Tool for Promoting Equity	Mooring, S. R., et al..	2020	Journal of Chemical Education	Q2
A10	Effectiveness of Flipped Classroom in Teaching Organic Chemistry at Standard XI	Birundha, S.	2020	Shanlax International Journal of Education	Q4
A11	Systematic Review of Flipped Instruction in Undergraduate Chemistry	Bancroft, S. F., et al.	2021	Journal of Chemical Education	Q2
A12	Getting Students Back on Track: Persistent Effects of Flipping Accelerated Organic Chemistry on Student Achievement, Study Strategies, and Perceptions of Instruction	Reimer, L. C., et al.	2021	Journal of Chemical Education	Q2
A13	Flipped Pedagogy: Strategies and Technologies in Chemistry Education	Anand, S. A. A..	2021	Materials Today: Proceedings	Q3
A14	Implementasi Flipped Classroom Menggunakan Mind Mapping	M., M.; Alqadri, Z.	2022	Orbital: Jurnal Pendidikan Kimia	Q4
A15	Future of the Flipped Classroom in Chemistry Education: Recognizing the Value of Independent Preclass Learning and Promoting Deeper Understanding of Chemical Ways of Thinking During In-Person Instruction	Eichler, J. F.	2022	Journal of Chemical Education	Q2
A16	Investigating the Impact of the Flipped Classroom in Organic Chemistry Course	Dehghan, S., et al.	2022	Journal of Chemical Education	Q2
A17	Impacts of Flipped Classroom on Student Performance and Problem-Solving Skills in secondary school chemistry courses	Yu, L., et al..	2023	Chemistry Education Research and Practice	Q1
A18	Flipped Online Active Learning Environment for General Chemistry.	Brady, D.; Voronova, K.	2023	Journal of Chemical Education	Q2
A19	Project-Based and Flipped Learning in the Classroom: A Strategy for Enhancing Students' Scientific Literacy	Sholahuddin, A., et al..	2023	European Journal of Educational Research	Q3
A20	Enhancing Student Engagement and Outcomes by Utilizing Lightboard Videos to Facilitate a Flipped Classroom in General Chemistry	Rojas, A. J., et al..	2023	Journal of Chemical Education	Q2

Code	Article Title	Writer	Year	Journal	Indexed
A21	Integration of Various Digital Media with Flipped Classroom Models in Chemistry Learning: An Analysis of Student Activities	Paristiowati, M., et al.	2024	Orbital: Jurnal Pendidikan Kimia	Q4
A22	Context-based learning in flipped middle school chemistry class.	Assi, A., & Cohen, A.	2024	International Journal of Science Education	Q1
A23	Using Flipped Classroom Modules to Facilitate Higher Order Learning in Undergraduate Organic Chemistry	Holloway, L. R., et al.	2024	Journal of Chemical Education	Q2
A24	Transforming Student Interactions with Flipped Content from an Isolated, Passive Activity into a Collaborative and Engaging Endeavor	Sigmon, A. J., et al.	2024	Journal of Chemical Education	Q2
A25	The Flipped Classroom as a Pedagogical Approach for Stereochemistry Learning in an Undergraduate Course	Arteaga, D., et al.	2024	Journal of Chemical Education	Q2
A26	Student comprehension of biochemistry in a flipped classroom format	Harris, E. N., et al.	2024	Smart Learning Environments	Q1
A27	The Effectiveness of Flipped Classroom Pedagogy in Promoting learning engagement in Organic Chemistry in Grade-12 Students in the Context of South Africa and Covid-19	Chakawodza, J. M., et al.	2024	International Journal of Science Education	Q2
A28	The Flipped Lab: Combining the Flipped Classroom Model with an Electronic Lab Notebook for Enhanced Digitalization and Preparation in Laboratory Courses	Geisenberg, S.	2025	Journal of Chemical Education	Q2
A29	Examining students' engagement and motivation in organic chemistry through the use of a multimedia-supported flipped classroom approach	Nsabayezu, E., et al.	2025	Education for Chemical Engineer	Q2
A30	Optimizing Pedagogical Strategies in Organic Chemistry: Examining Students' Conceptual Mastery and Perspectives on the Use of Multimedia-Supported Flipped Classroom Approach in Organic Chemistry	Nsabayezu, E., et al.	2025	Journal of Chemical Education	Q2
A31	Student perceptions of a flipped second-semester postsecondary organic chemistry course through the lens of the community of inquiry framework	Crowder, C. J., et al.	2026	Chemistry Education Research and Practice	Q1

This research is a literature review and not a field study. The Author did not create new instruments. This study employs instruments that have already been utilized in primary research. These instruments include learning outcome tests, pre-tests and post-tests, Likert-scale surveys, critical thinking assessments, and laboratory tasks. Primary research reports reliability values, for instance, Cronbach's Alpha values ranging from 0.89 to 0.91, and Aiken's V values approaching 1.00. Primary research also includes instrument trials and expert validation. Although these instruments are not directly employed in this review, their quality remains significant, as weak instruments can diminish the overall credibility of the synthesis. Therefore, only studies utilizing validated instruments are included in the final dataset.

Inclusion and Exclusion Criteria

To ensure consistency and relevance, predefined inclusion and exclusion criteria were applied during the selection process. Studies were included if they focused on the application of the flipped classroom in chemistry education, were published in peer-reviewed journals indexed in Scopus (Q1–Q4), and provided complete bibliographic information, including a valid DOI. Only studies published within the specified timeframe and employing empirical or review-based methodologies were considered. Conversely, studies were excluded if they were not directly related to chemistry education, were not peer-reviewed, lacked sufficient methodological clarity, or did not provide complete metadata. Duplicate studies were also removed to ensure that each article contributed uniquely to the analysis.

Study Selection Procedure (PRISMA)

The study selection process followed the PRISMA framework, comprising four stages: identification, screening, eligibility, and inclusion. Initially, approximately 64 records were identified through database searching. A total of 20 articles were excluded for irrelevance to the research topic. Following this initial screening, 44 full-text articles were thoroughly evaluated for their eligibility. Out of these, 13 articles were excluded for various reasons, including their lack of relevance to the research question, failure to be indexed in Scopus, or the absence of complete data necessary for analysis. Ultimately, 31 articles were included in the final analysis. This structured selection process ensures transparency and addresses methodological concerns related to data traceability and consistency.

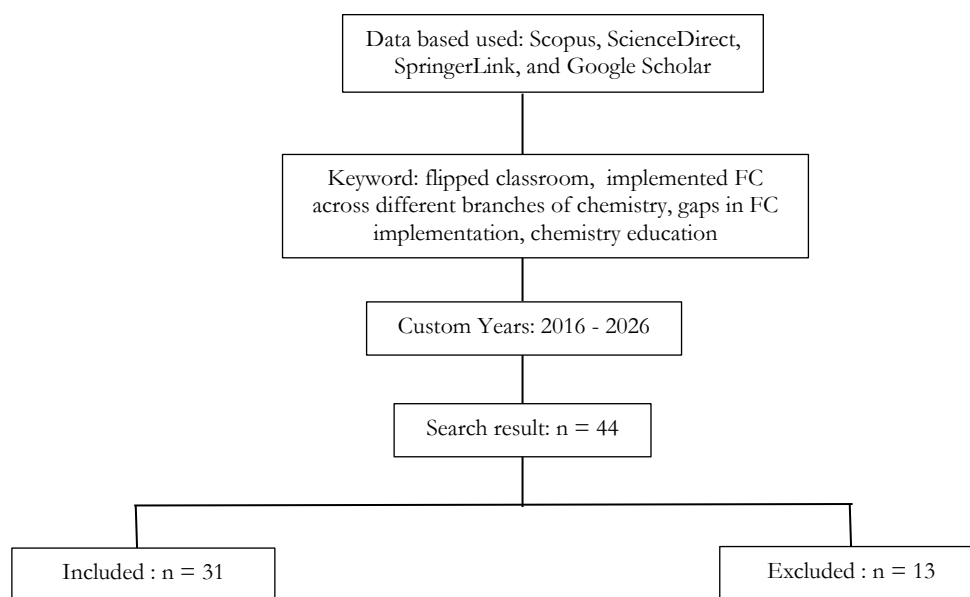


Figure 1. Stages of the Systematic Literature Review (SLR) Process

Quality Appraisal

To ensure the quality and credibility of the included studies, a quality appraisal process was conducted using an adapted checklist based on standard SLR criteria. Each study was evaluated based on the following indicators: (1) clarity of research objectives, (2) appropriateness of research design, (3) validity and reliability of instruments, (4) transparency of data analysis, and (5) relevance of findings to the research questions. Each criterion was scored using a three-point scale (0 = low quality, 1 = moderate, 2 = high quality). Only studies with moderate to high quality scores were retained for analysis. This process ensured that the synthesis was based on reliable and methodologically sound evidence.

Data Analysis Technique

This study employs a systematic thematic synthesis approach to analyze the collected data. The analysis was conducted in three stages. First, open coding was applied to identify key concepts and recurring patterns across the selected studies. Second, axial coding was used to organize these concepts into broader thematic categories, such as cognitive outcomes, affective responses, and instructional design factors. Third, a cross-study comparative analysis was conducted to examine similarities, differences, and contradictions among the findings. The text encompasses a range of comparisons that delve into various educational levels, examining how different stages of learning—such as primary, secondary, and higher education—interact with distinct learning environments. It also explores diverse implementation strategies for these contexts to enhance educational outcomes. By applying this structured analytical approach, this study moves beyond descriptive summarization and provides a more interpretative and critical synthesis of the literature.

RESULT AND DISCUSSION

Result

The Influence of the Flipped Classroom on Student's Cognitive, Affective and Psychomotor Performance

This section presents findings from 31 selected studies examining the impact of the Flipped Classroom (FC) model on three domains of student competencies: cognitive, affective, and psychomotor. Overall, the majority of studies report positive effects of FC across these domains, although the magnitude of improvement varies depending on instructional design, topic complexity, and learner characteristics.

Table 3. The Impact of the Flipped Classroom on Students' Cognitive, Affective, and Psychomotor Learning Outcomes.

Competency Domain	Key Findings	Supporting Evidence	Interpretation	Supporting Articles
Cognitive	The Flipped Classroom (FC) significantly enhances learning outcomes, including conceptual understanding, problem-solving, reasoning, and higher-order thinking skills (HOTS).	Studies report increased post-test scores, improved HOTS, better literacy, and higher achievement across general, organic, and physical chemistry.	Pre-class learning allows students to acquire basic scientific knowledge independently, while in-class activities focus on deeper problem-solving and conceptual discussion.	A1, A2, A3, A5, A7, A8, A10, A11, A12, A15, A16, A17, A19, A22, A23, A25, A26, A30
Affective	FC increases motivation, interest, enjoyment, self-confidence, and overall engagement in chemistry learning. The model also helps reduce anxiety and improves students' learning experience attitudes.	Multimedia-supported FC, collaborative learning, and interactive platforms improve students' enjoyment and learning experience.	The student-centered and flexible nature of FC fosters autonomy and emotional engagement.	A4, A6, A13, A14, A18, A20, A21, A24, A27, A29, A31
Psychomotor	FC improves laboratory skills, experimental procedures, and hands-on investigation, especially when integrated with inquiry-based or flipped lab approaches.	Studies using pre-class video materials support better laboratory performance, where students spend less time on procedural tasks and more time on analysis and interpretation.	Efficient lab preparation enhances practical skill development...	A9, A17, A28

Table 4. General Patterns of Student Competency Improvement Across Cognitive, Affective, and Psychomotor Domains

Competency Pattern	Number of Articles	Percentage of 31 Articles
Cognitive Improvement	18 articles	58.1%
Affective Improvement	11 articles	35.5%
Psychomotor Improvement	3 articles	9.7%

The cognitive domain emerges as the most dominant area of improvement in the application of the Flipped Classroom (FC) model, as evidenced by studies A1, A2, A3, A5, A11, A12, A16, A17, A23, and A25. These studies consistently report significant improvements in conceptual understanding, problem-solving, and higher-order thinking across various chemistry topics, including stereochemistry, equilibrium, and organic reaction mechanisms. This trend aligns with cognitive load theory, which suggests that shifting initial knowledge acquisition to pre-class activities reduces cognitive load during in-class sessions, allowing students to engage in deeper learning.

The affective domain ranks second, supported by studies A4, A6, A14, A20, A27, and A29. These studies indicate that the FC approach positively influences students' motivation, engagement, and attitudes toward chemistry learning. The use of multimedia tools, collaborative learning, and flexible learning environments significantly enhances students' emotional engagement. However, several studies highlight that the effectiveness of FC in the affective domain depends heavily on the quality of instructional design, particularly the clarity and duration of pre-class materials.

The psychomotor domain is less frequently explored, with evidence drawn from studies A9, A17, and A28. These studies demonstrate that the FC model can enhance laboratory skills, experimental understanding, and procedural efficiency. Pre-class instructional videos help students familiarize themselves with laboratory procedures before class, allowing more time for hands-on experimentation and analytical activities during face-to-face sessions. Despite these promising findings, the limited number of studies indicates that this domain remains under-researched. Overall, the findings suggest that while the Flipped Classroom model shows strong potential in improving cognitive and affective outcomes, further research is needed to explore its impact on psychomotor skills in chemistry education.

Comparison of the Implementation of Flipped Classroom in Various Subfields of Chemistry

This section discusses how the Flipped Classroom (FC) model is applied across six primary subfields of chemistry: general chemistry, organic chemistry, physical chemistry, biochemistry, environmental chemistry, inquiry-based laboratory learning, and Pedagogical & Technology Integration (Cross-Field). Each subfield possesses distinct competency requirements, content structures, and pedagogical challenges. Consequently, the effectiveness and specific forms of FC implementation vary significantly across these domains, reflecting the differing learning demands and instructional objectives inherent to each branch of chemistry.

Table 5. Differences in the Implementation of Flipped Classroom in Subtopics of Chemistry Education

Subfield	Key Findings	Supporting Evidence (from 31 studies)	Interpretation	Supporting Articles
General Chemistry	FC improves students' understanding of fundamental concepts such as stoichiometry, improved	Quasi-experimental studies report post-test scores, improved	The linear and foundational nature of general chemistry allows students to learn basic concepts independently	A1, A2, A3, A8, A18, A20, A24

Subfield	Key Findings	Supporting Evidence (from 31 studies)	Interpretation	Supporting Articles
	atomic structure, and understanding, and before class, enabling in-class reaction mechanisms, as enhanced problem- time to be used for application well as problem-solving solving ability in and problem-solving. skills. introductory chemistry topics.			
Organic Chemistry	FC enhances students' understanding of The spatial and mechanistic ability to visualize 3D reaction mechanisms, nature of organic chemistry molecular structures, resonance, aligns well with FC, as pre-understand reaction stereochemistry, and class content allows students interpret chemical spectroscopy through to review visual materials representations. multimedia-supported repeatedly, reinforcing learning (e.g., videos, conceptual interactive platforms).	Studies show improved understanding of reaction mechanisms, nature of organic chemistry stereochemistry, and spectroscopy through to review visual materials multimedia-supported repeatedly, reinforcing learning (e.g., videos, conceptual interactive platforms).		A5, A10, A12, A16, A23, A25, A27, A29, A30
Physical Chemistry	FC strengthens students' understanding of complex mathematical and theoretical concepts, such as thermodynamics, kinetics, and equilibrium.	Students demonstrate FC helps reduce students' better performance in cognitive load by allowing interpreting them to grasp theoretical mathematical equations, models at home and focus graphs, and class time on intensive thermodynamic models. problem-solving exercises.		A7, A17, A22
Biochemistry	FC improves knowledge retention and understanding of molecular processes.	Studies report enhanced comprehension of topics such as enzyme kinetics, metabolism, protein structure, and biomolecular interactions.	The sequential and process-oriented nature of biochemistry benefits from repeated visualization, allowing students to revisit complex mechanisms.	A26, A12
Environmental Chemistry	FC increases motivation by connecting learning to real-world environmental contexts.	Research shows higher participation, interest, FC allows students to learn and engagement when fundamental concepts at learning is home and use classroom time contextualized with to analyze and discuss real-environmental case world environmental cases. studies.		A19, A11
Laboratory Instruction (Inquiry-Based)	FC enhances inquiry skills, collaboration, safety awareness, and time efficiency in laboratory activities.	Pre-lab videos improve FC moves technical student readiness, while instruction outside class time, in-class activities enabling students to use emphasize laboratory sessions for direct experimentation, data practice, exploration, and analysis, and teamwork. investigation.		A9, A17, A28
Pedagogical & Technology Integration (Cross-Field)	FC effectiveness is influenced by digital media, instructional design, and learning strategies.	Studies highlight the role of multimedia tools, Technology integration and digital platforms, and instructional design act as key pedagogical strategies in mediators of FC effectiveness enhancing engagement across all subfields. and learning outcomes.		A4, A6, A13, A14, A15, A21, A31

Table 6. Patterns of Flipped Classroom (FC) Implementation Across Chemistry Subfields

Chemistry Subfield Pattern	Number of Articles	Percentage
General Chemistry – strong improvements in conceptual understanding and problem-solving skills	7 articles	22.6%

Chemistry Subfield Pattern	Number of Articles	Percentage
Organic Chemistry – enhanced visualization of three-dimensional structures and reaction mechanisms	9 articles	29.0%
Physical Chemistry – better comprehension of mathematically intensive and theoretical content	3 articles	9.7%
Biochemistry – improved retention and understanding of molecular processes	2 articles	6.5%
Environmental Chemistry – increased motivation and engagement through real-world contextual learning	2 articles	6.5%
Laboratory Instruction – strengthened inquiry skills, collaboration, and laboratory safety awareness	3 articles	9.7%
Pedagogical & Technology Integration (Cross-field)	3 articles	22.6%

The Flipped Classroom (FC) model does not function uniformly across all branches of chemistry, as its effectiveness is strongly influenced by the nature of the content and the specific learning objectives within each subfield. Based on the distribution of the reviewed studies, organic chemistry emerges as the most extensively investigated area, accounting for 29.0% of the total studies, followed by general chemistry and pedagogical–technological integration (cross-field), each contributing 22.6%. In contrast, physical chemistry and inquiry-based laboratory learning each account for 9.7% of the studies, while biochemistry and environmental chemistry remain less explored, each accounting for only 6.5% of the total. These variations indicate that the application of the FC model is context-dependent and shaped by the cognitive and practical demands of each chemistry domain.

In general chemistry, the structured and foundational nature of topics—such as stoichiometry, atomic structure, chemical bonding, and reaction mechanisms—renders the FC model particularly effective. Students can independently study these core concepts through pre-class instructional videos, allowing classroom time to be dedicated to problem-solving, conceptual discussions, and the application of knowledge in new contexts.

Organic chemistry shows the strongest representation in the literature, with significant advancements in students' ability to visualize three-dimensional molecular structures and understand reaction mechanisms. Multimedia-supported learning, including interactive videos and visualization tools, enables students to repeatedly observe molecular behavior, stereochemical transformations, and mechanistic pathways. As a result, the FC format facilitates deeper conceptual understanding and promotes higher-level scientific reasoning.

Physical chemistry, which is often perceived as challenging due to its strong mathematical and theoretical components, also benefits from the FC approach. Students can engage with complex equations, graphs, and theoretical models prior to class, thereby reducing cognitive load during face-to-face sessions. It allows classroom time to focus on intensive problem-solving activities, which have been shown to improve conceptual understanding and reduce mathematical anxiety.

In biochemistry, which involves highly complex, sequential molecular processes, the FC model enhances learning by enabling students to revisit biochemical pathways, visualize enzyme mechanisms, and engage in deeper analytical discussions in class. Similarly, in environmental chemistry, the FC approach increases student engagement by linking theoretical content to real-world environmental issues, fostering relevance, motivation, and positive learning attitudes.

The FC model also demonstrates strong potential in inquiry-based laboratory learning. By shifting procedural instruction—such as experimental steps and safety protocols—to pre-class materials, students arrive better prepared for laboratory sessions. Consequently, in-class time can be optimized for experimentation, data analysis, and collaborative inquiry, thereby improving practical skills and increasing confidence in laboratory work.

In addition, several studies fall under a cross-field category, emphasizing that the effectiveness of the FC model is not solely determined by content area but also by pedagogical design and technology integration. The use of multimedia tools, digital platforms, and interactive learning environments plays a crucial role in enhancing both cognitive and affective learning outcomes across different chemistry contexts.

Overall, these findings confirm that the Flipped Classroom model is a flexible and adaptable instructional approach that can be effectively applied across diverse chemistry domains. However, its success depends on the alignment between content characteristics, instructional design, and the intended learning outcomes, highlighting the importance of context-sensitive implementation in chemistry education.

Recurring Patterns and Gaps in the Application of the Flipped Classroom (FC) (Exploratory Analysis)

An analysis of 31 articles reveals a consistent pattern in the implementation of the Flipped Classroom (FC) model. One of the primary findings is that the quality and design of multimedia materials are critical determinants of FC effectiveness. Well-structured and interactive pre-class materials significantly enhance student engagement and conceptual understanding. However, the effectiveness of the FC model is not solely dependent on technology; it is also influenced by classroom implementation and learner characteristics. Challenges arise when educators lack adequate technological resources or pedagogical readiness. At the same time, student factors—such as self-regulation skills, prior academic achievement, and digital literacy—also play a crucial role in shaping learning outcomes.

Despite the growing body of evidence supporting the FC model, several recurring limitations persist. There remains a lack of longitudinal studies examining long-term learning outcomes, limited research on the application of FC in laboratory-intensive contexts, and insufficient attention to issues of equity and accessibility, particularly in diverse or resource-constrained educational environments.

Table 7. Recurring Patterns and Gaps in Flipped Classroom (FC) Implementation — Technology, Classroom Environment, and Learner Characteristics

Dimension	Observed Patterns	Identified Gaps	Supporting Articles
Technology	High-quality multimedia (videos, interactive tools, digital platforms) enhances engagement, visualization, and self-paced learning.	Limited discussion on digital inequality, internet access, and infrastructure constraints in low-resource contexts.	A4, A8, A12, A15, A18, A20, A21, A24
Classroom Environment	FC promotes collaboration, peer instruction, inquiry-based learning, and active engagement when well designed.	Few studies examine teacher facilitation, classroom culture, and assessment alignment.	A9, A14, A17, A19, A23, A28, A30
Learner Characteristics	Students with higher self-regulation, digital literacy, and prior achievement benefit more from FC, showing stronger motivation, engagement, and conceptual mastery.	Limited research explores strategies to support low-achieving, less autonomous, or digitally disadvantaged learners in FC settings.	A2, A3, A5, A10, A22, A27, A29, A31

Table 8. Distribution of Flipped Classroom (FC) Implementation Patterns Across Three Dimensions

Dimension	Number of Related Articles	Percentage of Total Studies (n = 31)
Technology	8 articles	25.8%
Classroom Environment	7 articles	22.6%
Learner Characteristics	8 articles	25.8%

The technological dimension highlights that the success of the FC model depends heavily on the quality of multimedia learning resources. Studies such as A4, A8, A12, A15, A18, A20, A21, and A24 demonstrate that well-designed instructional videos and interactive platforms significantly enhance student engagement and conceptual understanding. However, persistent challenges related to technological access and digital inequality remain underexplored, particularly in contexts with limited infrastructure.

The classroom environment dimension emphasizes the importance of pedagogical design in FC implementation. Studies (A9, A14, A17, A19, A23, A28, and A30) indicate that collaborative learning, inquiry-based activities, and structured classroom interaction foster deeper learning and student engagement. Nevertheless, there is a lack of research examining how teacher roles, classroom culture, and assessment strategies influence the effectiveness of FC.

The learner characteristics dimension underscores the role of individual differences in shaping learning outcomes. Evidence from A2, A3, A5, A10, A22, A27, A29, and A31 shows that students with higher levels of self-regulation, prior knowledge, and digital literacy benefit more from the FC model. However, limited attention has been given to supporting students who lack these competencies, highlighting the need for more inclusive instructional strategies.

It is important to note that the total number of supporting articles across the three dimensions does not equal the total number of studies included in this review ($n = 31$). This is because the analysis employs a thematic classification approach, in which some studies contribute to multiple dimensions. In contrast, others do not explicitly address technology, classroom environment, or learner characteristics. Therefore, the counts presented in this table reflect only the subset of studies relevant to each dimension, rather than a mutually exclusive categorization.

Discussion

Building upon the synthesized findings presented in the previous sections, a more critical examination is required to understand the broader implications of Flipped Classroom (FC) implementation across chemistry education contexts.

Critical Interpretation of Flipped Classroom Effectiveness

A deeper analysis of the 31 reviewed studies indicates that the effectiveness of the Flipped Classroom model cannot be generalized across all educational contexts. While the majority of studies report positive impacts—particularly in the cognitive (58.1%) and affective (35.5%) domains—the magnitude of these improvements varies significantly depending on instructional design, content complexity, and learner characteristics.

Importantly, several studies implicitly suggest that poorly designed FC implementations may lead to unintended consequences, such as cognitive overload, reduced engagement, or ineffective use of classroom time. These inconsistencies highlight that the success of the FC model is not determined solely by the instructional approach itself, but rather by the degree of alignment between pre-class materials, in-class activities, and assessment strategies.

Moreover, variability in technological access, instructional quality, and student readiness further contributes to inconsistent learning outcomes. This reinforces the notion that FC should be viewed not as a fixed pedagogical model, but as a flexible framework that requires careful adaptation to contextual conditions.

Another critical limitation emerging from the analysis is the predominance of short-term quasi-experimental studies. Although these studies demonstrate immediate improvements in learning outcomes, they provide limited insight into long-term knowledge retention, transfer of learning, and sustained skill development. This gap highlights the need for more longitudinal and mixed-method research designs in future studies.

Implications Across Chemistry Subfields

The variation in FC effectiveness across chemistry subfields further emphasizes the importance of context-sensitive instructional design. Organic chemistry, which accounts for the largest proportion of studies (29.0%), benefits significantly from visualization-based approaches that support understanding of molecular structures and reaction mechanisms. In contrast, general chemistry (22.6%) shows strong gains in conceptual understanding and problem-solving due to its structured, foundational nature.

Physical chemistry (9.7%), characterized by mathematically intensive content, benefits from pre-class exposure to theoretical models, allowing in-class time to focus on complex problem-solving. Meanwhile, biochemistry and environmental chemistry (each 6.5%) remain underrepresented, indicating a need for further exploration in these domains.

Laboratory-based learning (9.7%) also shows promising potential, particularly in enhancing inquiry skills and experimental readiness. However, the relatively small number of studies in this area suggests that the integration of FC in laboratory contexts remains underdeveloped and warrants further investigation.

The Role of Technology, Pedagogy, and Learner Readiness

A key contribution of this study is the identification of three interdependent dimensions that influence FC effectiveness: technology, classroom environment, and learner characteristics. The findings demonstrate that these dimensions should not be treated as isolated factors, but rather as an integrated system that collectively determines learning outcomes. The technological dimension underscores the importance of high-quality multimedia design, with well-structured, interactive pre-class materials that enhance engagement and conceptual understanding. However, persistent issues related to digital inequality and limited infrastructure highlight the need for more inclusive technological strategies.

The classroom environment dimension emphasizes the role of pedagogical design, particularly the use of collaborative learning, inquiry-based activities, and effective teacher facilitation. Without well-structured in-class activities, the potential benefits of FC may not be fully realized. The learner characteristics dimension highlights that students with strong self-regulation, prior knowledge, and digital literacy tend to benefit more from FC. Conversely, students with lower levels of these competencies may struggle to adapt to self-directed learning, indicating the need for differentiated instructional strategies.

Limitations of Existing Studies and Future Research Directions

Short-term experimental designs dominate the current body of research and lack diversity in both context and methodology. There is limited exploration of long-term learning outcomes, cross-cultural and low-resource educational settings, and inclusive strategies for diverse learner populations. Furthermore, while many studies emphasize positive outcomes, fewer critically examine the conditions under which FC may be less effective. This imbalance suggests a potential publication bias toward favorable results.

Future research should therefore adopt more integrative, longitudinal approaches to examine the interactions among technology, pedagogy, and learner characteristics. In particular, studies that combine experimental, qualitative, and design-based methodologies could provide deeper insights into how FC can be effectively implemented across diverse chemistry learning contexts. This study contributes to the existing literature by not only synthesizing prior research findings across 31 studies but also critically examining inconsistencies, contextual dependencies, and methodological limitations in FC implementation. Unlike previous reviews that predominantly emphasize positive outcomes, this study offers a more balanced, nuanced perspective by identifying both the strengths and limitations of the FC model.

By integrating findings across cognitive, affective, and psychomotor domains, as well as across different chemistry subfields and implementation dimensions, this study offers a more comprehensive framework for understanding FC effectiveness. This contribution provides a stronger theoretical and empirical foundation for future research aimed at improving the consistency, inclusivity, and scalability of Flipped Classroom implementation in chemistry education.

CONCLUSION

Based on an analysis of 31 studies, the Flipped Classroom (FC) model shows strong potential to enhance students' learning outcomes in chemistry education, particularly in the cognitive (58.1%) and affective (35.5%) domains. In contrast, its impact on psychomotor skills (9.7%) remains relatively underexplored. The effectiveness of FC is highly context-dependent, varying across chemistry subfields, with organic chemistry (29.0%) and general chemistry (22.6%) showing the most substantial benefits, especially in visualization, conceptual understanding, and problem-solving. However, the success of FC is not determined solely by the instructional model, but by the alignment among multimedia design, classroom implementation, and learner readiness. The findings also reveal critical limitations in the current literature, including the dominance of short-term studies, limited attention to laboratory-based applications, and insufficient exploration of equity and accessibility issues. Therefore, while FC offers a flexible and promising framework for improving chemistry learning, its effectiveness depends on context-sensitive implementation, and future research should focus on longitudinal, inclusive, and integrative approaches to ensure its scalability and sustainability across diverse educational settings.

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