

**A Decade of Evolution in Flipped Classroom Innovations in Undergraduate Chemistry (2013–2023)**Cao JianLei<sup>1,2</sup>, Sharipah Ruzaina Syed Aris<sup>3\*</sup>, Nor Tutiaini Ab. Wahid<sup>4</sup>**ARTICLE INFO****ABSTRACT****Article History:**

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**Purpose:** Although flipped classrooms have been implemented across numerous educational domains, their specific application within undergraduate chemistry education remains insufficiently explored. This study seeks to address this gap by conducting a comprehensive examination of the utilisation and impact of flipped classroom methodologies in undergraduate chemistry courses. **Method:** The review evaluates the effectiveness and influence of flipped classroom strategies on undergraduate chemistry instruction between 2013 and 2023. Following PRISMA assessment standards, a total of 30 studies were analysed. The review encompasses a broad array of themes, including theoretical underpinnings, technological integration, research

methodologies, data collection and analysis techniques, as well as pre-class and in-class activities, and associated learning outcomes. **Findings:** The analysis identifies cognitive load theory, social constructivism, and self-determination theory as the predominant conceptual frameworks underpinning flipped classroom approaches. Educational technologies, particularly video editing tools and content management systems, feature prominently across the studies. A significant portion of the literature employs quasi-experimental designs and combines quantitative and qualitative research methods. Data collection methods typically include quizzes, surveys, and qualitative assessments. Pre-class preparation commonly involves video-based instruction and quizzes, whereas in-class sessions focus on collaborative tasks such as group discussions and problem-solving exercises, which facilitate active learning and enhance educational outcomes. Overall, the flipped classroom model contributes positively to undergraduate chemistry learning by enhancing academic achievement, student engagement, conceptual understanding, and collaborative skills. Moreover, it appears effective in narrowing academic disparities among learners. **Novelty:** This systematic inquiry reveals how flipped classroom pedagogy successfully bridges theoretical foundations and instructional practice through the integration of digital technologies that reinforce educational principles. **Significance:** The study provides an in-depth assessment of flipped classroom implementation in undergraduate chemistry education, offering insights into its future prospects.

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Additionally, it furnishes valuable implications for educators and policymakers aiming to develop inclusive and effective strategies for educational reform.

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## Introduction

### *Research Background*

Amidst rapid technological progress and shifting educational expectations, higher education institutions face mounting pressure to implement instructional strategies that cultivate critical thinking, innovation, and active participation. Conventional lecture-based methods, especially in content-heavy disciplines like chemistry, frequently hinder student involvement and offer limited scope for deep, constructive learning (Birgili, 2015; Sgambi et al., 2019). In response, the flipped classroom (FC) model has gained prominence as a transformative pedagogical approach, creating a student-focused setting where learners interact with core instructional materials before class and engage in collaborative, activity-based learning during in-person sessions (Akçayır & Akçayır, 2018).

### *Rationale of the Study*

This systematic review demonstrates that FCs generally enhance academic achievement, student engagement, and collaborative competencies within undergraduate chemistry instruction. However, the extent of these benefits is influenced by factors such as learners' readiness, the quality of instruction, and the degree to which technology is effectively integrated (Gregorius, 2017; Li & Jiang, 2022; Ryan & Reid, 2015; Wu et al., 2021). Although theoretical models such as Cognitive Load Theory, Social Constructivism, and Self-Determination Theory have been effectively utilised in FC settings to mitigate cognitive overload and foster learner motivation (Flynn, 2017; Ojennus, 2015), persistent challenges remain, particularly in relation to inadequate pre-class preparation and inconsistent use of educational technologies.

This review aimed to consolidate ten years of empirical findings concerning the deployment of FCs in undergraduate chemistry courses, with the objective of identifying prevailing trends, effective practices, and ongoing challenges. By offering discipline-specific insights into evidence-based instructional methods, the study addresses a significant gap in pedagogical literature. The findings are intended to assist educators and policymakers in designing coherent, effective, and scalable educational strategies that ensure FCs are both technologically integrated and pedagogically robust, while remaining adaptable to specific instructional contexts (Freeman et al., 2014; Hava, 2021). To this end, the review systematically examines literature published between 2013 and 2023, focusing on how FC techniques have been implemented and evaluated in the context of undergraduate chemistry education. Employing the PRISMA framework to ensure methodological rigour in study selection, the investigation is guided by the following research questions:

1. Which theoretical and pedagogical foundations inform the implementation of FCs in undergraduate chemistry teaching?
2. What forms of technology are employed to facilitate FC delivery in chemistry curricula?
3. What research methodologies and data collection techniques are commonly used in studies of flipped chemistry education?
4. What types of pre-class and in-class activities are typically incorporated?
5. What learning outcomes are associated with the adoption of FC models in undergraduate chemistry?

By addressing these key questions, the study seeks to equip educators, curriculum developers, and policymakers with a thorough understanding of effective FC practices, emerging issues, and directions for future pedagogical development within the domain of chemistry education.

## Literature Review

### *Definition of Flipped Classroom*

The FC represents a transformative reconfiguration of the conventional educational model. As described by Akçayır and Akçayır (2018), traditional classrooms are typically characterised by passive student engagement during lectures, followed by independent task completion outside the classroom. In contrast, the FC model requires students to engage with instructional materials, such as videos or digital resources, prior to class, thereby reserving in-class time for interactive, collaborative learning experiences. This approach goes beyond a simple rearrangement of instructional activities, reflecting a comprehensive pedagogical framework that combines self-directed study before class with dynamic, participatory learning during class sessions. FCs have been shown to enhance knowledge acquisition, promote active learning, and strengthen learners' capacity for independent thinking and critical analysis (Akçayır & Akçayır, 2018). The overarching aim is to prioritise learners' needs and motivations while fostering a more dynamic and responsive educational environment.

According to Bishop and Verleger (2013), the FC is defined as a pedagogical structure that blends asynchronous learning (undertaken independently outside of class) with synchronous, instructor-led activities during class sessions. Improved academic outcomes are often associated with the integration of diverse teaching approaches and instructional strategies. Scholars such as Akçayır and Akçayır (2018) and Chen et al. (2017) argue that the FC model seeks to optimise student learning conditions by altering the sequence of instructional delivery and incorporating multimedia resources. Core components of FC-based instruction include essential preparatory materials to be reviewed prior to class, combined with in-person activities designed to reinforce and expand upon the content. While some studies reference optional enrichment exercises, these are generally regarded as supplementary and not central to the structure of the FC model.

### *Insights from Previous Flipped Classroom Research*

The FC serves as a learner-centred pedagogical strategy that contributes significantly to improving the overall quality of education. Findings by [Hidayat and Ningsih \(2022\)](#) reveal that FC environments strengthen classroom practices by integrating problem-based learning with deep learning processes and peer collaboration. Within FC contexts, students transition from passive recipients of information to active participants who independently explore and construct knowledge. Numerous studies have confirmed the effectiveness of the FC model in enhancing students' academic performance. In a comprehensive meta-analysis, [Cheng et al. \(2018\)](#) evaluated the impact of FC practices across a range of disciplines, including mathematics, science, engineering, social sciences, health, business, arts, and humanities. The findings indicated substantial improvements in students' mastery of course content at various educational levels when FC strategies were applied. [Hava \(2021\)](#) investigated the specific components within FCs that positively affect student outcomes, concluding that FC environments are more effective than traditional models in fostering deep learning and supporting both cognitive and emotional development. Similarly, research by [Anggoro and Khasanah \(2022\)](#) found that learners engaged in English as a Foreign Language (EFL) courses showed improved academic performance when FC strategies were implemented.

In addition to enhancing subject-specific knowledge, the FC model also supports the development of students' social competencies and self-regulation skills ([Çevikbaş & Argün, 2017](#)). By enabling learners to manage their own study routines, FCs contribute to the cultivation of creativity and autonomy. Empirical evidence also suggests that FC approaches significantly bolster student self-efficacy, reinforcing their engagement and ability to pursue self-directed learning. One notable study implemented the Guided Cooperative Flipped Classroom (GCFC) model within the context of Molecular Orbital Theory, demonstrating improved instructional outcomes through a focus on intentional content delivery, higher-order thinking tasks, and reflective practices such as feedback and feedforward strategies. Students preferred the GCFC format, citing the engaging and accessible nature of its content in supporting their understanding of complex chemical concepts.

Despite the documented benefits, several limitations hinder the effective adoption of FC practices. [Vuong et al. \(2018\)](#) identified various challenges, including the difficulty students face in developing self-directed learning habits, which can undermine the success of FC implementation. Furthermore, [Muniandy and Ping \(2023\)](#) argued that excessive demands for pre-class preparation may reduce the potential gains offered by the FC model. Some studies suggest that active learning techniques within traditional classroom environments may yield greater benefits than the additional workload often associated with preparing FC materials. In conclusion, the FC approach offers considerable pedagogical value by deepening conceptual understanding, strengthening interpersonal and independent learning skills, enhancing cognitive development, and fostering collaborative abilities. These advantages provide strong justification for the broader integration of FC strategies into diverse educational settings ([Anggoro & Khasanah, 2022](#); [Cheng et al., 2018](#); [Hava, 2021](#)). Nonetheless, for successful implementation, several obstacles must be addressed, such as ensuring appropriate technological infrastructure and securing the commitment of both instructors and learners to the required time and

expertise. Thus, careful optimisation of FC design and instructional resources across disciplines remains essential for its sustained effectiveness.

### *Effectiveness of Flipped Classroom in Undergraduate Chemistry Education*

According to the findings of [Coyle et al. \(2017\)](#), student-centred learning environments are fundamental to effective instruction in STEM (Science, Technology, Engineering, and Mathematics) disciplines. The study highlights that advanced STEM-based FC courses demand strong self-regulatory skills from students in order to effectively integrate independent online learning with classroom-based engagement. Within chemistry education specifically, the FC model is associated with enhanced and more durable comprehension of subject matter, offering a more impactful pedagogical alternative to conventional lecture-based formats. A review by [Seery \(2015\)](#) encompassing twelve studies on FC practices within undergraduate chemistry education reported that students generally respond positively to the approach. [Freeman et al. \(2014\)](#) observed that students enrolled in FC-based courses experienced, on average, a 6 percent increase in examination performance. While outcomes can differ depending on instructional context, student feedback consistently reflects improved understanding and deeper engagement with course content as a result of FC implementation. Taken collectively, the existing body of literature demonstrates the considerable advantages of FC strategies within undergraduate chemistry instruction, affirming its potential as a superior instructional model.

## **Methods**

### *Data Sources*

This systematic review was carried out following the full procedural guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. PRISMA is an internationally recognised protocol that provides a structured and methodical approach to conducting comprehensive and transparent literature reviews. In line with these standards, the authors undertook an extensive and detailed examination of existing literature concerning the application of the FC model within undergraduate chemistry education.

### *Search Strategies*

Acquiring comprehensive insights into the implementation of FCs in undergraduate chemistry education required an extensive and methodical search across multiple academic sources. The databases employed for this purpose included Web of Science, Scopus, and ScienceDirect, all of which are recognised for their rigorous indexing standards and international scholarly credibility. These platforms served as the primary sources for identifying high-quality, peer-reviewed literature relevant to various dimensions of undergraduate chemistry instruction. A well-structured search strategy was adopted, focusing on titles, abstracts, and keywords to locate pertinent studies. In addition, the scope of the review was broadened by incorporating studies retrieved from the Science Citation Index (SCI) via Google Scholar. This inclusion aimed to enrich the comprehensiveness and depth of the systematic evaluation. [Table 1](#) provides a detailed

overview of the search procedures applied to each database. It outlines the refinement criteria employed and the corresponding number of articles identified, supporting the qualitative content analysis carried out in this review.

**Table 1**

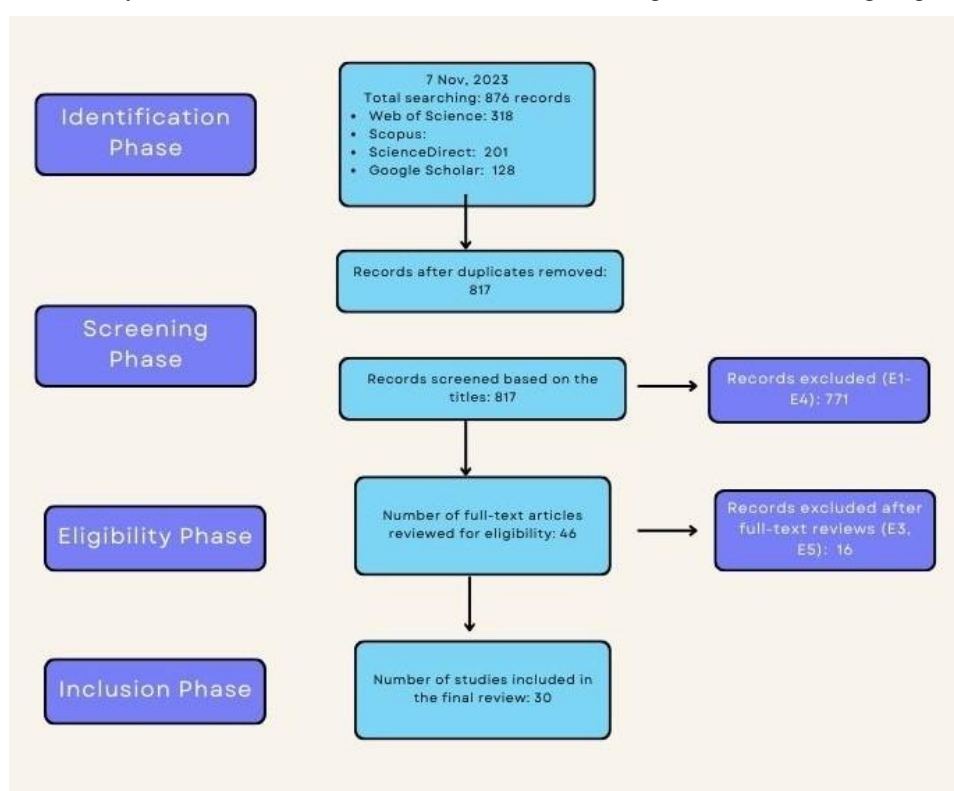
*Database Search*

Database	Search Query	Refinement Criteria	Total Articles Retrieved
Web of Science (WOS)	TOPIC: (fip* OR invert*) AND (class* OR learn* OR teach* OR instruction) AND (Chemistry*)	Document Types: Article; Citation Topics Meso: Education & Educational Research; Languages: English; Publication Years: 2013-2023.	318
Scopus	TITLE-ABS-KEY (( fip* OR invert* ) AND ( class* OR learn* OR teach* OR instruction ) AND ( science AND education ))	Publication Years: 2013-2023; Document Type: Article; Language: English	229
ScienceDirect	(Flipped OR inverted) AND (classroom OR learning OR teaching OR instruction) AND (science education)	Publication Years: 2013-2023; Document Type: Article; Language: English; Subject Areas: Social Sciences	201
Google Scholar	(Flipped classroom OR inverted classroom) AND (Chemistry)	Publication Years: 2013-2023; Only papers that are included in the SCI database are included.	128

This study rigorously followed the four essential phases outlined by the PRISMA framework. The first phase, identification, involved gathering potentially relevant literature through a comprehensive database search. This was followed by the screening phase, during which titles and abstracts were examined to eliminate studies that did not align with the predetermined inclusion criteria. The third phase, eligibility, required a full-text review of the remaining studies to assess their relevance and methodological suitability. The final phase, inclusion, entailed selecting only those articles that fully satisfied all criteria for detailed analysis. A total of 876 articles were initially retrieved and imported into EndNote 20 using the established search queries and refinement procedures. Following this, the software was employed to remove duplicate records, which resulted in a final dataset of 817 unique studies for further review.

This study undertakes a systematic review and analysis focused on the application of the FC model within undergraduate chemistry education. The process of literature identification, selection, and final inclusion of eligible studies is visually represented in [Figure 1](#) through a modified PRISMA flow diagram. Exclusion criteria were applied to

eliminate studies that did not relate specifically to undergraduate education, as well as review articles, conference proceedings, and publications not directly situated within the discipline of chemistry. Research related to chemical engineering courses was also excluded, as earlier investigations have already documented the effective implementation of the FC model in such programmes, where students have demonstrated a high degree of adaptability to this instructional approach. To facilitate a more detailed evaluation during the full-text review phase, studies that could not be conclusively included or excluded based solely on their titles and abstracts were retained during the initial screening stage.



**Figure 1:** PRISMA Flow Diagram

Following the screening of titles, abstracts, and keywords in accordance with exclusion parameters (E1-E4), a total of 46 studies were identified for further examination. Two independent reviewers applied the inclusion and exclusion standards specified in Table 2 to determine study eligibility. These reviewers conducted a comprehensive analysis of the selected papers to ensure adherence to rigorous methodological and thematic criteria. Articles that mentioned FCs without actively employing them as a pedagogical framework were removed from consideration. After completing the detailed review process, a final set of 30 studies was deemed suitable for inclusion in the systematic review. This rigorous filtering process ensures the robustness and academic integrity of the review.

**Table 2***Selection Criteria*

<b>Criteria</b>	<b>Inclusion</b>	<b>Exclusion</b>
Article Types	I1: Peer-Reviewed	E1: Non-Peer Reviewed
Academic Discipline	I2: Chemical	E2: Non-Chemical (Excluding Chemical Engineering)
Stage	I3: Undergraduate Education	E3: Non-Undergraduate Education
Type of Study	I4: Quantitative (Randomized Controlled Trial (RCT), Quasi-Experimental Design, Cross-Sectional Study, Longitudinal Studies ); Qualitative (Action Research, Case Studies), Mixed Research	E4: Reviews, Conference Papers
Study Focus	I5: Flipped Classroom is the Focus of the Research	E5: Flipped Classroom is not the Focus of the Research (Although it has been Mentioned)

This study employed a qualitative content analysis methodology to facilitate a comprehensive and impartial interpretation of FC practices within undergraduate chemistry education. The analysis concentrated on six primary domains: theoretical and pedagogical foundations, technological integration, research design and methodology, data collection and analysis techniques, pre-class and in-class learning activities, and resulting educational outcomes. Qualitative content analysis is a recognised approach for systematically categorising textual data, allowing for the identification of recurring patterns and thematic trends. This method enables a nuanced understanding of core concepts and essential elements within the data, thereby offering valuable insights and compelling justifications for the continued development of undergraduate chemistry education, both in academic theory and instructional practice.

To preserve analytical objectivity and transparency, this study avoided the use of predetermined coding schemes. Relying on pre-established coding frameworks may compromise the validity of findings by inadvertently shaping the researcher's interpretive lens. For this reason, no predefined codes were employed during the analysis process. The primary objective of this investigation is to assess the impact of FC implementation and its implications for educational strategies. By systematically examining practical outcomes across varied instructional contexts, the study aims to provide a research-based foundation for future educational policy and instructional design. Drawing on 34 peer-reviewed publications from diverse national and curricular settings, the study evaluates both the relevance and efficacy of the FC model in undergraduate chemistry instruction.

### Findings

The findings of this systematic review are based on the analysis of 30 studies selected in accordance with the PRISMA framework. These studies were examined across six key analytical dimensions: (1) fundamental information related to each selected study, (2) underlying theoretical and pedagogical frameworks, (3) types of technological tools

employed, (4) research designs and methodological approaches, (5) learning activities conducted before and during class sessions, and (6) the educational outcomes associated with the implementation of FCs.

### Basic Information of Selected Studies

Research about flipped classroom innovations in undergraduate chemistry education emerged throughout the period from 2013 to 2023. Research outputs in this field appear mainly in the Journal of Chemical Education and Chemistry Education Research and Practice since these journals combined total 35 publications (Figure 2). The vital role of chemistry-focused educational journals lies in delivering flipped classroom research results.

### Journal Titles

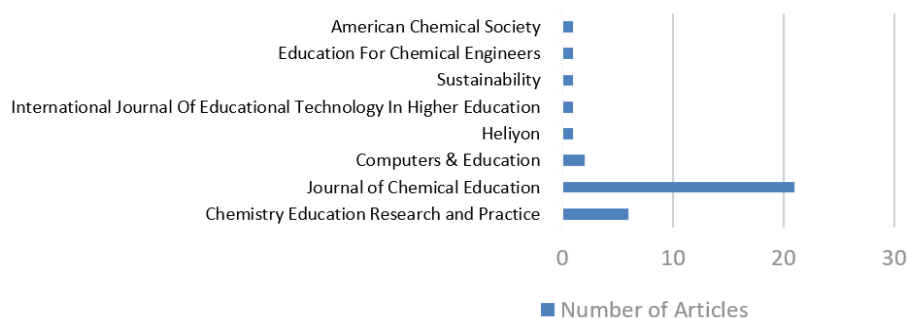


Figure 2: Distribution of Selected Articles Across Journals

The United States accounts for the highest proportion of research on FCs, contributing approximately 67 percent of the total studies reviewed (Figure 3). In addition to the United States, notable contributions also originate from countries such as China, Singapore, Brazil, Japan, Australia, and the Philippines. The prevalence of FC research within American chemical education demonstrates a strong correlation between the development of this pedagogical model and its integration into undergraduate chemistry instruction in the United States.

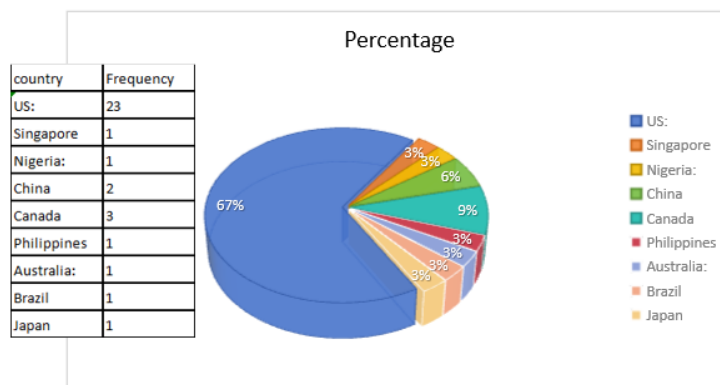


Figure 3: Distribution of Selected Articles Across Countries

As depicted in Figure 4, the volume of research publications addressing FC pedagogy displayed a steady increase from 2012 to 2022, with particularly notable growth occurring between 2016 and 2022. This upward trajectory aligns with broader trends in the digitalisation of education and reflects the heightened interest in online learning modalities, especially in response to the educational disruptions brought about by the COVID-19 pandemic (Li & Jiang, 2022; Wu et al., 2021).

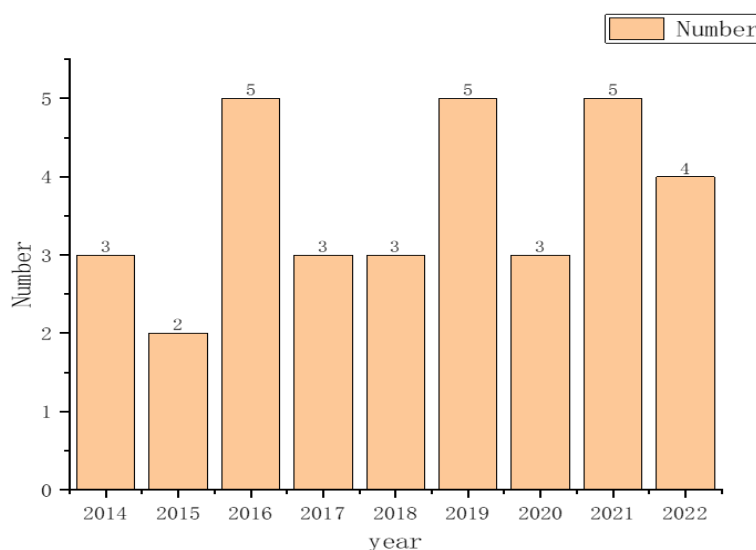


Figure 4: Number of Articles Published from 2013 to 2023

#### Theoretical and Pedagogical Frameworks

The various theoretical foundations supporting the implementation of FCs are unified by their reliance on core principles of established learning theories. The analysis reveals the following key findings:

1. A significant portion of the reviewed literature (including studies 1, 2, 4, 13, 21, 25, and 32) employs Cognitive Load Theory to improve content presentation, thereby alleviating the cognitive burden students often encounter when engaging with complex chemistry tasks.
2. Social Constructivism underpins studies such as 16, 18, 22, and 34, emphasising the importance of collaborative knowledge construction among students within FC environments.
3. Several studies (4, 5, and 10) demonstrate that student motivation can be effectively enhanced through increased autonomy and perceived competence, in line with the principles of Self-Determination Theory.
4. The concept of the Zone of Proximal Development (ZPD) is utilised in studies 19 and 30, focusing on differentiated instructional support to address learners' varying levels of readiness.

These theoretical models validate the effectiveness of FC pedagogies by supporting structured pre-class preparation and promoting deeper conceptual mastery during in-class activities (Flynn, 2017).

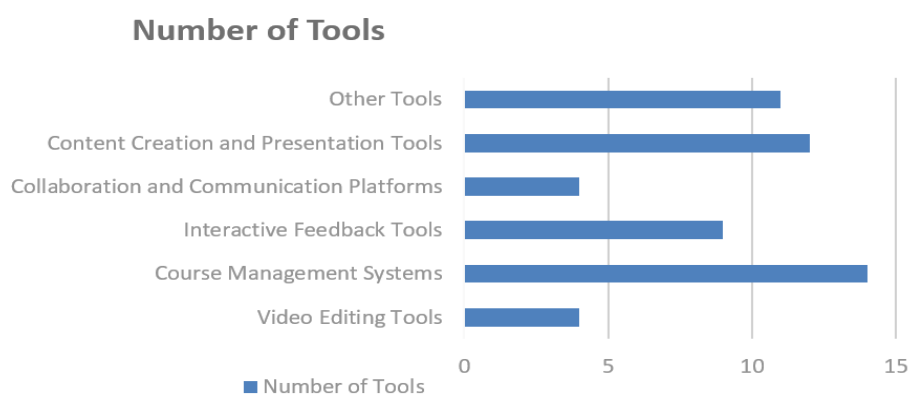
### Technological Tools Applied

The review identified a wide range of technological tools that support student learning within FC frameworks as shown in Figure 5 and Table 3. These digital resources can be organised into categories as summarised in Table 3. The applications used for content creation and presentation are at the forefront of institutional engagement, particularly through the use of recorded video lectures and interactive visual tools (Wu et al., 2021). Platforms such as Blackboard and Moodle function as learning management systems, facilitating the distribution of course materials, assignment monitoring, and student progress tracking. Additionally, tools like Learning Catalytics and iClicker offer real-time response systems that enhance in-class interaction and student engagement. The FC model supports the establishment of comprehensive educational management infrastructures across academic institutions. A thorough evaluation of these technological tools allows instructors to identify more effective strategies for integrating digital resources into instructional planning. Student success within FC environments is closely tied to the consistency of training programmes and the ongoing development of digital competencies.

**Table 3**

#### Technological Tools

Tool Category	Tool Names
Video Editing Tools	Camtasia, Movavi, Screencast-O-Matic, Ensemble Video
Course Management Systems	Blackboard, Moodle, Blackboard Learn, CONNECT System, Blackboard Course Management Site, Homework System, OWLv2, Desire2Learn (D2L), SPOC, Online Course Management System, McGraw-Hill Connect Platform and ALEKS, Sapling Learning
Interactive Feedback Tools	Clicker System, Socrative, Mixable, Learning Catalytics (LC), Remark Software, TopHat, Playposit platform, COPUS, Classroom Response System
Collaboration and Communication Platforms	Google Meet, WhatsApp, Interactive Video-Conferencing (IVC), Video Conferencing
Content Creation and Presentation Tools	PowerPoint, SMART Podium, Voice-Over PowerPoint based Videos, Large Electronic Whiteboards, Portable "Huddle Boards", Videos, iPad Tablet with Explain Everything, Laptop Doc Cam, ECHO360, Explain Edu App, Preclass Materials (PCMs), YouTube
Other Tools	PhET Simulations, SCALE-UP, WACOM Bamboo Tablet; Tablet; Flipped Classroom with an Animation-Based Content Knowledge Development System, Flipped Classroom and PLTL Pedagogies (Flip-PLTL), Blended/Flipped Format, MOOC-Based Flipped Classroom, Cloud Computing, Anonymous Course Evaluation Results, E-Learning



**Figure 5:** Classification of Technology Tools

Initial implementation of the FC model encountered obstacles primarily due to financial constraints associated with integrating appropriate technologies. Over time, however, advancements in technological infrastructure have mitigated these challenges, reducing the impact of budgetary limitations (Li & Jiang, 2022; Wu et al., 2021). Figure 5 illustrates the distribution of instructional technologies utilised across Chinese higher education institutions. The category labelled "Other Tools" reflects a range of specialised technological advancements that support specific instructional functions within the field of educational technology. Contemporary educational models increasingly promote student-centred learning by incorporating tools for content development and presentation, alongside course management systems that offer educators innovative instructional strategies. Platforms that support collaboration and provide interactive feedback features play a vital role in facilitating remote learning and delivering real-time formative assessment.

#### *Research Design and Methods*

The majority of studies employed quasi-experimental research designs, largely due to the impracticality of conducting fully randomised controlled trials within typical educational settings. These quasi-experimental approaches included one-group pre-test and post-test formats, non-equivalent group comparisons, and parallel control group experiments (studies 1, 3, 4, 12, 16, 25). A number of investigations adopted mixed-methods designs, combining quantitative and qualitative data sources (studies 5, 15, 16, 17, 19, 24, 30, 31, 32, 34). These studies often integrated test scores and quiz results with student interviews, reflective journals, and narrative feedback. The application of longitudinal methodologies and cross-institutional comparisons further enhanced the reliability and broader applicability of the research findings.

#### *Data Collection Methods*

- Standardized Tests and Final Exams
- Surveys and Questionnaires
- Open-Ended Reflections
- Interviews and Focus Groups
- Classroom Observations

The research methodologies reviewed incorporated a variety of statistical techniques, ranging from basic inferential tools such as t-tests and ANOVA to more complex models including ANCOVA and regression analysis (Flynn, 2015).

#### *Pre-Class and In-Class Activities*

Pre-Class Activities predominantly consist of:

- Watching Video Lectures
- Completing Quizzes and Pre-Class Assignments
- Reviewing Reading Materials

These preparatory activities ensure that students enter class sessions equipped with foundational knowledge, enabling them to engage effectively in applied, inquiry-driven learning tasks.

In-Class Activities focus on active learning:

- Group Problem-Solving
- Peer Discussions and Collaborative Exercises
- Real-Time Quizzes using Clicker Systems
- Application of Concepts through Simulations like PhET (Study 1)
- Interactive Presentations and Problem-Based Learning (Studies 8, 10, 16)

This instructional strategy prioritises the application of knowledge rather than the passive absorption of information, aligning closely with principles of constructivist theory and active learning frameworks (Çevikbaş & Argün, 2017; Seery, 2015).

#### *Educational Outcomes*

A review of the selected studies reveals several recurring positive outcomes associated with the implementation of FCs:

1. Numerous studies (1, 2, 5, 6, 13, 18, 20, 24, 25) report that students engaged in FC environments tend to achieve higher academic performance, as reflected in improved examination scores, increased assignment completion rates, and elevated course grades. For example, Ojennus (2015) observed that students enrolled in a flipped biochemistry course outperformed their peers on assessment tasks.
2. The FC model appears to reduce disparities in academic performance among students from diverse educational backgrounds, including those with lower grade point averages. Research by Ryan and Reid (2015) and Chakawodza et al. (2024) suggests that this instructional design helps narrow achievement gaps across varied learner profiles.
3. Several investigations (studies 7, 12, 14, 17, 20, 30) indicate that FC structures enhance students' attentiveness, satisfaction, and motivation, largely due to the emphasis placed on active and participatory learning methods.
4. The FC approach also fosters the development of social competencies, as students are encouraged to collaborate, engage in peer-led learning, and cultivate self-management skills within cooperative classroom settings (Çevikbaş & Argün, 2017).

5. Despite its overall benefits, the influence of FCs on examination performance has shown some inconsistency. Studies including those by [Ryan and Reid \(2015\)](#) and [Gregorius \(2017\)](#) suggest that the effectiveness of the model is closely linked to specific contextual factors such as student selection criteria and course design.

### *Summary of Findings*

Undergraduate chemistry education delivered through the FC model is grounded in well-established theoretical principles that inform both its design and practical application. A further indicator of the model's reliability lies in its integration of educational technologies, which facilitate student preparation prior to class sessions and support active engagement during lessons. This preparatory phase is typically followed by classroom-based learning activities, where problem-solving serves as a catalyst for collaborative learning experiences. Existing educational literature reinforces the connection between the FC approach and increased levels of student engagement and academic achievement. Successful implementation of this method requires careful instructional planning that not only addresses discipline-specific challenges but also accommodates the diverse needs of learners. This review contributes to the broader understanding of prior research that highlights the FC model's effectiveness in enhancing both educational outcomes and student involvement.

### **Discussion**

In the context of undergraduate chemistry education, the application of FC pedagogy has produced favourable outcomes within the framework of three dominant theoretical models: Cognitive Load Theory, Social Constructivism, and Self-Determination Theory. These theoretical approaches collectively aim to reduce mental strain, promote peer collaboration, and foster confidence and psychological well-being through intrinsic motivation. [Cheng et al. \(2018\)](#) highlight that active learning strategies are integral to the effective implementation of FC methods across STEM disciplines. Constructivist learning environments are further enhanced when instructional strategies are designed to encourage students to engage with course material in advance and participate actively during class sessions. The substantial body of research supporting these theoretical perspectives provides strong justification for the integration of FC strategies in undergraduate chemistry instruction.

The increasing use of virtual educational technologies represents a significant trend in supporting the delivery of FC models. Tools such as Camtasia for video production, Blackboard and Moodle for managing coursework, and interactive platforms like Learning Catalytics and iClicker have become fundamental components of active FC learning environments. Evidence from [Seery \(2015\)](#) and [Wu et al. \(2021\)](#) indicates that these digital resources not only enhance student preparation before class but also enable real-time instructional feedback during sessions. However, although these technologies contribute to improved engagement, several studies report inconsistent findings regarding their effect on academic performance. This inconsistency suggests that the mere presence of technology is insufficient; its effectiveness depends on well-structured instructional design,

adequate student preparation, and active instructor involvement, all of which play essential roles in shaping successful technology-enhanced learning environments.

The studies included in this review demonstrate a strong association between FC implementation and improved academic outcomes, higher levels of student engagement, and enhanced group collaboration skills. These findings are consistent with broader educational research supporting the benefits of active learning strategies [Freeman et al. \(2014\)](#). Nonetheless, the review also identified several limitations in the overall impact of FC practices. Investigations by [Ryan and Reid \(2015\)](#) and [Gregorius \(2017\)](#) revealed that, in some instances, FC instruction did not yield superior results compared to traditional teaching methods when assessed through examination performance. Variations in effectiveness may be attributed to differences in instructional design, course structure, and the composition and preparedness of student cohorts. While the general trend supports the value of FC methods, successful implementation requires thoughtful adaptation to the specific learning objectives and contextual needs of each institution.

### Conclusion

The findings of this review evaluate how universities have incorporated FC approaches into undergraduate chemistry education since 2010 and assess the outcomes achieved through such implementations. Integrating Social Constructivism and Cognitive Load Theory into FC frameworks has contributed to improved student performance, enhanced active engagement, and strengthened collaborative learning dynamics. The combined use of video editing tools, learning management systems, and real-time feedback applications has supported learners' preparation prior to class, thereby facilitating more effective participation in classroom-based instruction. While technological access remains a fundamental requirement, the quality of instructional design and student-centred pedagogical strategies continues to be a critical determinant of success. Despite these advances, the academic impact of FC implementation has not been uniformly positive across all studies. Variability in course design, student demographics, and instructional structures has led to inconsistencies in learning outcomes. To address these discrepancies, future research should explore the long-term effectiveness of FC strategies in different academic contexts. Emphasis should be placed on assessing how this pedagogical model influences knowledge retention, critical thinking development, and the advancement of professional competencies. The adoption of FC methodologies must therefore be guided by evidence-based strategies, ensuring that undergraduate chemistry instruction is both pedagogically sound and responsive to the evolving demands of higher education.

### Recommendations

The findings of this review provide valuable guidance for educators and policymakers seeking to reform undergraduate chemistry instruction through the adoption of FC approaches. Successful implementation of FC strategies requires deliberate planning informed by established evidence. Instructors should align their pre-class and in-class activities with clearly defined learning objectives, while ensuring students receive consistent support in adapting to active learning environments and effectively using educational technologies to streamline content delivery. Future investigations should

focus on evaluating the broader impact of FC methodologies across diverse learning contexts. This includes examining variations in student performance across demographic and academic subgroups and identifying evidence-based practices suitable for different branches of chemistry. The insights gained from this review establish a foundational framework for cultivating inclusive, interactive learning environments that enhance student engagement and academic achievement in undergraduate chemistry education.

### Limitations

This study is subject to several limitations. Firstly, the review was restricted to peer-reviewed publications written in English, which may have excluded relevant contributions from non-English sources and grey literature. Secondly, the 30 studies analysed exhibited considerable variation in research design, institutional settings, and the extent to which FC models were implemented, potentially limiting the transferability of findings to other educational contexts. Thirdly, the synthesis was conducted using qualitative methods based on thematic patterns, rather than employing a statistical meta-analytical approach, which may reduce the precision in comparing educational outcomes. Furthermore, the absence of standardised evaluation criteria across the reviewed studies poses a challenge to assessing the overall effectiveness of FC approaches in undergraduate chemistry education.

### Future Directions

Future research in this field should prioritise longitudinal investigations into the sustained effects of FC interventions on students' knowledge retention, critical thinking development, and the acquisition of professional competencies within chemistry education. There is also a need for the establishment of standardised evaluation frameworks and clearly defined outcome indicators, which would facilitate meaningful comparisons across studies and institutional contexts. Further exploration is warranted regarding the integration of emerging technologies, including artificial intelligence-driven adaptive learning systems and virtual reality applications, within FC models tailored to chemistry instruction. In addition, studies that examine both student and instructor perspectives from underrepresented regions and institutions can offer valuable insights into localised challenges and supportive factors. Such investigations will contribute to the development of more inclusive, equitable, and scalable pedagogical strategies.

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**Appendix I**

Basic information on the research matrix of flipped classrooms in undergraduate chemistry education.

Author	Topic	Country	Year	Course	Duration	Journal
Hoi-Ting Wu	PhET sims in flipped classroom	US	2021	General Chem	1 sem	Chem Educ Res Pract
James C. Shattuck	Partially flipped org chem outcomes	US	2016	Org Chem	8 sessions	J Chem Educ
Michael D. Ryan	Flipped class: perf. & retention	US	2016	General Chem	2 sem	J Chem Educ
Jenay Robert	Flip + peer-led learning	US	2016	General Chem	1 sem	J Chem Educ
Lorico DS. Lapitan Jr	Online flipped chem eng course	US	2023	Analyt Chem	1 sem	Educ Chem Eng
J. M. Chakawodza	Challenges in high school flipped use	US	2024	Org Chem	---	Int J Learn Teach Educ Res
Tang Wee Teo	Flip teaching in chem lab	Singapore	2014	Chem Lab	---	Chem Educ Res Pract
R. Ma. Gregorius	Traditional vs animated flip class	US	2017	General Chem	4 yrs	Chem Educ Res Pract
Mark Blaser	Prep + in-class collab activities	US	2019	General Chem	1 sem	ACS Symp Ser
Paul Baepler	Flip & blend in active learning	US	2014	General Chem	3 sem	Computers Educ
Wenliang He	Partial flip: large undergrad chem	US	2018	Intro Chem	10 weeks	Computers Educ
Cecilia O. Nja	Attitude & achievement in flip	Nigeria	2022	Chemistry	6 weeks	Heliyon
Kai Wang & C. Zhu	MOOC-based flipped learning	China	2019	Inorg Chem	1 sem	Int J Educ Tech High Educ
Wenliang He	Impact of partial flip chem	US	2018	Undergrad Chem	1 sem	Computers Educ
Zan Li	SPOC & FCM for inorg chem	China	2022	Inorg Chem	6 weeks	Sustainability
Daniele Ramella	Flip class for learning skills	US	2019	General Chem	1 sem	ACS Symp Ser
Beverley J. Allan	Perceptions in flipped foundation chem	Canada	2018	Org Chem	1 sem	J Found Year Netw
Julie Schell	Flip + peer instruction	US	2015	General Chem	1 sem	Wiley Online Libr
David Gross	Prep impact on flip outcomes	US	2015	Fund Chem	1 sem	CBE Life Sci Educ
Rahmi E. Witri	Green chem PBL for high school	US	2025	Chem Law	1 sem	J Res Sci Educ
Alison B. Flynn	Structure of flipped chem courses	Canada	2015	Org & Spectro	1 year	Chem Educ Res Pract
D.D. Ojennus	Learning in flipped biochem	US	2015	Biochem	1 week	Biochem Mol Biol Educ
Alison B. Flynn	Flip chem: align LOs & eval	US	2017	Gen Chem	1 sem	Online Chem Educ

Author	Topic	Country	Year	Course	Duration	Journal
Elise M. Heiss	Remote flip in phys chem	US	2021	Phys Chem	1 sem	Anal Bioanal Chem
Timothy Casasola	Flip effect in undergrad chem	US	2017	Analyt Chem	1 sem	Int J Teach Learn High Educ
Chui-Man Lo	Blended learning in pandemic	US	2021	Undergrad Chem	1 sem	Interact Tech Smart Educ
Fiona Ponikwer	Flip in analytical chem	US	2018	Analyt Chem	---	Anal Bioanal Chem
Caroline Cormier	Flip class impact in org chem	US	2018	Org Chem	1 sem	Frontiers ICT
Alison B. Flynn	Flip chem: LOs & eval	Canada	2017	Org & Spectro	---	Am Chem Soc
Lorico DS. Lapitan Jr	Blended teaching during COVID	Philippines	2021	Phys & Analyt Chem	1 sem	Educ Chem Eng

## Appendix II

### Matrix of Research on Flipped Classroom in Undergraduate Chemistry Education

Theoretical Framework	Tech Tools	Design	Data & Analysis	Pre/In-Class Activities	Outcomes
Cognitive Load Theory, Constructivism	PhET simulations	Quasi-exp	SPSS, Wilcoxon	Video, quiz, group PhET	Improved conceptual understanding
Cognitive Load, Constructivism	Screencast-O-Matic, Blackboard	Exploratory Mixed	T-tests, surveys	Video, group work	Higher performance, lower dropout
Student-centered	Camtasia, CONNECT	Parallel controlled	CTT, Rasch	Videos, discussion	Lower DFW rate, higher satisfaction
Cognitive Load, Self-Determination	Camtasia	Quasi-exp	Exam analysis	Videos, quizzes, clickers	Higher achievement and retention
Collaborative learning	Online platforms	Design and evaluation	Survey + performance	Video + group work	Higher engagement and learning
Socio-cultural lens	Digital tools	Qualitative	Interviews, observations	Videos + group tasks	Improved grades, conceptual gain
ICAP Framework	OWLv2, PC/tablet	Quasi-exp	MANOVA, ANCOVA	Quizzes, group work	Higher performance, lower attitude
—	ICT tools	Quasi-exp	Mixed methods	Manual, demo video	Better theory and lab work
Collaborative model	Clickers, online video	Case study	Survey, task eval	Videos, quizzes, teamwork	Better engagement and success
—	Socrative	Phenomenological	Content & theme analysis	Chapter reading, TA-led	Deeper understanding, less stress