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Transforming Undergraduate Chemistry: A Decade of Flipped Classroom Innovations (2013-2023)

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Abstract: The flipped classrooms have been studied across a wide range of educational disciplines, but its use in undergraduate chemistry education is still not yet fully understood. This study addresses this issue by providing an in-depth review of how flipped classrooms are implemented within, and impact on, undergraduate chemistry courses. This review analyses the influence and effectiveness of flipped classroom as used in undergraduate chemistry education from 2013 to 2023. We follow the systematic review guidelines (PRISMA) to assess (30 studies) that looked at various aspects of flipped classrooms; including theoretical frameworks, technology, research methodologies, data collection and analysis, pre-class and in-class activities, and educational outcomes. Findings show that flipped classrooms, predominantly used theoretical frameworks, focusing on cognitive load theory, social constructivism, and self-determination theory. Editing videos and using content management systems were also commonly explored. Most studies used quasi-experimental methods, with many of the studies used hybrid methods of research. Data collection and analysis predominantly relied on quizzes, questionnaires, and qualitative analysis. Pre-class students watched videos and completed quizzes, while in-class activities included cooperative group discussion and problem-solving to promote active learning and greater learning outcomes. Overall, flipped classrooms provided benefits for undergraduate chemistry education, as it tended to improve academic performance, and or student engagement, and or comprehension and or group work skills. The pedagogical approach also attempted to reduce the performance gap between students. A systematic review of the literature and analysis demonstrate how the practice of flipped classrooms demonstrates theory and practice, and the use of educational technology to further support the pedagogical principles. A comprehensive review of flipped classrooms in undergraduate chemistry education has been established, and potential future directions have been articulated. The results of this review not only support educators, and policymakers, to create policy that is effective to promote education reform, but also to reimagine education and evaluation of potential.

Keywords: Undergraduate Chemistry Education, Flipped Classroom, Educational Outcomes, Evolution, Transformation.

1. Introduction

1.1. Research Background

As technology continues to accelerate and educational needs shift, universities face increasing pressure to use innovative pedagogical approaches that promote critical thinking, creativity, and active learning. Traditional, lecture-based instructional methods often limit student involvement and restrict chances for students to construct knowledge meaningfully (Birgili, 2015; Sgambi et al., 2019). The flipped classroom model has emerged as a prominent pedagogical innovation, allowing for a student-centered pedagogy in which students access instructional materials before class time and experience active, collaborative learning activities during class time (Akçayır & Akçayır, 2018).

1.2. Rationale of the Study

This systematic review shows that flipped classrooms generally promote higher academic outcomes, student participation, and collaboration skills in undergraduate chemistry courses. However, the research demonstrates that the effectiveness of flipped classrooms is dependent on students' preparation, quality of teaching, and level of technology use (Gregorius, 2017; Li & Jiang, 2022; Ryan & Reid, 2016; Wu et al., 2021). Evidence-based frameworks such as Cognitive Load Theory, Social Constructivism, and Self Determination Theory have been demonstrated to be effective when used in flipped classrooms by introducing a lower cognitive load and increasing motivation (Flynn, 2017; Ojennus, 2016). There are also challenges in terms of insufficient preparation before class and uneven technological adoption.

This study aimed to systematically review a decade of empirical research on the flipped classroom method in order to identify common themes, effective practices, and problems yet to be resolved specifically to flipped classroom implementation in an undergraduate chemistry education course. In this way it addresses the important need to develop discipline specific evidence-based models of instruction. This type of outcome aims to help educators and educational policymakers develop a synergy of pedagogical innovation that are coherent, scaleable and effective so that flipped classrooms are technologically supported, pedagogically sound, and contextually informed (Freeman et al., 2014; Hava, 2021).

The present study serves to systematically review the literature from 2013-2023 to demonstrate how the flipped classroom model of instruction has been applied and researched in undergraduate chemistry. This inquiry is guided by a PRISMA framework to rigorously select research that answer the following focused inquiry questions:

1. What theoretical and pedagogical frameworks underpin the implementation of flipped classrooms in undergraduate chemistry education?
2. What technological tools are integrated to support flipped classroom delivery in chemistry courses?
3. What research design and data collection methods characterize studies on flipped chemistry education?
4. What pre-class and in-class activities are commonly utilized?

5. What educational outcomes are associated with flipped classroom implementation in undergraduate chemistry?

With this examination, the research aims to give educators, curriculum developers, and policymakers a detailed account of best practice, challenges, and future directions in improving chemistry education through flipped classroom innovations.

2. Literature Review

2.1. Definition of Flipped Classroom

The flipped classroom is a creative reorganizing of the conventional classroom. "In a conventional format in a classroom, students often demonstrate passive behavior while attending to the lecture, and they will independently complete their in-class assignments" (Akçayır & Akçayır, 2018). Whereas, in the flipped classroom, students develop their learning independently prior to the course period by learning with instructional videos and/or materials. The primary emphasis of the in-class portion of the flipped classroom is to encourage interaction and promote cooperative learning with a focus on stress-free learning experiences in the classroom. Flipped classroom encompass more than a mere rearrangement of activities; they embody a full instructional style that entails pre-class self-study and in-class interactive learning. Flipped classroom improves the transmission of knowledge and encourages active participation and self-directed learning, thus fostering the development of critical thinking abilities (Akçayır & Akçayır, 2018). The objective of creating this educational setting centers on putting student requirements and motivations first while enabling a live and expanding educational experience.

The flipped classroom defines as a pedagogical model which combines both asynchronous and synchronous learning activities according to Bishop and Verleger (2013). Students achieve better learning outcomes when teachers implement multiple instructional methods together with various teaching activities. According to Akçayır and Akçayır (2018) and Chen, Lui and Martinelli (2017) and some scholars the flipped classroom strategy aims to create better student learning conditions by changing instructional sequencing and integrating multimedia materials. Flipped classroom education consists mainly of required pre-class preparation materials together with classroom-based learning activities. Research provides optional supplemental learning exercises but these activities are deemed supplementary to the main aspects of the flipped classroom model.

2.2. Insights from Previous Flipped Classroom Research

The flipped classroom functions as a student-led method that primarily improves educational quality. Research by Hidayat and Ningsih (2022) demonstrates how the flipped classroom improves classroom activities that incorporate problem-driven learning together with deep learning and peer collaboration. Through flipped classroom teaching students develop deep learning practices by moving from being passive receivers of information toward actively searching for knowledge.

Multiple investigations demonstrate that the flipped classroom method boost academic student achievement results effectively. The systematic meta-analysis by Cheng, Ritzhaupt and Antonenko (2019) assessed flipped classroom effects on student

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academic achievement across mathematics, science, social sciences, engineering, arts, humanities, health and business education. Students achieved meaningful advancement in their academic performance throughout different subjects by adopting flipped classroom approaches in their education. In their study Hava (2021) analyzed which elements of flipped classroom create positive influences for students. Research determined that flipped classrooms outperform traditional methods by boosting deep learning stages and enhancing both cognition and emotions of students. Students participating in EFL education experienced enhanced academic achievement through the adoption of flipped classroom methodology according to Anggoro and Khasanah (2022).

The flipped classroom model improves both students' subject mastery and social development as well as self-management capabilities (Cevikbas & Argün, 2017). The independent management of learning becomes possible in the flipped classroom environment which leads to positive effects on student creativity. Evidence shows that flipped classrooms boost student self-efficacy effectively thus demonstrating their importance for student engagement and self-directed learning. A research study implemented Guided Cooperative Flipped Classroom (GCFC) for Molecular Orbital Theory and discovered that GCFC boosts teaching effectiveness through Intentional Content along with higher-order thinking Activities and Sharing and Feedforward Feedback and Reflection activities. Research indicates that students choose GCFC as their preferred learning method because it enhances chemical theories through enjoyable accessible content.

Multiple barriers prevent effective execution of flipped classroom approaches from succeeding. Specific deficits surveyed by Vuong, Tan and Lee (2018) show how such deficits diminish flipped classroom effectiveness when teaching self-direction to students. According to Muniandy and Ping (2023) intense pre-classroom study can reduce the benefits that the flipped classroom provides. Studies indicate that students gain greater benefits from implementing strong active learning approaches in conventional classroom settings rather than spending significant efforts on developing materials for the flipped teaching paradigm.

In conclusion, the flipped classroom offers several significant educational advantages: more profound understandings of content, simpler social skills development, an improvement in student independence and confidence, better cognitive skills, and increased collaboration skills. The benefits mentioned justify the extensive implementation of the flipped classroom as a very effective teaching method (Anggoro & Khasanah, 2022; Cheng et al., 2019; Hava, 2021). Nevertheless, there are still obstacles that need to be overcome in order to implement this pedagogical approach across various domains. For instance, they should use suitable technology equipment and the students' and educators' dedication to sufficient time and expertise. Therefore, it is crucial to Optimize the design and instructional materials of the flipped classroom in various academic disciplines.

2.3. Effectiveness of flipped classroom in undergraduate chemistry education

As indicated in the study by Coyle, Newman and Connor (2017), it is proposed that student-centered learning settings play a crucial role in STEM (Science, Technology, Engineering, and Mathematics) education. Results show that higher-level STEM flipped courses require robust student self-regulation to effectively link online and classroom activities. A flipped classroom promotes a more profound and long-lasting understanding of the chemistry content among students. It is regarded as a more effective pedagogical strategy in chemistry than the traditional lecture-based pedagogical approach.

Seery (2015) reviewed 12 studies on flipped classroom in undergraduate chemistry education. Research indicates that students generally have a positive perspective of the flipped classroom. Freeman et al. (2014) found that students in flipped classroom reported a 6% improvement in their exam scores. The outcomes of a flipped classroom may fluctuate depending on the specific circumstances. Nonetheless, in the end, the students felt this system was more effective in conceptually understanding the material as well as providing opportunities for deeper learning. Overall, a fair amount of research has documented the advantages of a flipped classroom model in undergraduate chemistry courses.

3. Methods

3.1. Data Sources

A systematic review was adhere to all guidelines set forth by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) is an internationally accepted set of guidelines that supplies organized practices and a reasonably comprehensive set of methods for organized investigation of the literature. The study completed an extensive review of the literature that addresses the flipped classroom in undergraduate chemistry education.

Search strategies.

Gaining a thorough understanding of undergraduate chemistry education with flipped classrooms involved extensive reading of literature from multiple sources eventually. A systematic study involved searching through Scopus and ScienceDirect , and Web of Science as a systematic level of database sources. The databases were selected based on the quality indices of the sources which included opting for areas related to being indexed as high recognition in the scientific community. Using these sources, numerous academic publications study the experiences of undergraduate chemistry education. A rigorous search strategy involved conducting searches of academic publications against titles and publications with keywords to gather publications related to the flipped classrooms.

Furthermore, this study utilized papers from the Science Citation Index (SCI) acquired through Google Scholar to enhance the breadth and thoroughness of systematic assessment. The following Table 1, presents a thorough summary of the search tactics used in each database. It includes information on the criteria for refining the search and the number of articles obtained.

The four critical stages of PRISMA are adhered to in this study: Initially, *identification* involves the collection of potentially relevant studies through database retrieval. Subsequently, *screening* involves the review of titles and abstracts to exclude studies that do not meet the criteria. *Eligibility* assessment involves reading the full texts to confirm appropriateness of the identified articles. Finally, *inclusion* involves the selection of studies that fully meet the criteria for the final analysis. Eight hundred

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seventy-six papers (876) were identified and imported into EndNote 20 based on the Search Query and Refinement Criteria. Subsequently, the EndNote 20 program was utilized to eliminate duplicate entries, resulting in a final count of 817 articles.

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
Science Direct	(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

Table 2: Selection Criteria.

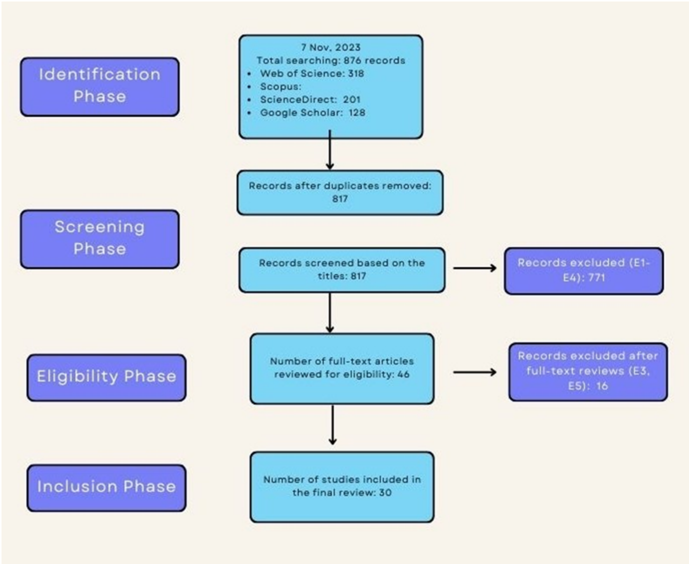
Criteria	Inclusion	Exclusion
Article types	I1:Peer-reviewed	E1:Non-peer reviewed,
Academic discipline	I2:Chemical	E2:Non-chemical(excluding chemical engineering)
Stage	I3:Undergraduate Education	E3:Non-Undergraduate Education
Type of study	I4:Quantitative (Randomized Controlled Trial (RCT), Quasi-experimental 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 investigation aims to implement a systematic review and analysis of flipped classroom in undergraduate chemistry education. The literature retrieval, identification, screening, and final determination of the number of eligible studies is illustrated in Figure 1 using the adaptive PRISMA flowchart.

The exclusion criteria were utilized to exclude papers that did not pertain to undergraduate education, review articles, conference papers, publications outside the field of chemistry. Chemical engineering classes were excluded because previous studies have shown the advantageous effects of flipped classroom in these programs, with students in these courses displaying a high level of adaptation to this pedagogical approach. In order to conduct a more thorough assessment during the subsequent full-text review, publications that could not be definitively included or excluded based solely on their titles and abstracts were included in the initial screening process. After thoroughly screening titles, abstracts, and keywords using the exclusion criteria (E1-E4), 46 articles met the criteria for further inquiry.

In this study, two screeners determined by the inclusion-exclusion criteria provided in Table 2 which papers should be included. After that, they then reviewed the selected papers to ensure that they met stringent screening criteria. Studies that mentioned flipped classroom but did not use flipped classrooms as a pedagogical approach were also removed. Papers that met any of the prescribed criteria were excluded after an exhaustive review of the studies. As a result, 30 publications were included in the systematic review. This process assures the study had strict criteria, and the review has a high bar for quality.

Figure 1: PRISMA Flow Diagram.



A complete and impartial assessment related to flipped teaching practices in undergraduate chemistry education is illustrated through the process of qualitative content analysis. The study concerned six overarching categories including Theoretical and/or pedagogical framework, Technological uses, Research Design Methods, Data collection, Data analysis, Pre-class Activities/In-class Activities, and Educational Outcomes. Qualitative content analysis is trustworthy and constructive to explain qualitative data and provide a synopsis of patterns and trends established. This method provides researchers the opportunity to comprehensively understand basic ideas and/or details of importance in the data they are studying, while also providing important insights and strong arguments for continuing the academic and practical evolution of undergraduate chemistry courses.

Researchers are encouraged not to use pre-defined coding schemes, in order to uphold the intellectual honesty and transparency of their analysis. The trustworthiness and authenticity of the study can be jeopardized in regards to the results if a pre-defined coding scheme directed the researchers thinking process either consciously or subconsciously. There are not pre-written coding schemes utilized in this study.

This study was designed to assess the outcomes or impacts of applied flipped teaching, and the study may have, within the context of flipped teaching evaluated subsequent educationalism. In so doing, this study attempts to provide a scientific basis on educational policy and instructional design based on the emplaced demonstrated outcomes of flipped teaching across diverse educational settings. The study provides an evaluation in regards to whether the 34 pieces of literature have been published based on 34 different key authors from various countries and curricular backgrounds in relation to the effectiveness of flipped teaching via multi-layered qualitative content analysis.

4. Findings

The results from the systematic review stem from analyzing 30 studies which were identified using the PRISMA methodology. Thirty selected studies were analyzed through six major dimensions which include (1) Basic Information of Selected Studies, (2) Theoretical and Pedagogical Frameworks, (3) Technological Tools Applied, (4) Research Design and Methods, (5) Pre-Class and In-Class Activities, and (6) Educational Outcomes.

4.1. 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.

Figure 2: Distribution of Selected Articles Across Journals.

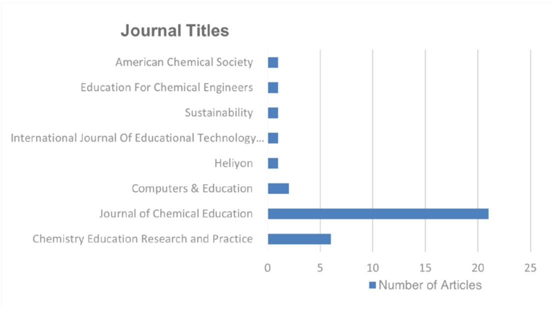
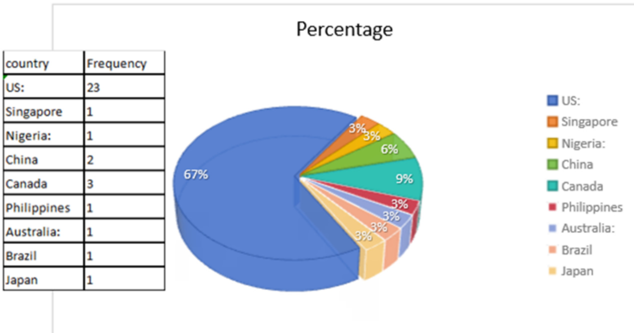


Figure 3: Distribution of Selected Articles Across Countries.

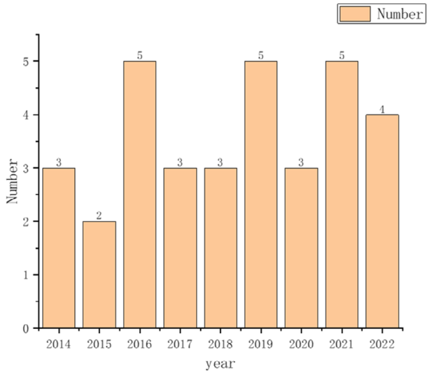


country	Frequency
US:	23
Singapore	1
Nigeria:	1
China	2
Canada	3
Philippines	1
Australia:	1
Brazil	1
Japan	1

United States represents the largest concentration of research due to its contributions which reach approximately 67% of the studies (Figure 3). Besides the United States, China stands alongside Singapore and Brazil along with Japan, Australia and the Philippines among the most significant contributors. Research about flipped classrooms shows a direct correlation within chemical education in America.

As illustrated in Figure 4 the number of research publications about flipped classroom pedagogy experienced a consistent upward trend from 2012 to 2022 but demonstrated strong growth during the 2016 to 2022 period. The upward trend is consistent with educational digitalization movements along with increased interest regarding online learning because of the COVID-19 pandemic (Li & Jiang, 2022; Wu et al., 2021).

Figure 4: Number of Articles Published from 2013 to 2023.



4.2. Theoretical and Pedagogical Frameworks

The different theoretical foundations used to implement flipped classrooms share fundamental learning theories as their common basis. As summarized from the analysis:

1. The literature (including studies 1, 2, 4, 13, 21, 25, and 32) consistently utilizes Cognitive Load Theory to enhance content delivery which reduces student mental strain experienced during difficult chemistry learning assignments.
2. The Social Constructivism theory highlights how students should build knowledge together while participating in flipped classroom activities (studies 16, 18, 22, 34).
3. The research demonstrates how motivation in students can be enhanced through both autonomy and competence based on Self-Determination Theory principles (studies 4, 5, 10).
4. Studies that focus on customized educational assistance utilize the concept of Zone of Proximal Development (ZPD) according to research numbers 19 and 30.

Learning frameworks validate the active teaching techniques of flipped classrooms by helping students prepare before class with materials and gain mastery of complex concepts during their sessions (Flynn, 2017; Li & Jiang, 2022).

4.3. Technological Tools Applied

A review confirmed a diverse selection of technological resources that help students learn through flipped classroom approaches (Figure 5; Table 3). The identified digital tools form the following categories:

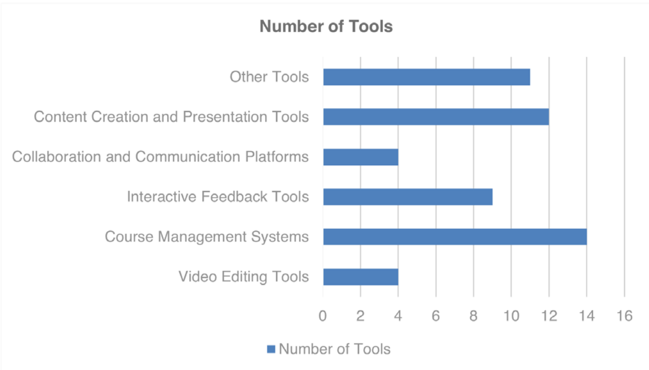
Table 3: Technological Tools.

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

Content generation and presentation applications lead the way in institutional engagement especially through recorded video classes and interactive visual aids (Wu et al., 2021). Blackboard and Moodle serve as learning management systems to distribute assignments and track students while Learning Catalytics and iClicker provide instant feedback systems to boost classroom interaction.

A flipped classroom enables the development of an extensive educational management system across various institutions. The complete analysis of these tools enables educators to discover better ways of integrating resources for optimizing their instructional design effectiveness. Student learning outcomes depend on regular training initiatives combined with technological knowledge maintenance.

Figure 5: Classification of Technology Tools.



The flipped classroom faced its first difficulties due to problems with connecting technology to a functional budget. The challenge of infrastructure became less significant as technology evolved along with the passage of time (Li & Jiang, 2022; Wu et al., 2021). The chart presented in Figure 5 illustrates the usage distribution of various instructional tools among Chinese higher education institutions. The “Other Tools’ category represents substantial technological developments in the specific functional tools used in educational technology. Modern educational practices promote student-centered instruction by offering "content creation and presentation tools" and "course management systems" which provide teachers with innovative teaching strategies. Educational technology platforms which enable collaboration and features that enable interactive feedback to serve essential roles for remote education and instant feedback delivery.

4.4. Research Design and Methods

Most of the research design adopts a quasi-experimental approach because performing complete randomized controlled trials remains impractical within educational institutions. The quasi-experimental research methods consisted of one-group pre-posttests along with non-equivalent groups designs and parallel controlled experiments (studies 1, 3, 4, 12, 16, 25).

Multiple approaches to research mix quantitative and qualitative data for investigations (studies 5, 15, 16, 17, 19, 24, 30, 31, 32, 34) through examination scores and quizzes linked with student interviews and reflection materials. The research credibility and generalizability increase through the implementation of longitudinal designs as well as cross-institutional comparisons.

Data collection methods include:

- Standardized tests and final exams
- Surveys and questionnaires
- Open-ended reflections
- Interviews and focus groups
- Classroom observations

The research design includes statistical methods ranging from t-tests and ANOVA to more advanced models of ANCOVA and regression analysis (Flynn, 2015).

4.5. Pre-Class and In-Class Activities

Pre-Class Activities predominantly consist of:

- Watching video lectures
- Completing quizzes and pre-class assignments
- Reviewing reading materials

The activities prepare students to arrive at class sessions fully informed before taking part in application-based investigations. 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)

The teaching approach focuses on knowledge application above information reception and this matches both constructivist theory and active learning models (Cevikbas & Argün, 2017; Seery, 2015).

4.6. Educational Outcomes

Across studies, flipped classrooms yielded multiple positive outcomes:

1. Research shows that students who learn in flipped classrooms experience better academic achievements as documented in numerous works (1, 2, 5, 6, 13, 18, 20, 24, 25) through their improved examination results and higher grades and better assignment submission rates. Ojennus (2016) found that flipped biochemistry students performed better on their tests.
2. The flipped classroom design works to minimize educational performance differences between students holding various background qualifications including low GPA students according to research by Ryan and Reid (2016) and Chakawodza, Mushayikwa and Stephen (2024).
3. Research findings show that flipped classroom structures improve student attention levels and student contentment along with motivational levels (studies 7, 12, 14, 17, 20, 30) because of their emphasis on active learning approaches.
4. Students developed better social management abilities because the approach promoted teamwork experiences together with peer-to-peer learning and self-management opportunities (Cevikbas & Argün, 2017).
5. Flipped classrooms have shown inconsistent results regarding their impact on test scores according to studies such as Ryan and Reid (2016) and Gregorius (2017) along with other studies because the effectiveness depends on how students are selected and how courses are designed.

4.7. Summary of Findings

Undergraduate chemistry education utilizing flipped classroom depends upon established theoretical foundations which direct both its development process and practical application. The implementation of educational technologies serves as strong support for this method by enabling students to complete pre-class preparation followed by in-class work. In advance of class, students prepare for active classroom experiences, using problems to drive learning and produce collaborative spaces. The educational research supports how flipped classroom approaches enhance students' engagement and their education achievement. Instructional success from this teaching approach requires a purposeful plan of instruction, to combat content area challenges, all while meeting the needs of each student exploring their instruction. This analysis assists in the understanding of the research evidence that has come before us that reveals the influence of flipped classroom constructs on both educational outcome improvement and active student engagement development.

5. Discussion

The implementation of flipped classroom methods in undergraduate chemistry education provides evidence from a systematic body of educational research which supports three existing theories: Cognitive Load Theory which assumes that the cognitive load of learning material can be reduced, theories of Social Constructivism which creates opportunities for conversation and interaction among students, and Self-Determination Theory which leads to self-directed learning and intrinsic motivation. The overall frameworks reduce cognitive load, allow students themselves to engage and work in pairs, and facilitate perceived outcome success for the students in their study. Cheng et al. (2019) put forward the argument that active learning methods remain a key component for implementing flipped teaching practices in STEM courses, and again in reference to constructivist teachers, it becomes a far greater proposition for student agency when the materials for study are shared in advance in their educational designs, and when educational materials are designed for student interaction in lesson work. There is a compelling scientific basis for constructing flipped classroom designs that is supported by theory and practice for undergraduate chemistry education.

Virtual educational tools have emerged as the primary developmental pattern for supporting flipped classroom delivery methods. Active flipped learning benefits from essential tools that include Camtasia for video creation as well as Blackboard and Moodle for course management alongside Learning Catalytics and iClicker for conducting interactive learning activities. Research evidence from Seery (2015) and Wu et al. (2021) shows that digital platforms assist student engagement before classes and give real-time instructional feedback. Several research studies documented inconsistent findings about performance enhancement in flipped classroom models since technology stands alone is not sufficient to ensure these educational results. The enduring value of instructional design, preparation for students, instructor facilitation, and technology are dynamic components influencing the effectiveness of technology-enhanced learning environments. The studies reviewed indicate a strong relationship between flipped classrooms and improved students' academic performance, increased students: engagement, and improved students' group work skills. The educational research literature has consistently verified the benefits of active learning pedagogies, such the advantages evidenced in the studies (Freeman et al., 2014). However, review of the analysis did identify several limitations associated with the effectiveness of flipped classroom instruction.. The research conducted by Ryan and Reid (2016) together with Gregorius (2017) showed flipped instruction did not surpass traditional teaching methods based on examination performance. Various differences emerge because of distinctive classroom designs together with differences in the student body composition and their readiness for the course material. The results from flipped classrooms tend to be positive although proper adjustments must be made to fit individual course purposes and student requirements within specific institutions.

6. Conclusion

Results assess how universities implemented flipped learning in undergraduate chemistry pedagogy throughout 2010 and its achieved outcomes. Using the foundations of Social Constructivism and Cognitive Load Theory in flipped classrooms leads to better student outcomes regarding performance and active participation and improved teamwork dynamics. In addition to the use of video editing platforms and learning management systems, we provided students with real-time feedback software to prepare for the in-class active training. While the quality of instructional design and student-centered pedagogy are essential to being successful, having different levels of access to technology is an important consideration.

Numerous research findings produced conflicting academic outcomes, mainly due to course design and the learner composition where the structure of instructional activities contributed to these outcomes. Future research should explore the potential long-term impacts of the flipped classroom methods in a variety of academic settings, as well as examine these pedagogy methods' effects on students' retention of knowledge, critical thinking skills, and professional competency gains. It will remain vital to develop and implement a flipped pedagogy approach using guided methodological research to achieve the best possible outcome for present-day undergraduate chemistry education.

6.1. Recommendations

The findings of the research present crucial implications for educators as well as educational decision-makers who are interested in advancing chemical education through flipped pedagogy. Successful integration of flipped pedagogy is contingent on intentional preparation in regard to the pre-existing literature. Outcome statements about learning objectives are important to educators as they prepare for classroom experiences, including pre-class activities and in-class activities, while also providing students with continuous support around engaging with active learning methods and using educational technology as a facilitator for education and learning related to instructional practice. Further research needs to study extensive flipped classroom outcomes and analyze performance discrepancies between different student groups and implement best practices for using flipped methods in different chemical specialties. The reported findings from this review create a vital framework for preserving and increasing the advancement of engaging learning spaces that welcome all students successfully in undergraduate chemistry education.

6.2. Limitations

Several limitations are associated with this study. First, the review comprised systematic review of only peer reviewed articles that were written in English, thereby excluding potential relevant research from English and grey literature sources. Second, the 30 reviewed studies have a diversity in study design, institutional context, and implementation fidelity that may constrain generalization to other contexts. Third, our qualitative synthesis was based on descriptive patterns rather than on statistical meta analysis, thus limiting precision of comparisons of outcomes. Moreover, there is no standardized evaluation metrics across the studies which makes direct evaluation of effectiveness of flipped classroom in undergraduate chemistry hard.

6.3. Future Directions

Future work in the domain should look at longitudinal studies of flipped classroom intervention on students' knowledge retention, critical thinking and professional competencies in chemistry. Moreover, standardized evaluation frameworks and outcome indicators are also needed to allow comparisons among studies and institutions. Research should also examine the incorporation of developing technologies, such as AI based adaptive learning tools, virtual reality focused on a flipped chemistry classroom. More interesting opportunities for further inquiry include students' and instructors' perspectives in underrepresented regions and institutions—a combination of which can provide richer understanding of contextual implementation barriers and enablers for discerning more inclusive and scalable pedagogical approaches.

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Appendix 1: Basic Information on the Research Matrix of Flipped Classrooms in Undergraduate Chemistry Education.

	First Author	Topic	Country	Year	Course/program	Duration	Journal
1	Hoi-Ting Wu	Incorporating concept development activities into a flipped classroom structure: using PhET simulations to put a twist on the flip	US	2021	general chemistry	one semester	Chemistry Education Research and Practice
2	James C. Shattuck	A Parallel Controlled Study of the Effectiveness of a Partially Flipped Organic Chemistry Course on Student Performance, Perceptions, and Course Completion	US	2016	Organic chemistry	eight sessions (a third of the course)	Journal of Chemical Education
3	Michael D. Ryan	Impact of the Flipped Classroom on Student Performance and Retention: A Parallel Controlled Study in General Chemistry	US	2016	General Chemistry	two semesters	Journal of Chemical Education
4	Jenay Robert	Coordinated Implementation and Evaluation of Flipped Classes and Peer-Led Team Learning in General Chemistry	US	2016	general chemistry	one semester	Journal of Chemical Education
5	Lorico DS. Lapitan Jr	Design, implementation, and evaluation of an online flipped classroom with collaborative learning model in an undergraduate chemical engineering course	US	2023	Analytical chemistry	One semester	Education for Chemical Engineers
6	Josphine Munyaradzi Chakawodza	Exploring Challenges Influencing the Discontinued Utilisation of the Flipped Classroom Pedagogy: A Case of South Africa Underprivileged High School and Organic Chemistry	US	2024	Organic chemistry	------	International Journal of Learning Teaching and Educational Research
7	Tang Wee Teo	How flip teaching supports undergraduate chemistry laboratory learning	Singapore	2014	undergraduate chemistry laboratory session	----	Chemistry Education Research And Practice
8	R. Ma. Gregorius	Performance of Underprepared Students in Traditional versus Animation-based Flipped-Classroom Settings	US	2017	general chemistry	four-year period	Chemistry Education Research And Practice
9	Mark Blaser	Combining Pre-class Preparation with Collaborative In-Class Activities to Improve Student Engagement and Success in General Chemistry	US	2019	General chemistry	one semester	ACS Symposium Series
10	Paul Baepler	It’s not about seat time: Blending, flipping, and efficiency in active learning classrooms	US	2014	general chemistry	Three semester	Computers & Education
11	Wenliang He	Impact of Partially Flipped Instruction on Immediate and Subsequent Course Performance in a Large Undergraduate Chemistry Course	US	2018	introductory chemistry course	ten-week quarter-based system	Computers & Education
12	Cecilia Obi Nja	Students’ attitude and academic achievement in a flipped classroom	Nigeria	2022	chemistry course	6 weeks	Heliyon
13	Kai Wang and Chang Zhu	MOOC-based flipped learning in higher education: students’ participation, experience and learning performance	china	2019	inorganic chemistry	one semester	International Journal Of Educational Technology In Higher Education
14	Wenliang He	Impact of partially flipped instruction on immediate and subsequent course performance in a large undergraduate chemistry course	US	2018	Undergraduate Chemistry Course	one semester	Computers & Education
15	Zan Li	Research on the Teaching Reform of Inorganic Chemistry Based on SPOC and FCM during COVID-19	china	2022	inorganic chemistry	6 weeks	Sustainability
16	Daniele Ramella	Using Flipped Classroom Settings to Shift the Focus of a General Chemistry Course from Topic Knowledge to Learning and Problem-Solving Skills: A Tale of Students Enjoying the Class They Were Expecting to Hate.	US	2019	General chemistry	one semester	ACS Symposium Series
17	Beverley J. Allan	Investigating Learner Perceptions and Outcomes of the Flipped Classroom in Foundation Chemistry Classes	Canada	2018	Organic Chemistry	one semester	Journal of the Foundation Year Network
18	Julie Schell	Flipping the Chemistry Classroom with Peer Instruction	US	2015	General Chemistry	one semester	Wiley Online Library
19	David Gross	Increased Preclass Preparation Underlies Student Outcome Improvement in the Flipped Classroom.	US	2015	Fundamentals of Chemistry	one semester	CBE—Life Sciences Education,
20	Rahmi Eka Witri	Integrated Green Chemistry Problem-Based Learning Module Development to Improve Science Process Skills Senior High School Students on Basic Chemicals Law.	US	2025	Chemistry Law	one semester	Journal of Research in Science Education
21	Alison B. Flynn	Structure and evaluation of flipped chemistry courses: organic & spectroscopy, large and small, first to third year, English and French	Canada	2015	organic & spectroscopy	One academic year	Chemistry Education Research and Practice

22	Deanna Dahlke Ojennus	Assessment of learning gains in a flipped biochemistry classroom.	US	2015	Biochemistry	1 week	Biochemistry and Molecular Biology Education
23	Alison B. Flynn	Flipped Chemistry Courses: Structure, Aligning Learning Outcomes, and Evaluation	US	2017	General Chemistry Course	one semester	Online Approaches to Chemical Education
24	Elise M. Heiss	Implementing a flipped classroom approach in remote instruction	US	2021	Physical Chemistry	one semester	Analytical and Bioanalytical Chemistry
25	Timothy Casasola	Can Flipping the Classroom Work? Evidence From Undergraduate Chemistry.	US	2017	Analytical Chemistry	One semester	International Journal of Teaching and Learning in Higher Education
26	Chui-Man Lo	Flexible learning with multicomponent blended learning mode for undergraduate chemistry courses in the pandemic of COVID-19.	US	2021	Undergraduate Chemistry Course	one semester	Interactive Technology and Smart Education
27	Fiona Ponikwer	Implementation and evaluation of flipped learning for delivery of analytical chemistry topics.	US	2018	Analytical Chemistry	------	Analytical and Bioanalytical Chemistry
28	Caroline Cormier	Flipped Classroom in Organic Chemistry Has Significant Effect on Students' Grades.	US	2018	Organic chemistry	one semester	Frontiers in ICT
29	Alison B. Flynn	Flipped Chemistry Courses: Structure, Aligning Learning Outcomes, and Evaluation	Canada	2017	Organic Chemistry courses Spectroscopy courses	-------	American Chemical Society
30	Lorico DS. Lapitan Jr	An effective blended online teaching and learning strategy during the COVID-19 pandemic	Philippine	2021	Physical Chemistry and Analytical Chemistry	one semester	Education For Chemical Engineers

Appendix 2: Matrix of Research on Flipped Classroom in Undergraduate Chemistry Education.

	RQ1: Theoretical/ Pedagogical Framework	RQ2: Technological Applications	RQ3: Research Design Methods	RQ4: Data Collection and Analysis	RQ5: Pre-class/In-class Activities	RQ6: Educational Outcomes
1	Cognitive Load Theory; Social Constructivism; Constructivism	PhET simulations	quasi-experimental design:one-group, pre-post-post research design	A single-group pre-test-post-test-post-test design was used, with five learning cycle activities, four using PhET simulations, completed in groups. Data Analysis: (SPSS): Friedman Test; Wilcoxon Signed-Rank Test; Effect Size (r) Calculation; Sankey Diagrams	Pre-Class Activities: Online video; pre-lecture quiz; self-study preparation. in-class: Students use PhET simulation tools to conduct interactive experiments, observe and record the results; group work; applied theory.	incorporating concept development activities into a flipped classroom structure using PhET simulations can lead to improved conceptual understanding in general chemistry courses.
2	Cognitive load theory; Constructivist Framework	Production Tool: Screencast-O-Matic Video Platform: Ensemble Video Access Method: Blackboard Learn. Recording Tool: Echo360	Exploratory Mixed-Methods Study	Data Collection: Ten quizzes; Three exams; One final exam; Three student surveys; One focus group discussion Data Analysis: One-tailed t-tests; Cohen's d effect size; Survey reliability assessment; Analysis of changes in student feedback; Qualitative insights from focus group discussion	Pre-Class Activities: Watch Instructional Video; Note-Taking; Complete Exercises; Checking and Grading In-Class Activities: Group Discussion; Note Checking; Large Group Discussion; Mini-Lectures; Problem Sets Instructor Interaction; Student Presentation; Discussion and Summary	The flipped classroom improved students' academic performance; The flipped classroom student dropout rates, indicating an increased willingness to complete the course.
3	Student-centered, active learning methodologies	voice-over Powerpoint based videos; captured and edited using CAMTASIA 2 software with a WACOM Bamboo tablet; each accompanied by an assignment delivered via the CONNECT system	parallel controlled experiment: quasi-experimental	Data Collection: Students self-selected into experimental and control groups; Standardized pre-test and five common exams used; Student evaluation data collected Data Analysis: Exam items validated using classical test theory and Rasch analysis	Pre-Class Activities: watch assigned video; complete online assignments In-Class Activities: Weekly Discussion Sessions; Active Engagement through Online Discussion Board	Overall exam performance showed no significant difference, but the bottom third of students significantly improved in the flipped classroom; The flipped classroom significantly reduced the DFW rate, with a substantial decrease in withdrawal rates for the lowest-performing students; In the flipped classroom, the correlation between online homework and exam performance was stronger; The flipped classroom received positive feedback and high satisfaction from students.
4	Cognitive Load Theory; Self-Determination Theory; radical constructivist	Camtasia software was used to record and edit video.	Camtasia software was used to record and edit video.	Data Collection: Test Data Analysis: Analysis of Regular Exam Scores Analysis of Control Variables	Pre-Class Activities: Watch Instructional videos; Weekly Quizzes In-Class Activities: Group Work;Immediate Feedback via Clicker Questions	Students in the Flipped PLTL classes showed improvements in both achievement and retention rates.
5	Collaborative learning in online flipped models.	Online collaborative platforms.	Design and evaluation study of an online flipped classroom with collaborative learning elements in chemical engineering.	Surveyed students and analyzed performance data to evaluate online flipped classrooms with collaboration.	Pre-class: Video lectures on course material. In-class: Collaborative problem-solving and group-based learning activities.	Increased engagement and learning outcomes in chemical engineering through collaborative flipped learning.
6	Socio-cultural challenges in flipped classrooms.	Digital learning tools.	Qualitative analysis exploring challenges in adopting flipped classrooms in underprivileged schools.	Used interviews and classroom observations to explore barriers in flipped classroom adoption.	Pre-class: Videos introducing foundational concepts. In-class: Group-based problem-solving and collaborative activities.	Higher grades and improved conceptual understanding in organic chemistry topics.

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7	ICAP framework	OWLv2; personal computer or Tablet	quasi-experiment	Data Collection: Student demographic information; Academic background of students; Student performance data; Student attitude surveys Data Analysis : Descriptive statistical analysis; Multivariate Analysis of Variance (MANOVA); Analysis of Covariance (ANCOVA); Partial correlation analysis	Pre-Class Activities: Textbook Study; complete self-study tasks; pre-class quizzes; Mini-lectures and videos. In-class Activities Collaborative discussions; group problem solving; instant feedback from Instructor.	Combined Flipped Classroom and Collaboration Support Outperforms Traditional and Single Collaboration Support Models; Flipped Classroom with Collaboration Support May Negatively Impact Student Attitudes.
8	-------	ICT-based resources	The methods and strategies utilized in this study align with quasi-experimental design.	Data Collection: Student Demographics and Academic Background; Performance Data; Student Attitudes and Feedback; Classroom Observations Data Analysis: Qualitative Analysis; Quantitative Analysis; Comparative Analysis; Thematic Analysis	Pre-class Activities: Students read the manual, watching demonstration video, and answering pre-lab questions. In-class Activities: Engage in pre-laboratory discussions, conduct the actual laboratory work.	Enhanced Theoretical Understanding; Mastery of Experimental Procedures;Reduced Learning Anxiety;Improved Lab Work Efficiency
9	Collaborative learning framework in flipped classrooms.	Pre-class online materials, clickers.	Case study examining the impact of combining collaborative learning with flipped classroom pedagogy.	Evaluated through student surveys and collaborative activity results to measure engagement and success.	Pre-class: Video content designed for clarity. In-class: Group problem-solving tasks and clicker-based quizzes.	Increased student engagement and overall success in general chemistry courses.
10	-------	Socrative: a free class room response system	phenomenological research design	Data Collection: Open-ended surveys and interviews; Classroom observations; Attendance and grade records Data Analysis: Content analysis; Theme identification; Interview analysis	Pre-class activities: Read one chapter before class;Complete two comprehensive questions. In-class activities: Teacher-led discussion on main ideas and key points; Group work based on class concepts; Graded by the teaching assistant for correctness.	The flipped classroom deepens the understanding of physical chemistry concepts through group discussions and interactions; Traditional exams are replaced with continuous assessments and feedback, reducing student stress and anxiety;
11	-------	blended/flipped format: Solving problems in small groups; working with computer simulations; playing a chemistry version of the Jeopardy game; answering clicker questions	quasi-experimental: posttest-only nonequivalent groups design	Data Collection: Academic Performance Measurement. Data Analysis: Statistical Analysis (Descriptive Statistics, Independent Samples t-Test, Chi-Square Test, Regression Analysis)	Pre-class activities: Engage in learning or preparatory work In-class activities: Problem-solving in small groups; Computer simulations; Game-based learning (Jeopardy); Clicker questions	Teacher-student contact time is reduced to one-third in active learning classrooms; Students achieve better or comparable outcomes to traditional classrooms; Students view the active learning environment more positively.
12	Cognitive Load Theory (CLT); Spaced Learning; levels of processing theory; Active Learning activities	Learning Catalytics: an in-class response system that allows students to answer questions in real time through the internet	The methods and strategies utilized in this study align with quasi-experimental design.	Data Collection: Student performance, survey data (motivation and perception). Data Analysis: Statistical data analysis (descriptive statistics, t-tests, chi-square tests, OLS regression analysis).	Pre-class Activities: Watch Online Videos; Complete Pre-Class Assignments In-class Activities: Conduct Quiz at Start of Class; Review Video Content Briefly; Engage in In-Depth Problem-Solving Activities	Flipped instruction had little impact on final exam performance but significantly improved subsequent course grades; Students with lower GPAs benefited more, while high GPA students showed no significant change; Overall motivation increased, especially among students with initially lower motivation; Students rated the flipped course highly .
13	-------	videos WhatsApp	A quasi non-equivalent, non-randomized factorial design	Data collection: students' attitudes, academic achievement Data analysis: statistical analysis (descriptive statistics; t-test; analysis of covariance (ANCOVA))	Pre-class Activities: Watch videos; Complete pre-class assignments In-class Activities: Start with quizzes; Brief review of video content by the teacher; Engage in in-depth problem-solving activities	The flipped classroom strategy has had a positive impact on students' attitudes toward learning chemistry and their academic performance; The flipped classroom strategy effectively increased student engagement.

14	Partial flipping for active engagement.	Online content delivery systems.	Quasi-experimental study analyzing how partial flipping impacts immediate and subsequent academic performance.	Compared performance data across cohorts to evaluate flipping's impact on academic results.	Pre-class: Video resources presenting theoretical aspects. In-class: Hands-on problem-solving and group discussions.	Improved immediate and long-term performance in large undergraduate chemistry courses.
15	-------	SPOC	Mixed research methods that combine quantitative(quasi-experimental) and qualitative data	Data Collection: Student engagement Student Experience Academic Performance Students' self-efficacy (SE) and subjective norms (SN) Data Analysis: Statistical data analysis(Descriptive statistical analysis Independent samples t-test Paired samples t-test Analysis of covariance (ANCOVA)), Qualitative data analysis	Pre-Class Activities: Watch micro-lectures on SPOC platform; Complete online exercises; Record incorrect answers. In-Class Activities: Group discussion on exercise errors; Teacher reviews key discussion points.	Increased Student Engagement and Activity; Better Performance in Final Exams Compared to Traditional Classroom; No Significant Change in Self-Efficacy and Subjective Norms; Improvement in Self-Directed Learning and Teamwork Skills; Enhanced Technical Communication and Innovation Skills; High Student Satisfaction with the Learning Platform.
16	Flipped classroom pedagogy emphasizing active learning and problem-solving skills.	Online videos, digital resources, and LMS integration.	Case study examining how a flipped classroom affects student attitudes and problem-solving in general chemistry.	Collected student feedback and evaluated performance metrics, emphasizing problem-solving skills improvement.	Pre-class: Video lectures focusing on foundational knowledge. In-class: Problem-solving and application-focused activities to reinforce learning.	Enhanced problem-solving skills and increased student satisfaction with the learning experience.
17	Flipped classroom in foundation chemistry.	LMS tools, recorded lectures.	Mixed-methods study examining student perceptions and academic performance in foundation chemistry courses	Tracked academic performance and surveyed students to link perceptions with flipped learning outcomes.	Pre-class: Videos introducing foundational concepts. In-class: Group-based problem-solving and collaborative activities.	Positive student perceptions and improved academic outcomes in foundation chemistry courses.
18	Peer Instruction model in flipped learning.	Clickers and polling software for peer instruction.	Mixed-methods study analyzing peer instruction's role in improving learning in flipped chemistry classrooms.	Surveyed students and analyzed engagement metrics, focusing on peer instruction effectiveness.	Pre-class: Conceptual videos and preparatory materials. In-class: Peer-led discussions and collaborative problem-solving exercises.	Greater engagement and deeper understanding of key chemistry concepts through active learning.
19	Active learning theory in flipped classrooms.	Pre-class videos and quizzes hosted on LMS.	Experimental design comparing student outcomes in flipped versus traditional classroom setups.	Tracked quiz scores and exam performance to measure preparation and outcome differences.	Pre-class: Short, focused video lectures. In-class: Active group discussions and hands-on applied exercises.	Improved pre-class preparation resulting in better exam performance and conceptual understanding.
20	Problem-Based Learning with a green chemistry focus.	Digital green chemistry modules.	Design-based research assessing the effectiveness of green chemistry problem-based modules on learning outcomes.	Used observations, pre/post-tests, and interviews to evaluate science process skill development.	Pre-class: Green chemistry digital modules. In-class: Laboratory experiments and collaborative problem-solving scenarios.	Development of enhanced scientific process skills, particularly in problem-solving and collaboration.
21	Constructivism	Camtasia; Sapling Learning; SMART Podium; ECHO360; TopHat	Mixed research methods that combine quantitative(quasi-experimental) and qualitative data	Data Collection: Student Performance Data; Student Feedback and Satisfaction; Students' feedback and opinions Data Analysis : Statistical Tests(Chi-square tests, t-test,Descriptive Statistics) ; Course Evaluation Analysis	Pre-Class Activities: Watch Videos; Self-study Materials; Pre-class Tests In-Class Activities: Group discussions; interactive learning activitie; problem-solving; and real-time Q&A using a classroom response system (TopHat).	The students' final grades significantly improved in the flipped classroom model; The dropout rate was significantly lower compared to historical data; Courses using the flipped classroom model showed a significant decrease in failure rates; The majority of students gave positive feedback about the flipped classroom model.
22	Constructivist learning in flipped settings.	Pre-recorded lectures and online simulations.	Longitudinal study tracking biochemistry knowledge retention and application over time in flipped settings.	Quantified learning gains through pre/post-tests and tracked long-term knowledge retention.	Pre-class: Pre-recorded lectures covering key concepts. In-class: Interactive, scenario-based problem-solving activities.	Stronger retention and comprehension of biochemistry concepts over time.

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23	Alignment of learning outcomes with flipped pedagogy.	Video lectures and online discussion forums.	Combination of surveys, interviews, and assessments to measure the alignment of learning outcomes with flipped classroom techniques.	Analyzed surveys, learning reflections, and alignment of assessments with intended outcomes.	Pre-class: Recorded lectures targeting learning outcomes. In-class: Group activities and peer review sessions.	Improved alignment of educational outcomes with structured learning objectives in flipped settings.
24	Flipped classroom for remote learning during COVID-19.	Online meeting platforms and LMS tools.	Case study analyzing remote learning adaptations of flipped classrooms during the COVID-19 pandemic.	Collected grades and conducted surveys to evaluate learning outcomes during remote flipped implementation.	Pre-class: Online instructional videos. In-class: Synchronous virtual discussions emphasizing collaboration.	Flexible, pandemic-resilient learning opportunities leading to improved outcomes in remote settings.
25	Evidence-based flipped classroom model.	Online video platforms and quizzes.	Experimental design comparing the efficacy of flipped classrooms on undergraduate chemistry learning outcomes.	Analyzed exam scores and conducted student surveys to assess the effectiveness of flipped instruction.	Pre-class: Short video lectures introducing topics. In-class: Active learning tasks like problem-solving.	Significant improvements in student performance and engagement in undergraduate chemistry.
26	Blended learning framework during COVID-19.	LMS, video lectures, online quizzes.	Mixed-methods research investigating the effectiveness of blended learning strategies in chemistry education.	Surveyed students and analyzed pre/post-tests to determine blended learning's adaptability and success.	Pre-class: Digital video content. In-class: Hybrid collaborative activities integrating traditional and online learning.	Adaptability to pandemic constraints with effective learning outcomes in chemistry courses.
27	Flipped learning for analytical chemistry.	Online tools for content delivery.	Case study on the implementation of flipped learning for analytical chemistry topics and associated outcomes.	Conducted surveys and performance reviews to determine flipped learning's impact on analytical chemistry education.	Pre-class: Digital resources and preparatory materials. In-class: Collaborative group problem-solving activities.	Enhanced understanding and application of analytical chemistry concepts through active learning.
28	Flipped model in organic chemistry.	Pre-class videos, online quizzes.	Quantitative study focused on the impact of flipped classrooms on organic chemistry student grades.	Analyzed exam grades and collected student perceptions to measure flipped learning's success in organic chemistry.	Pre-class: Video lectures emphasizing concepts. In-class: Application-based interactive problem-solving tasks.	Higher grades and improved conceptual understanding in organic chemistry topics.
29	social constructivism, meaningful learning, and modern information processing theory	YouTube; e-Learning (part of our Teaching and Learning Support Service); COPUS; anonymous course evaluation results; classroom response system	Mixed research methods that combine quantitative and qualitative data	Data Collection: Student Grades; Student Satisfaction; Student Attendance and Participation; Course Withdrawal and Failure Rates; Classroom Observation Data Data Analysis: Descriptive Statistical Analysis; Hypothesis Testing; Effect Size Analysis; Chi-Square Test; Classification and Frequency Analysis of Classroom Activities; Consistency Assessment	Pre-class activities: Preparation and review of learning materials; Online pre-class tests. In-class activities: Interactive learning activities; In-depth learning and complex problem-solving.	Students in flipped classrooms show significant improvements in their grades; The dropout and failure rates in flipped courses are lower than those in traditional lecture courses; Student satisfaction is high; There is a significant increase in active student participation during class. It helps students achieve deeper learning.
30	-------	Microsoft PowerPoint; Movavi video editor software; YouTube; Blackboard	Mixed research methods that combine quantitative and qualitative data	Data Collection: Student learning experiences; Student academic performance; Instructor observations Data Analysis: Descriptive statistics; Student performance analysis; Text analysis	Pre-Class Activities: Learning through the Blackboard Learning Management System (LMS) or YouTube. In-Class Activities: Self-assessment Questions (SAQs); Synchronous Teaching via Zoom or Google Meet; Online Quizzes or Exams	flipped classroom" approach (Discover, Learn, Practice, Collaborate and Assess (DLPCA)): Strengthened Understanding and Mastery of Physical Chemistry and Analytical Chemistry; Improved Academic Performance; Enhanced Interaction and Participation Among Students and Between Students and Teachers; Teachers Gained More Insights and Skills in Effectively Using Online Educational Tools; High Student Satisfaction.