

Fostering Deep Learning: The Impact of Flipped Classroom on Academic Performance and Thinking Skills in Organic Chemistry I

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Abstract: Organic chemistry is widely regarded as one of the most challenging subjects in undergraduate STEM education, often contributing to decreased student motivation and academic persistence. This study aimed to evaluate the effectiveness of the flipped classroom (FC) model compared to the traditional classroom (TC) approach in enhancing academic performance and thinking skills among students enrolled in an Organic Chemistry I course. A quasi-experimental Pre-test-Post-test non-equivalent group design was implemented over 16 weeks with 110 sophomore students (55 per group). Achievement was measured using standardized tests, and data were analyzed using Generalized Estimating Equations (GEE). Results showed that the FC group achieved significantly higher post-test scores than the TC group, with a moderate effect size. While Pre-test scores showed no significant differences, the FC model notably improved higher-order thinking skills (HOTS), whereas the TC model was more effective in reinforcing lower-order thinking skills (LOTS). The findings support the integration of flipped classroom pedagogy in organic chemistry, aligning with social constructivism and cognitive load theory. A mixed instructional approach is recommended: using FC to foster analytical and creative thinking, and TC to solidify foundational knowledge, thereby equipping students with both conceptual understanding and applied skills relevant to Industry 4.0.

Keywords: Flipped Classroom, Organic Chemistry Teaching, Higher-order Thinking Skills, Quasi-experimental Design, Generalized Estimating Equations.

1. Introduction

1.1. Research Background

Undergraduate Organic Chemistry I is generally praised as a tough course in STEM education, calling for intensive uses of analytical thinking, critical thinking and problem-

solving (Arnaud, 2020; Bodner, Ferguson & Çalimsiz, 2017; Crimmins & Midkiff, 2017; Dehghan, Horan & Frome, 2022). Success in this course is possible when students memorize tough material and also grasp key concepts such as reaction mechanisms, stereochemistry and analysis of the structure of molecules, since these require them to apply their knowledge in fresh situations (Salame, Satter & Warda, 2024). Many successful students find it difficult to meet these requirements, demonstrating the continued difficulty that Organic Chemistry-I represents for undergraduates (Elbulok-Charcape et al., 2021). Many people think that the tough academic work in STEM majors causes students to lose interest and switch to other courses because they often go without enough assistance (Harris et al., 2020).

Using the traditional paradigm causes students to focus more on simply memorizing information. Traditionally, classroom approaches depend heavily on the teacher providing information to students one way. In school, students usually listen carefully, take notes, finish assignments and manage problems themselves. Moreover, while this teacher-centered, lecture-based pedagogy can effectively convey content, it often fails to provide personalized learning assistance, particularly in fostering students' higher-order thinking skills. This results in diminished student engagement, restricted growth of independent learning skills, and difficulty navigating the course's complexities (Dehghan et al., 2022).

This can be a barrier to implementing instructional innovations and the student's ability to comprehend the material in greater depth. This method may need to be more effective in engaging students to participate actively and think, which has a detrimental impact on the students' grasp of scientific topics and their attitude toward those concepts. This paradigm is still widely used in most students' science classes (Lund & Stains, 2015). According to Crimmins and Midkiff (2017), the traditional paradigm negatively affected the performance of students who were enrolled in organic chemistry classes, and it also decreased the students' enthusiasm for doing well in the class.

Given the demands of 21st-century skills and the Fourth Industrial Revolution (Schwab, 2024), educational reform is important. In order to cope with the rapid changes and technological advancements of the work environment, contemporary society is placing a greater emphasis on the importance of fundamental qualities such as collaboration, communication, critical thinking, and creativity (Eteris, 2024). Mastering fundamental abilities like problem-solving complexity is crucial to remaining competitive in this transformative period (Postelnicu & Calea, 2019). Simultaneously, the significance of technology in education has grown markedly. Information and communication technology is an important tool for boosting students' academic performance (Galanek, Gierdowski & Brooks, 2018). Expanding technologies such as autonomous learning and mobile learning are firmly integrating ICT into how education is carried out (Admiraal et al., 2017; Lalima & Dangwal, 2017). At present, because of their higher demand for learning freedom, students are relying on digital resources and multimedia tools to get more involved and practical experiences in their studies (Verawati et al., 2024). For this reason, the educational model has to be flexible to respond to what next generation students require.

In a Flipped Classroom, students learn foundational concepts with the help of videos or resources before coming to class. Consequently, teachers and students will spend more time talking, working together, answering questions and doing hands-on exercises in the classroom. Using this approach encourages students to actively learn

and understand things better, making classroom activities more efficient (Khadjieva & Khadjikhanova, 2019; Nja et al., 2022; Torres-Martín et al., 2022). It reflects the move in current education from focusing on the teacher to making students the center, encouraging their creativity, how they collaborate and needed competencies (Ozdamli & Asiksoy, 2016).

The research by Bergmann and Sams (2012) greatly supports the spread of flipped classroom practices. According to Bishop and Verleger (2013), the flipped classroom model works with classroom instruction being interactive and collaborative and outside the classroom, individualized study is dependant on utilizing educational resources online. It emphasizes joining classroom with informal education to let students learn more and do it themselves.

Students are introduced to the classroom's theoretical subjects using online videos, written materials or other forms of multimedia before class. It supports better class functioning, encourages independent learning by each student and boosts self-learning.

Students use application, analysis and synthesis skills during class activities, so they can develop both critical and creative thinking (Munir et al., 2018). Doing these exercises helps students become better critical thinkers, develop solution-finding skills and strengthen their intellectual skills, according to Bloom's taxonomy. Boost students' ability to learn about difficult topics and increase their mental skills (Fischer et al., 2023; Lundin et al., 2018; Yang, 2017).

Flipped classrooms are especially appropriate for 21st-century learners, who are increasingly susceptible to using digital platforms and social media for learning. (Yildirim & Kiray, 2016). This pedagogical methodology enhances students' learning potential and considerably improves their autonomous learning and self-regulation abilities.. Simultaneously, it improves opportunities for contact and feedback between instructors and students, increasing students' classroom participation (Aguilar et al., 2021; Hussain et al., 2020; Price & Walker, 2021; Sun, Xie & Anderman, 2018; Yang, 2017).

1.2. Problem Statement

Organic Chemistry is often perceived as one of the most challenging courses in undergraduate STEM education due to its abstract content and heavy cognitive demands. This difficulty contributes to low academic performance and student disengagement. Although there are many studies on active learning and flipped classrooms in science education, most are done in general science courses at the secondary grade level. According to Strelan, Osborn and Palmer (2020), studies indicate that flipped classrooms moderately help students in various subject areas. Nevertheless, research concentrating on the flipped classroom approach in Organic Chemistry I, with a focus on its role in improving higher-order and lower-order thinking skills, is uncommon. This difference points out the importance of targeted research in this particular learning situation.

1.3. Research Objectives

1. "To analyze the impact of the flipped classroom approach on students' academic performance in an undergraduate Organic Chemistry I course, in comparison with traditional classroom instruction."

2. "To study the differentiated effects of flipped and traditional teaching methods on the development of higher-order thinking skills (HOTS) and lower-order thinking skills (LOTS) among undergraduate students."

1.4. Research Questions

1. What is the impact of the flipped classroom approach on students' academic performance in an undergraduate Organic Chemistry I course compared to traditional classroom instruction?
2. How do flipped and traditional teaching methods differently influence the development of higher-order thinking skills (HOTS) and lower-order thinking skills (LOTS) among undergraduate students?"

1.5. Significance of the Study

The study demonstrates how using a flipped classroom in Organic Chemistry I can improve grades and strengthen critical thinking skills in students. The study helps to improve chemistry education research by exploring the difference between traditional and flipped instructional approaches. The study's outcomes support the practice of active learning in university settings and add to social constructivist and cognitive load theories. Moreover, the research teaches curriculum designers and educators to incorporate blended learning to make sure students learn basic subjects and develop important 21st-century thinking abilities.

2. Literature Review

2.1. Theoretical Foundations of the Flipped Classroom

Cognitive load theory (CLT) and social constructivism are crucial for flipped classroom and form the basis for developing science curricula for undergraduates (Bancroft et al., 2020; Bokosmaty, Bridgeman & Muir, 2019; Flynn, 2017; Naibert et al., 2020; Robert et al., 2016).

CLT stresses that the way we design educational materials must consider the limits of working memory capacity (Atkinson et al., 2020). The efficiency of learning and how much is understood could be hampered if the lessons and tools used go beyond what students can deal with through working memory. In innovative ways, organic chemistry courses supported by cognitive load theory help students to manage information effectively and save time during their studies which results in better learning outcomes (Shattuck, 2016). Students can watch videos at their own pace in a flipped classroom which lowers the amount of information they must process during class and improves how well they can participate in activities (Fischer et al., 2023).

Social constructivism says knowledge is partly formed through conversations and the flipped classroom is a good place for students to have these exchanges. In flipped classrooms, the usual educational system shifts to let students learn through doing activities and experiments instead of just listening. By being involved in group conversations and teamwork, students develop practical knowledge in social situations. Some research reveals that when flipped classrooms are practiced with

social constructivism, students are able to learn more actively and better grasp difficult subjects. According to social constructivism, gaining new information occurs through social interaction (Noguera Fructuoso, Albó & Beardsley, 2022).

2.2. Review of the Application of the Flipped Classroom in Organic Chemistry

Teaching organic chemistry in universities using flipped classrooms has produced promising, yet not simple, results. According to Mooring and colleagues (2016), the flipped method gave students easier access to learning and made them happier in class, mainly thanks to its flexible structure and chances for student involvement. Nevertheless, not every student accepts this classroom model, as they believe the tasks before class are very demanding (Dehghan et al., 2022; Shattuck, 2016). Research indicates that although the flipped model could benefit students, its real value depends on their ability to study on their own.

Both Rein and Brookes (2015) discovered that partially flipped classrooms achieved small gains on tests and slightly fewer failures, yet students were more likely to give the course better evaluations. According to Crimmins and Midkiff (2017), the use of flipped instruction appears to help students in the middle which may help close some achievement gaps between student groups. In the same way, Reimer et al. (2021) stated that the model enables both repeaters and first-generation students to benefit more equally from higher education. The authors mention that asynchronous materials contribute greatly to the success of the flipped classroom process, explaining both fundamental concepts (LOTS) and advanced analysis concepts (HOTS) relevant to Bloom's taxonomy framework.

2.3. Bloom's Taxonomy and Higher Order Thinking Skills (HOTS)

Bloom's Revised Taxonomy is used as a basic tool in education research to study how students move from lower-order to higher-order thinking skills (Demir, 2024). These six cognitive levels organize the demands of Organic Chemistry I into a structure that makes sense (Rahayu, Syah & Najib, 2021). As the Fourth Industrial Revolution continues, HOTS now plays a crucial role in preparing learners for solving tough problems, critical thinking and being innovative (Widana et al., 2018).

In this research, Bloom's taxonomy does more than describe cognitive skills; it helps examine what students gain from each approach. Tasks involving designs and reactions in advanced organic chemistry such as how to create compounds or how they work are mainly aided by using the HOTS (analyze, evaluate and create) thinking skills. However, LOTS (remember, understand and apply) are important but are not enough for advanced reasoning.

Research has confirmed that flipped classrooms may increase students' involvement, but examining their consequences on HOTS is still limited (Holloway et al., 2024). As a result, Bloom's taxonomy is used in this study to compare and assess both HOTS and LOTS under different instruction methods. This reframing positions Bloom's taxonomy as a practical evaluative lens rather than a standalone theoretical reference, bridging pedagogical theory with measurable learning outcomes (Oktaviana & Susiaty, 2020; Yurdabakan, 2012).

To summarize, while there is a general agreement that flipped classrooms have the potential to improve student learning in Undergraduate-level chemistry instruction

and foster active learning, their effectiveness is inconsistent. Consequently, diversity research is required to elucidate the application of flipped classroom pedagogical approaches and their outcomes across various situations. The particulars of the instructional approaches employed in the course and their implementation significantly influence the students' learning outcomes (Weaver & Sturtevant, 2015).

Table 1: Bloom's Taxonomy: Higher Order Thinking Skills Descriptions (Sagala & Andriani, 2019).

HOTS	Description
Analyze	By dividing and structuring the information, the complex scenarios are discerned, and corresponding questions are developed.
Evaluate	Assess the validity of solutions and ideas using suitable criteria and determine whether to endorse them.
Create	Broadening of concepts, formulating innovative solutions, and integrating components to construct novel architectures.

2.4. Role of Flipped Classroom Pedagogy in Enhancing Academic Performance

The flipped classroom pedagogy has emerged as a student-centered instructional model aimed at enhancing academic performance by reallocating traditional lecture content to pre-class activities and utilizing class time for collaborative, application-based learning. According to Eltahir and Alsalhi (2025) in their publication, turning classrooms into flipped classrooms enables students to perform well, with consistent but modest achievements, thanks to more chances to participate and learn on their own schedule. According to Förster et al. (2022), these perks do not apply to all situations; rather, success in flipped approach depends on features like course planning, instructional planning and students' preparations. In organic chemistry, which is difficult and almost completely abstract, the flipped classroom appears to be helping. After using a flipped approach, Cormier and Voisard (2018) said that students not only did better in schoolwork but also showed the most improvement among those who performed poorly in lectures. According to Reimer et al. (2021), flipped modules were successful for students who repeated courses and first-generation students, which suggests the model, could help close achievement gaps. Research demonstrates that the flipped classroom helps to improve regular academic progress and make learning environments more open to all learners. To be effective, the use of pre-class and in-class activities should support the stated learning objectives and match the students' thinking levels. Consequently, to achieve the best educational results, flipped classrooms in higher education need thorough implementation, educational specialization and regular feedback.

2.5. Literature Gap

Although a lot of research has been done on flipped classroom methods in general, not much has been studied in the context of Organic Chemistry at the undergraduate level. Most research looks at how students feel about flipped classes or at their overall performance, not at how such teaching impacts different levels of thinking. In addition, not many studies have examined the effects of pedagogical models

with precise scientific experiments. This difference points out why it is important to conduct research that explores how flipped learning influences student thinking in tough classes such as Organic Chemistry I.

3. Methodology

3.1. Research Design

The study employed a widely recognized quasi-experimental methodology, specifically a pre-test and post-test nonequivalent group design (Debbag & Yildiz, 2021). aimed to investigate the effect of an innovative instructional approach, the flipped classroom, on students' academic performance. It is common practice to use quasi-experimental research to assess the potential effects of instructional interventions in contexts that are not entirely randomized (Chuang & Tsao, 2013; Hinojo-Lucena et al., 2018; Mingorance-Estrada et al., 2019).

Table 2: Pre-test and Post-test Nonequivalent Group Design.

	Pre-test	Intervene	Post-test
G1(experimental group)	O ₁	X	O ₂
G2(Control Group)	O ₃		O ₄

Experimental group (G1):

O₁: Pre-test the experimental group before the intervention gathers baseline data.

X: The experimental group utilized a flipped classroom

O₂: Conducting post-tests on the experimental group

Control Group (G2):

O₃: Pre-test the control group gathers baseline data.

The control group employed traditional classroom instruction.

O₄: Conducting post-tests on the control group

3.2. Online Materials and Platforms

The design of pre-class learning materials follows the principle of “short time and high efficiency.” The content includes short online videos, teacher-created microlesson videos, and concise reading materials. These resources are strategically developed to support pre-test and post-test instructional design, ensuring alignment with the course's learning objectives while maximizing cognitive engagement in minimal time. One or two leading questions will facilitate students' self-directed learning before the lesson. The pre-class learning materials are available on Xuexitong, an online learning platform, to facilitate independent study for students. Xuexitong is a comprehensive, multifunctional educational application platform that amalgamates mobile teaching, learning, reading, and social functionalities, and is compatible with both PC and mobile devices. This platform facilitates an integrated environment for educators and learners, encompassing course learning, resource exploration, and social engagement. Interaction is another application of this platform. It is a comprehensive online learning platform that offers educators and learners various resources to augment the educational experience.

Figure 1: XueXiTong Online Learning Platform Interface Examples.



3.3. Course Arrangement

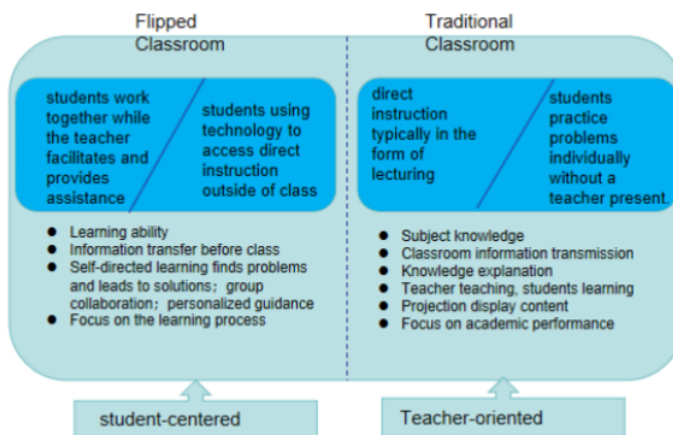
The study was carried out in an undergraduate organic chemistry course extending over a semester, including topics such as aromatics, alkanes, alkenes, and spectral analysis etc.. The research was conducted at a local university in Hebei Province. Comprised 110 second-year undergraduate students. The students were divided into two groups: experimental group and control group, each including 55 students. The experimental group employed the flipped classroom pedagogical approaches, whereas the control group utilized the traditional Classroom pedagogical approaches.

The flipped classroom is a student-centered pedagogical approach that emphasizes enhancing students' interactive participation and collaborative abilities. Students acquire fundamental knowledge outside of class, and after that, they tackle challenges collaboratively with peers in class under the supervision of educators. Furthermore, it underscores the importance of personalized tutoring for students. The traditional classroom is a teacher-centered pedagogical approach that primarily transfers knowledge through direct instruction by educators. Frequently utilize devices like multimedia projectors to provide instructional material (see Fig. 2). The two groups were maintained consistently regarding syllabus, course content, instructional duration, educator's educational background, and resource distribution to assure the dependability of the research findings (Debbağ & Yıldız, 2021).

Table 3: Comparative Instructional Design: Task Timing and Format with Equal Time Investment.

Groups	Out-of-class Tasks	In-class Activities
TC group	Watch videos + Pre-class quizzes	Group discussions, Problem-solving
FC group	Read materials + Post-class exercises	Instructor-led instruction
Both groups spent equal time on tasks, with variations only in timing (pre-class/post-class) and format (video/reading), ensuring differences stemmed from pedagogical approaches rather than time invested.		

Figure 2: Flipped Classroom and Traditional Classroom: A Comparative Overview.



3.4. Instrument: Achievement Test

Both sets of students were given a pre-test and a post-test of the final examination, which served as an achievement test to evaluate students' level of comprehension regarding organic chemistry.

The examination paper has single-choice questions, fill-in-the-blank questions, true or false questions, short-answer questions, and comprehensive questions. According to the commonly used item types from recent years, it thoroughly encompasses all chapters, and the overall score is 100 points; the Delphi approach was utilized, involving several iterations of expert feedback and modifications to ensure that the question types effectively assess students' higher-order thinking skills (HOTS) and lower-order thinking Skills (LOTS). Aimed to accurately evaluate students' mastery of knowledge and the holistic growth of their cognitive abilities.

A total of 36 students were recruited for pilot testing to evaluate the reliability and validity of the assessment instrument. Participants were selected from upper-level undergraduate cohorts with prior exposure to Organic Chemistry I to ensure content familiarity. After excluding three incomplete responses, data from 33 completed tests were analyzed. The results confirmed that the instrument demonstrated strong reliability and validity, making it suitable for use in the main study.

The results showed that the content validity index is 0.95, which means that the questions were highly consistent with the test objectives. The difficulty index was 0.58, indicating that the test questions were moderately difficult. The Item Discrimination Index is 0.303, demonstrating that the test can differentiate between people with

varying ability levels. The internal consistency coefficient is 0.90, and the split-half reliability is 0.93, demonstrating that the achievement test exhibits strong consistency and stability. These measurement indicators demonstrate that the test possesses good reliability and validity.

Table 4: Validity and Reliability of Achievement Test.

Item	Content Validity Index	Item Difficulty Index	Item Discrimination Index	Internal Consistency	Split-Half Reliability	Interrater Agreement
	0.95	0.58	0.303	0.90	0.93	0.990

3.5. Data Collection and Analysis

This study employed a quasi-experimental, non-randomized group design to evaluate the effectiveness of different instructional approaches in an undergraduate Organic Chemistry I course. A 16-week intervention was implemented with two intact class sections: the experimental group (n = 55), which received flipped classroom instruction, and the control group (n = 55), which followed traditional lecture-based teaching. To assess learning outcomes, both groups completed a pre-test at the beginning and a post-test at the end of the semester using the same validated instrument (Nja et al., 2022). The design controlled for potential internal validity threats, such as historical and maturation effects, by maintaining consistent content, duration, and instructor across groups.

“The study sample consisted of 110 sophomore students enrolled in an undergraduate Organic Chemistry I course, divided equally into two groups: the Flipped Classroom (FC) group (n = 55) and the Traditional Classroom (TC) group (n = 55). Demographic information was collected at the beginning of the study, including gender, place of residence, only-child status, family income, and class leadership role. Chi-square tests were conducted to determine whether there were significant differences between the two groups in these demographic variables.”

For academic performance analysis, data were collected through pre-test and post-test assessments administered at the beginning and end of the 16-week instructional period. Descriptive statistics mean standard deviation, skewness, and kurtosis—were calculated for both groups to summarize performance distribution. The Shapiro-Wilk test was used to assess the normality of the data, confirming that it met the assumptions required for parametric statistical testing. These preliminary analyses ensured group equivalence at baseline and justified the use of inferential methods such as t-tests and Generalized Estimating Equations (GEE) in the subsequent analysis.

4. Results

The basic demographic information of the TC Group and FC Group has been described. Table 5 presents the detailed distribution of participants' demographic characteristics.

Table 5 compares the differences between the traditional classroom (TC group, n=55) and the flipped classroom (FC group, n=55) in terms of key socio-demographic indicators such as gender ratio (male/female), residential area type (rural/urban/town), only child (yes/no), family income, and class leadership (yes/no). The chi-

square test for homogeneity ($\chi^2=0.583-0.0$, $df=1-3$) indicates that all p-values were between 0.445 and 1.0 ($\alpha=0.05$). It confirms that differences in subsequent academic achievement can primarily be attributed to pedagogical approaches rather than demographic confounding.

Table 5: Demographic Characteristics and Chi-square Analysis: TC vs FC Groups.

Demographic Variable	Category	TC group Frequency	TC group Percentage	FC group Frequency	FC group Percentage	Chi-Square Statistic	p-value
Gender	1	26	45.61%	31	54.39%	0.583	0.445
	2	29	54.72%	24	45.28%		
Residence	1	16	29.09%	18	32.73%	0.430	0.806
	2	17	30.91%	14	25.45%		
	3	22	40.00%	23	41.82%		
Only Child	Yes	27	49.09%	30	54.55%	0.420	0.936
	No	28	50.91%	25	45.45%		
Family Income	1	27	49.09%	30	54.55%	0.420	0.936
	2	13	23.64%	12	21.82%		
	3	10	18.18%	8	14.55%		
	4	5	9.09%	5	9.09%		
class leadership	Yes	5	9.09%	6	10.91%	0.0	1.0
	No	50	91.91%	49	89.09%		

Table 6: Descriptive Statistics and Normality Assessment: Pre- test and Post-test Scores of FC vs. TC Groups.

Test Phase	Groups	Valid N	Mean	Standard Deviation	Skewness	Kurtosis	W Statistic	Shapiro-Wilk Test p-value	Levene's Test
Pre-test	FC Group	55	20.69	5.91	-0.115	-0.131	0.988	0.860	F value: 0.198
	TC Group	55	19.49	5.43	0.134	-0.872	0.968	0.164	Sig. (p value): 0.657
Post-test	FC Group	55	60.02	9.96	0.302	1.270	0.958	0.051	F value: 1.967
	TC group	55	53.93	11.68	0.305	0.194	0.974	0.288	Sig. (p value): 0.164

This study compared and analyzed the academic performance of students in flipped classroom (FC) and traditional classroom (TC) in the pre- and post-tests:

There was a 1.20 point difference in the average scores of the two groups of students in the pre-test (FC group $M=20.69$, TC group $M=19.49$). The standard deviation shows that the dispersion of the FC group is slightly higher (5.91 vs. 5.43) as shown in the table 6. The skewness values for the FC and TC groups are -0.115 and 0.134, respectively, signifying that both data distributions are fundamentally symmetrical with no significant skewness. The kurtosis values of -0.131 and -0.872 indicate that the distribution shapes are about normal or display minor platykurtosis. The Shapiro-Wilk normality test results indicated that neither the FC group ($W=0.988$, $p=0.860$) nor the TC group ($W=0.968$, $p=0.164$) rejected the hypothesis of normal distribution ($\alpha=0.05$). The homogeneity of variance test (Levene's $F=0.198$, $p=0.657$) indicated no significant variance difference between the two groups, fulfilling the requirement for parametric testing.

The post-test means indicate that the FC group's score (60.02 ± 9.96) is significantly higher than the TC group's (53.93 ± 11.68), with a difference of 6.09 points and only a minor disparity in standard deviations (1.72). Examining the distribution shapes, the absolute skewness values for both groups ($FC=0.302$, $TC=0.305$) suggest good

symmetry. Regarding kurtosis, the FC group's value is 1.270, indicating a mildly peaked distribution, whereas the TC group's kurtosis of 0.194 is closer to a normal distribution. The Shapiro-Wilk test results for the FC and TC groups were $W=0.958$ ($p=0.051$) and $W=0.974$ ($p=0.288$), respectively. The p-value for the TC group was significantly greater than 0.05, indicating that the data followed a normal distribution. For the FC group, the p-value approached the critical threshold (0.051). Although it did not reach the conventional 0.05 significance level, this borderline result may suggest the potential presence of an underlying effect that failed to achieve statistical significance due to limited sample size (Wasserstein & Lazar, 2016). Levene's test ($F=1.967$, $p=0.164$) demonstrated no significant variance differences between the two groups ($p>0.05$), confirming that the homogeneity of variance assumption was met. These results justify the subsequent use of an independent samples t-test (assuming equal variances) to compare post-test mean differences between the groups.

Table 7: Effectiveness of Interventions: Independent and Paired Samples Analysis.

Test Type	Test Phase	Sig. (2-tailed)	MD	SE	t	Cohen's d
Independent T-Test	Pre-test	.270	1.20	1.08	1.11	0.21
	Post-test	.004	6.09	2.07	2.94	0.56
Paired Samples T-Test	TC group	<.001	34.44	1.52	22.62	3.05
	FC group	<.001	39.33	1.34	29.33	3.95

The table 7 presents the results of independent-sample t-tests comparing pre-test and Post-test scores between two groups.

The pre-test analysis revealed no statistically significant difference between the groups ($p = .270$, $MD = 1.20$, $Cohen's d = 0.21$), indicating high baseline homogeneity. In contrast, the Post-test results demonstrated significant intergroup differences with statistical significance ($p = .004$), substantial mean difference ($MD = 6.09$), and moderate effect size ($Cohen's d = 0.51$). These statistical indicators collectively confirm both the statistical significance of the intervention effect and its moderate practical impact.

Paired samples t-tests were used to compare the performance of a single group of participants ($N = 55$) under different conditions (TC and FC) at two time points (pre-test and Post-test). Results indicated significant improvements in both conditions (both $p < .001$). Specifically, the TC group showed a mean difference of 34.44 ($SE = 1.52$) with a t-value of 22.62, suggesting a significant improvement in outcomes post-intervention. The FC group demonstrated a greater enhancement with a mean difference of 39.33 ($SE = 1.34$) and a t-value of 29.33, indicating that the improvements were not only significant but also larger in magnitude compared to the TC group. Both groups of samples showed a large Cohen effect size (TC group $d=3.95$, FC group $d=3.05$), reflecting the significant promotion of intervention. This effect may be due to two factors: first, students had not yet established a specialized organic chemistry knowledge system in the pre-test; second, the post-test content deeply matched the course objectives, and the systematic teaching effectively filled the students' cognitive gaps.

After confirming significant variations in overall scores, the research extended its examination to the impacts on Higher-Order Thinking Skills (HOTS) and Lower-

Order Thinking Skills (LOTS), utilizing the Generalized Estimating Equation (GEE) for robust statistical analysis. The GEE model included three main effects: a group main effect (comparing experimental and control groups), a time main effect (comparing scores from pre-test to post-test), and a group-time interaction effect, which aimed to measure score differences before and after the intervention among different groups. The statistical significance threshold was set at $p < 0.05$, indicating that an intervention effect is considered statistically significant when the p-value falls below this threshold.

The generalized estimating equation (GEE) method was employed to analyze higher-order thinking (HOTS) and lower-order thinking (LOTS) scores and assess model fit. Model fit tests showed QIC values of 33.41 for HOTS and 23.96 for LOTS. The comparison of QIC values in the model selection process helps identify the ideal model. Typically, models exhibiting lower QIC values demonstrate superior data-fitting performance.

Table 8: Statistical Outcomes for HOTS and LOTS Scores Using GEE.

Cognitive Scores	Variable	B	SE	Wald χ^2	p value	95 % Wald C.I.	
						L.B.	U.B.
HOTS Score	Intercep	1.72	0.04	1865.4	<.001	1.64	1.80
	Group(FC) ^a	-1.51	0.06	5.53	0.020	-0.28	-.003
	Time(Post-Test) ^b	1.19	0.06	330.8	<.001	1.06	1.32
	Group(FC)*Time(Post-Tes) ^c	0.53	0.09	36.1	<.001	0.36	0.70
LOTS Score	Intercep	2.79	0.04	4658.8	<.001	2.71	2.87
	Group(FC) ^a	0.09	0.06	2.2	0.130	-0.03	0.20
	Time(Post-Test) ^b	0.81	0.04	358.5	<.001	0.73	0.89
	Group(FC)*Time(Post-Test) ^c	-0.19	0.07	7.8	0.005	-0.32	-0.06
a Reference group: TC group. b Reference group: pre-test c Reference group: [Group=FC*[Time=Pre-Test]; [Group=TC]*[Time=Pre-Test]; [Group=TC]*[Time=Post-Test]							

Table 8 presents the results of a Generalized Estimating Equations (GEE) analysis comparing the effects of the control group (TC Group) and the experimental group (FC Group) on students' Higher-Order Thinking Skills (HOTS) and Lower-Order Thinking Skills (LOTS). For HOTS Scores: A significant main effect of the group was observed ($B=-0.151$, $SE=0.06$, $p=0.02$), indicating that the flipped classroom group scored lower than the traditional classroom group at baseline. A significant main effect of time was found ($B=1.19$, $SE=0.06$, $p<.001$), demonstrating a substantial improvement in scores during the post-test. The group-by-time interaction was also significant ($B=0.53$, $SE=0.09$, $p<.001$), suggesting that the flipped classroom group exhibited significantly greater improvement compared to the traditional classroom group over time; For LOTS Scores: No significant group difference was detected at baseline ($B=0.09$, $SE=0.06$, $p=.134$). A significant time effect emerged ($B=0.81$, $SE=0.04$, $p<.001$), reflecting notable score improvements in the post-test across both groups. Significant group-by-time interaction ($B=-0.19$, $SE=0.07$, $p=.005$) revealed that the flipped classroom group showed comparatively smaller improvement gains than the traditional classroom group. This analysis highlights that flipped classrooms outperformed traditional classrooms in fostering HOTS development.

5. Discussion

The current study aimed to evaluate the effectiveness of the flipped classroom (FC) model in comparison to traditional classroom (TC) instruction by analyzing pre- and post-test academic performance and changes in cognitive skill levels. According to the data, students improved in both groups, but those in the FC group had the most significant progress. Post-test results for the FC group ($M = 60.02$) were significantly higher than the TC group's ($M = 53.93$), with a moderate effect size (Cohen's $d = 0.56$). The results add to the increasing evidence that flipped learning is effective. Fan et al. (2020) discovered that nursing students who used FC had better memory and performed more successfully. In a similar way, Chen et al. (2021) observed an improvement in academic outcomes in healthcare education due to flipped learning. Additionally, Demir and Oksuz (2021) found that flipped teaching methods, whether in the classroom or at home, helped students succeed in planning and made them more productive in class.

Furthermore, this research applied Generalized Estimating Equations (GEE) to study the progress of Higher-Order Thinking Skills (HOTS) along with Lower-Order Thinking Skills (LOTS). There was a strong statistical improvement ($B = 0.53$, $p < .001$) for flipped classrooms, suggesting that these helped students build analytic and evaluative abilities. Scholars also uncovered that group flipped learning helped pre-service teachers improve their higher-order thinking skills. Similarly, Li and Li (2022) reported that student engagement and the abilities to work together and solve problems are stimulated by FC, all-important traits in HOTS. Moreover, according to a study by Shih and Huang (2020), students in flipped classrooms develop greater awareness of their thinking and can manage their own learning tasks better. According to the study, pre-class work and in-class practice in FC allow students to develop higher order thinking skills.

On the other hand, the TC group performed slightly better on LOTS than the GIDC group (interaction $B = -0.19$, $p = .005$), meaning that conventional instruction appears to work well for factual tasks. This is a similar conclusion to Buhl-Wiggers, la Cour and Kjærgaard (2023), who noticed that the FC method improves some cognitive areas more than others improve and is particularly helpful when connected to deeper-thinking activities. According to Al-Hroub (2021), strategies used in instruction should take into account learners' mental abilities. Because the model focuses on being active in lessons instead of repeating facts, there is less LOT for the FC group. Prior literature also determine in a meta-analysis that flipped learning supports stronger learning in higher-level skills, while performance in simpler skills is about the same compared to traditionally taught classes. Generally, this research indicates that both approaches bring value, though the flipped classroom is better at promoting more challenging thinking and success in school.

6. Conclusions

This research was performed to investigate how flipped classroom pedagogy aided students in Organic Chemistry I in improving performance as well as enhancing cognitive abilities. The main objective was to check if flipped instruction benefited students more than traditional teaching, especially in gaining academic points and improving their thinking abilities, known as HOTS and LOTS. This study also aimed to support existing literature that encourages new and student-centered methods in

teaching, along with the new trends in education and STEM reform.

In order to reach these goals, the study used a quasi-experimental, pre-test–post-test non-equivalent group model over 16 weeks of instruction. The 110 sophomore students were allocated to two complete class sections: one went through the flipped classroom style and the other took traditional lectures. Both groups took the same achievement tests at both the start and finish of the intervention. To measure HOTS and LOTS, the tests were thoroughly built and validated and during analysis, descriptive statistics, t-tests and GEE were performed to understand differences and effects at various time points.

According to the findings, students in the flipped classroom did much better overall and beat the traditional classroom group on post-test scores. The model also strongly improved how students used higher-order thinking skills, supporting its adherence to cognitive load theory and social constructivism since it allowed them to work smarter during lessons. In contrast, following structure by learning from others seems to make it slightly easier to strengthen lower-order thinking skills than independent, more open learning. As a result, using flipped classrooms for thinking and creativity and traditional teaching to master essential knowledge, can be beneficial. These findings help improve chemistry education and the teaching of STEM subjects by providing a tested solution to keep students mentally involved, achieve high grades and learn without bias in Organic Chemistry I.

5.1. Study Limitations

However, this research study has certain limitations. Assigning participants in this design does not happen without randomization, which may make it hard to make findings useful for larger populations. A second limitation is that the study was carried out at just one institution and looked only at an Organic Chemistry I course which could limit its broader uses. Following this, the intervention only lasted for one semester, making it difficult to check if participants retained the skills for a long time. In the future, researchers could carry out designs over time, involve various institutions and conduct random controlled trials to make the results stronger and more useful.

5.2. Future Directions

Future academic studies should address the ongoing effects of flipped teaching on remembering concepts, solving issues and persevering in courses similar to Organic Chemistry and related STEM areas. The study should be taken to additional institutions and examine students from different backgrounds to make its findings more generally useful. Adding personal comments from students and instructors can improve our understanding of how learning takes place. Further investigation should also look at the best ways to blend flipped and regular instruction to foster both advanced and basic thinking skills in students learning under any set of conditions.

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