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Enhancing Conceptual Understanding of Chemical Industry through Flipped Instruction: A Quasi Experimental Study

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ABSTRACT: The paper examined how the flipped teaching method can be used to develop the conceptual knowledge among secondary school students studying the chemical industry. The objective of the research was to understand whether a flipped classroom method could be an effective way of enhancing the conceptual learning of students as opposed to conventional lecture-based teaching. Quasi-experimental research design was adopted in which a pre-test-post-test control group design was used. The research was carried out among high school learners taking chemistry. Two intact groups were then taken with one being the experimental group taught by use of flipped instruction and the other group being treated as the control group taught in a traditional way. Experimental group students watched instructional videos before class; in-class time focused on collaboration, problem-solving, and concept clarification. A tested conceptual understanding test was applied in the form of pre-test and post-test in order to gather the data. A statistical test was made on the differences between the groups in terms of appropriate inferential statistics. The findings indicated a statistically significant difference in the conceptual knowing of students exposed to flipped teaching and those taught using the traditional way of teaching. Flipped classroom increased student engagement, promoted active learning, and enhanced understanding of complex chemical industry concepts effectively. The results indicate that the technique of flipped instruction could be also effective as a pedagogical method to teach the complicated topics in chemistry. Digital tools and interactive lessons boost students' conceptual understanding and make science learning more meaningful.

KEYWORDS: Flipped Classroom, Conceptual Understanding, Chemical Industry, Chemistry Education, Quasi-Experimental Design

Introduction

Enhancing conceptual knowledge among students is one of the key issues in modern science teaching especially in the field of chemistry where abstract ideas, representations, and industrial uses tend to confuse learners. The international large-scale tests like the Programme for International Student Assessment have been noted to show consistent lack of scientific literacy of students and higher order understanding in many countries (Pisa, 2019). In chemistry, the subject matter of study that is associated with industrial processes requires not just the simple

recollection of facts but also incorporation of chemical concepts into real-life applications, the environment, and technological mechanisms. With the growing focus on meaningful learning and conceptual change in the educational systems, novel instructional methods such as flipped have become popular to facilitate active learning and more profound thinking (Bishop & Verleger, 2013; Lo & Hew, 2017). The increasing trend of the replacement of a teacher-centered transmission with student-centered learning conditions places flipped learning as a prospective intervention in the improvement of conceptual learning in difficult chemistry courses like the chemical industry.

In spite of the changes in the curriculum and introduction of applied chemistry subjects to the secondary level, students tend to show disjointed and shallow knowledge of the concepts of industrial chemistry. Scientific education research states that a traditional lecture-based learning model often focuses on procedural instead of conceptual integration of the knowledge, which results in misperceptions and poor transfer of the knowledge (Taber, 2015; Flaherty, 2020; Güler et al., 2023). Applying to the content of chemical industry, the student might be taught chemical reactions like the Haber process or contact process with no understanding of the underlying chemical equilibria, economics, and environmental consequences (Van Heuvelen et al., 2020). Traditional classroom designs do not give time to question, discuss, and solve problems, which means that there is no chance to clarify the concept conceptually (Hansen, 2023). Though flipped instruction redesigns the process of acquiring knowledge, with direct delivery of instruction taking place outside the classroom, and the actual class time being used to undertake active learning, the relative impact of the instruction on the conceptual knowledge of a chemical industry among secondary school students has not been fully investigated.

Based on empirical studies, it is indicated that flipped instruction can have a positive effect on academic performance and learning of concepts in science subjects. A meta-analysis study by Lo and Hew (2017) indicated moderate positive outcomes of flipped classrooms on the learning outcomes of students in K to 12 and higher education settings. In the same vein, Chen et al. (2018) established that the use of flipped environments promoted engagement and higher order thinking among the students enrolled in science-related courses. This has been proven to be more so in chemistry education where it has been shown that there is improvement in problem solving, conceptual and classroom interaction when it is used (Ryan & Reid, 2016). Globally, flipped learning has been integrated in North America, Europe, and East Asia in order to instil active learning cultures (Sarnok & Piriyasurawong, 2019). In South Asia regionally, there are some emerging studies that show that there is an increase in experimentation with blended and flipped pedagogies, but implementation has been inconsistent because of infrastructural and pedagogical limitations. In Pakistan, studies of flipped instruction at the secondary level are in early development, and little attention is paid to particular units of chemistry that demand conceptual richness.

According to Muktiadji et al. (2025), students who received flipped classroom-based teaching had significantly greater conceptual knowledge than those who were taught using traditional lecture-based learning, despite the differences in learning styles. The results indicate that interaction in class and pre-class multimedia materials provide an environment that promotes conceptual learning. On the same note, Fatacharmita et al. (2022) discovered that peer instruction combined with flipped learning greatly improved the conceptual knowledge of students in the topics of chemistry, especially in the ones, which involve conceptual comprehension like colloidal chemistry. Flipped environments showed better performance of students in analysing chemical phenomena and those who can relate theoretical ideas and practical practices.

Specifically, in chemistry education, flipped learning has been found to enhance the engagement of students, critical thinking, and conceptual understanding of students. A more recent classroom-based study in secondary chemistry indicated that flipped instruction was able to facilitate students in reasoned thinking and better comprehension of chemical concepts due to the ability to have highly interactive learning activities during classroom

time. Those students, who attended flipped chemistry classes, stated that they were more motivated and were readier because they could watch learning videos before the lessons and spend time in the classroom to catch wrong ideas after using collaborative discussions and joint problem solving (Hamid & Rahmad, 2025). The results underscore the pedagogical significance of flipped learning in overcoming the conceptual challenges stipulated by the learning process as is evident in teaching chemistry.

The evidence of flipped instruction was further supported by the number of studies that took place after the world transition to digital learning in the context of the COVID 19 pandemic. With the growing adoption of online and blended learning methods in educational institutions, flipped classrooms became a viable approach to ensuring that learning in the technology mediated setting remained dynamic. Studies on the use of flipped science teaching methods had shown that when interactive classroom activities were supported by instructional videos, the students exhibited a better conceptual retention together with academic performance. As an illustration, a research study done in the senior high school chemistry subject showed significant progress in the students on the electron configuration after a flipped learning intervention, which means that the teaching method promotes clarity of concepts in abstract chemical subjects (Addo, 2024).

In addition to single classroom studies, systematic reviews and meta-analyses that have been developed during the last 10 years have also proved the efficiency of flipped learning in enhancing the academic performance. Tan et al. (2017) found out that the overall effects of flipped classrooms are moderate to high in terms of academic performance and conceptual learning of students in various subjects. The success of the strategy is also partly connected with the fact that it can lead to the better engagement of the students, the possibilities of the collaborative learning, and the flexibility that digital learning resources can offer. When they can access the instructional material repeatedly in the classroom, the students are in a better position to learn intricate concepts at their own speed, which eventually enhances the conceptual knowledge.

In South Asian education, investigation on flipped learning has been slowly increasing over the last few years. Researchers in Malaysia, Indonesia and India have also investigated how flipped pedagogies are integrated in science and mathematics education to overcome issues associated with passive learning and lack of classroom interaction (Mazlan et al., 2025). The outcomes of these studies are mostly positive such as, improved student engagement, conceptual reasoning and increased involvement in collaborative learning activities. These results suggest that the concept of flipped learning can be successfully implemented to emerging educational settings where educators aim to stimulate active learning even with limited resources.

Flipped learning strategies are currently taking shape in Pakistan, though recent empirical studies demonstrate some positive outcomes. Studies carried among Pakistani secondary schools have demonstrated that the pedagogy of flipped classrooms has a significant positive effect on the student engagement and student's achievement in sciences subjects by facilitating interactive and student-centered learning settings. The strategy promotes engagement of the learners in discussions and group work which helps them to gain deeper conceptual understanding of a problem (Sarfaraz et al., 2024).

Equally, a quasi-experimental study that was carried out in Khyber Pakhtunkhwa evaluated the effects of the flipped classroom model among science learners in secondary schools. The findings showed that there was a statistically significant difference between the students who received the instruction using the flipped instruction and those who received the traditional means of instruction, where the flipped classroom students showed higher results on the achievement scores and learning activities. The researchers advised that flipped pedagogical practices are recommended to be incorporated in the instruction of science subjects in the secondary level educational institutions to enhance the conceptual learning of students and their academic achievements (Bukhari & Ali, 2024).

Although the literature on flipped instruction in science teaching is slowly expanding, there exist quite few significant gaps in the current literature that can be filled by conducting additional research. A significant percentage of recent research on flipped learning mostly focuses on its effect on overall academic performance, student learning, and their motivation instead of investigating the more meaningful learning outcomes of the learning process such as the conceptual knowledge, which is a primary aim of an educational activity in chemistry (Hew & Lo, 2018). The conceptual learning is especially significant in chemistry since students are required to combine both theoretical knowledge and practical and industrial practice but there are comparatively few studies that investigate the outcomes of flipped learning on cognitive understanding of a certain chemistry subject in students.

In addition, a substantial part of the already available literature has explored flipped classes on a broad disciplinary basis (e.g. general science or general chemistry courses) with few looking at the more specialized units of instruction such as the chemical industry which need to make complex reasoning about chemical processes, industrial processes and environmental impacts. The other major limitation of the existing literature is the focus of the literature which is geographical where the most developed educational cultures such as North America, Europe and East Asia are geographically located where technological infrastructure and digital learning settings are relatively modernized. Although this research are quite informative, their results may not be quite applicable to developing educational systems where access to digital resources, teacher readiness, and classroom conditions are quite different. On a regional level, there has been a slow but steady growth in research of flipped learning in South Asia, but most studies focus on descriptive designs or small sampled information, and most studies do not focus on a particular science subject that necessitates conceptual richness. In Pakistan, research on flipped teaching is not extensive and was mostly on overall academic performance or perception of students instead of conceptual knowledge in learning chemistry. Moreover, there are very few quasi experimental studies that have made comparisons between flipped and traditional methods of instruction at the secondary school level and specific chemistry unit like the chemical industry. As a result, there lacks the adequate context specific data on whether flipped instruction is a remarkable boost to the conceptual level among students as opposed to the traditional classroom activities. This gap has to be addressed to come up with efficient teaching techniques that can enhance conceptual learning in high school chemistry teaching and to foster evidenced based pedagogical developments in the national school system.

This quasi experimental research aims to observe the impact of flipped instruction on conceptual knowledge of students of the chemical industry on the secondary school level, compared to the traditional non-flipped classroom teaching. The study provides the empirical data to the emerging research on innovative pedagogies in chemistry education by directly filling the research gap identified. The results are likely to guide classroom practitioners on how they can enhance conceptual clarity, curriculum planners on how to modernize on science training, and policymakers on the need to seek ways of improving quality of education as per world standards. Also, the study offers context specific information that can inform subsequent studies on the topic of technology supported instructional models in secondary science education.

Research Objectives
The following research questions were developed in current study.
1. To examine the effect of flipped instruction on students' conceptual understanding of the chemical industry at secondary school level.
2. To compare the conceptual understanding of the chemical industry between students taught through flipped instruction and those taught through non-flipped instruction.

Research Hypotheses

Based on research questions, following research null hypotheses were developed.

$H_0$1: There is no significant difference in conceptual understanding of chemical industry between students taught through flipped instructions and those taught through non-flipped instructions.

$H_0$2: There is no statistical difference between pre-test and post-test scores of students taught through flipped instructions regarding their conceptual understanding of chemical industry.

$H_0$3: There is no statistical difference between pre-test and post-test scores of students taught through non-flipped instructions regarding their conceptual understanding of chemical industry.

Conceptual Framework of Study

This theoretical approach is based on the constructivist learning theory (Chuang, 2021), which points to the significance of meaningful learning in case students are actively involved with the content, build knowledge in the process of interaction and apply the knowledge to real-world situations (Hsbollah & Hassan, 2022; Akhtar et al., 2019). The instructional approach is the independent variable in this model, which is the practice of flipped instruction, and the conceptual knowledge of the chemical industry in students is the dependent variable. Flipped instruction reorganizes the conventional learning system where instructional resources (videos, digital presentations or reading materials) are delivered to students prior to the classroom session so that they can have the initial exposure to the learning content by themselves. Interactive learning activities are then used in the classroom time, such as a discussion, problem solving, collaborative work and clarification of misconceptions by the teacher. It is hoped that this learner centered environment will enhance greater involvement of cognition and more understanding of intricate chemical concepts concerning industrial processes. By comparison, non-flipped classroom learning fosters a teaching-based approach to instruction in which most of the teaching occurs in the form of a teacher centered lecture whilst during classroom lessons, there is little to no active interaction and exploration of concepts. The framework thus presumes that learners being subjected to flipped teaching will have a greater level of conceptual knowledge of the chemical industry than their counterparts who are being taught using the traditional instructional approaches. Therefore, the research is focused on the concept of how instructional strategy affects learning outcomes of students concerning conceptual learning in secondary school chemistry studies.

Research Methodology

Research methodology is the systematic process and techniques applied in gathering, analyzing, and interpreting data to respond to research questions of a study. It gives a systematic guide by which the researcher can choose the suitable research design, sampling methods, data collection tools, and statistical methods of analysis to guarantee the validity and reliability of the results (Creswell & Creswell, 2017).

Research Paradigm and Design

The current research was performed within the context of positivist research paradigm that presupposes the possibility of the objective measurement and analysis of reality in terms of empirical data and statistical methods. Positivist studies focus on testing hypotheses, observable facts, and the cause and effect between variables (Creswell & Creswell, 2017; Cohen et al., 2018). As the aim of the current research was to investigate whether the conceptual learning of the chemical industry in students after receiving flipped instruction is any different, a quantitative research design was suitable.

A quasi-experimental pre-test post-test control group design was used in the study, as one of the most common designs in educational research since the study did not allow assigning participants to random groups in a natural

classroom environment. During this design, two intact groups were picked: one experimental group which would be flipped instructed and a control group which will be receiving classroom instruction. The difference in conceptual understanding was measured by giving the pre-test to the two groups at the start of the experiment and the post-test at the end to understand the difference (Fraenkel et al., 2012).

Population of Study

The population of the study was all Grade 10 female students in chemistry (N = 5415) that were taking chemistry as a subject of their science-based curriculum in district Haripur, in government secondary schools. These students are taught the subject chemical industry in the chemistry syllabus and thus form a fitting sample of students to study the conceptual knowledge of the industrial chemistry topics.

Sample and Sampling Technique

A sample of 70 students was selected from the target population. The participants were divided into two groups:

Table 1

Sample size of the study

Groups	Number of Students
Flipped Group	35
Non-Flipped Group	35
Total	70

The researcher employed a purposive sampling method because intact classes were used to ensure the natural classroom setting. One of the classes was given out as the flipped group where flipped instruction was given and the other group was given as the control group where non-flipped instruction was given.

Data Collection Tool

The main tool that was applied in data collection was a multiple-choice conceptual test constructed by the researcher. The exam had 50 multiple choice questions based on the key concepts that were taught in the Grade 10 chemistry syllabus. Every question contained four choices each with one correct choice.

Table 2

Characteristics of Research tool

Test Characteristics	Description
Type of Test	Multiple Choice Questions
Total Items	50
Marks per item	1
Total Marks	50
Purpose	Measure Conceptual Understanding

This test was administered as both pre-test and post-test

Validity of Research Tool

Expert review served as a means of content validity with regard to the instrument. Three subject experts in chemistry education and two experts in educational assessment were used to evaluate the test. They reviewed the instrument on the basis of content relevance, language comprehension, meeting curriculum goals, and coverage on the chemical

industry unit. According to their feedback, a number of items were changed and bettered to make sure that the test reflected good conceptual learning of the students.

Reliability of Research Tool

Split Half Reliability was used to determine the reliability of the test because it involves splitting the test into two equal parts and comparing the scores of both parts (Fraenkel et al., 2012).

Table 3

Split Half Reliability Test Description

Students	Odd items scores	Even items scores
1	18	17
2	16	15
3	19	18
4	17	16
5	20	19
….	….	….

After calculating the correlation between the two halves, the Spearman Brown Prophecy formula was applied.

Table 4

Reliability Scores of Research Tool

Reliability Measure	Values
Correlation between halves (r)	0.78
Spearman Brown corrected reliability	0.87

A reliability of 0.87 indicated that the instrument possessed high internal consistency.

Experimental Procedure

The experiment procedure was followed in a course of four weeks when teaching the chemical industry unit in Grade 10 chemistry. The experimental and the control group were pre-tested prior to the commencement of the experiment to establish their baseline of conceptual knowledge.

The flipped instruction model was used in the experimental group. Each classroom session was preceded by provision of pre-recorded instructional videos, PowerPoint presentations, and digital learning material pertaining to the chemical industry unit. They were advised to read these materials at home before they come to their classes. In the course of the classroom classes, the teacher managed to conduct interactive educational activities which included group discussions, problem solving exercises, clarification of the concepts, and collaborative problems associated with the industrial chemical processes. This enabled the students to learn by being active in the concepts and clearing of the misconceptions with the help of the teacher.

The non-flipped group, on the contrary, was taught using the conventional lecture-based technique. The lesson was provided through classroom lectures in which the teacher explained the concepts of the chemical industry as students listened and took notes. Homework and questions based on the practice were used after the lectures.

As soon as the instructional intervention ended, the post-test was carried out on both groups by a conceptual test that measured the difference in the understanding of students.

Threats Controlled during Experiment

The following table presented threats of the study.

Table 5

Threats Controlled in Experimentation

Threat	Control Strategy
Selection bias	Intact classes with similar academic backgrounds were selected
Testing effect	Same testing conditions maintained for both groups
Maturation	Experiment conducted within short duration
Instrumentation	Same instructions were used for pre and post-tests
Teacher effect	Volunteer teachers taught both groups

Data Collection Procedure

There were two stages of data collection. During stage 1, the pre-test was conducted on both groups, to determine their conceptual background knowledge level. The fourth week was the second phase and involved the implementation of the instructional intervention. The post-test of the two groups was conducted after the end of the teaching period with similar testing conditions. The results of the pre-test and post-test were noted to be used in statistical analysis.

Data Analysis

The SPSS statistical software was used to analyse the obtained data. Measures of central tendency were used to describe the performance of students by computing mean and SD. There was an independent samples t-test that was done to show whether a significant difference was observed between the experimental and the control groups. Also, the paired samples t -test was done to compare the pre-test and post-test scores of the experimental group.

Assumptions for T-Test Analysis

Before applying the independent sample t-test, the following assumptions were examined.

Normality of Data

The distribution of scores should appropriately normal (Field, 2024). In current study, the data shown normal distribution before administering parametric t-test analysis.

Table 6

Normality table

Tests	Groups	Shapiro Wilk Sig.
Pre-test	Flipped Group	0.086
Pre-test	Non-Flipped Group	0.091
Post-test	Flipped Group	0.072
Post-test	Non-Flipped Group	0.095

Since p >.05, the data was normally distributed

Homogeneity of Variance

The variance for both groups should be equal (Field, 2024). In this study, the following table depicts equal variance of both groups.

Table 7

Levene's Test

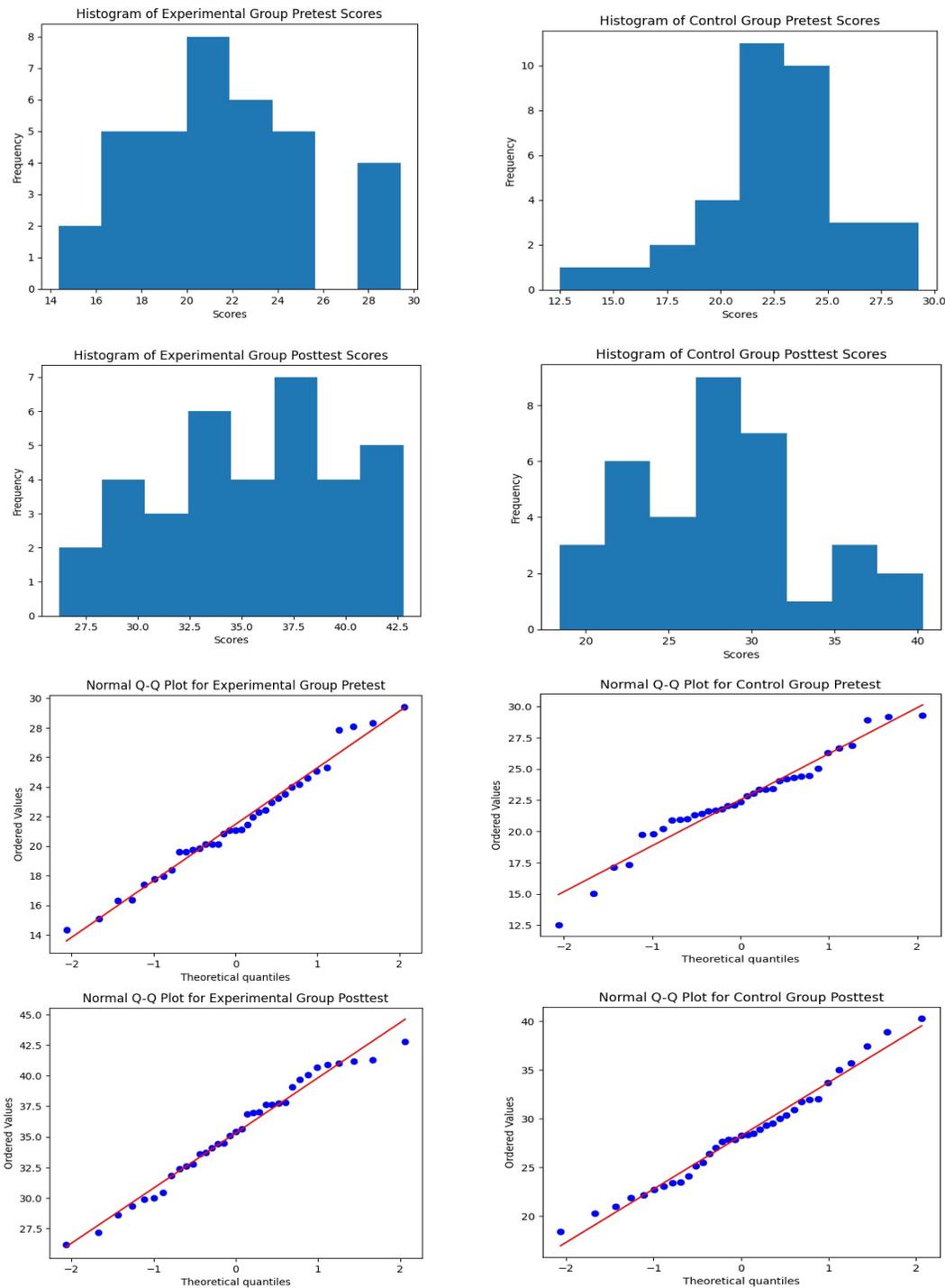| Test	F-value	Sig.
Post-test	1.21	0.27

Note: *Since p > .05, the assumption of homogeneity of variance was satisfied.*

Histogram and Normal Q-Q Plot

The following figures represents that data is normally distributed given robust evidence as shown.

Figure 1

Histogram and Q-Q Plot showing data normal distribution

The assumption of normality was checked with the help of histogram distributions and normal Q-Q plots. The histograms of post and pre-test scores of both experimental and control group were in the shape of a bell, and this indicates that the data were normally distributed. Moreover, the normal Q-Q plots indicated that the majority of the values were close to the diagonal reference line, which showed that the distribution of the scores did not vary significantly in being non-normative. Thus, the independent samples t-test presupposed that the normality could be assumed (Field, 2024).

Independence of Observation

The score of each participant should not be dependent on anyone (Pandis, 2015). This assumption was assured since the students took the test at an individual level without cooperation.

Analysis of Data

After ensuring assumptions for t-test analysis, the following tables represents findings of research.

Table 8

Descriptive Statistics

Group	N	Mean	SD
Flipped Group Pre-Test	35	21.47	3.73
Flipped Group Post-Test	35	35.32	4.40
Non-Flipped Group Pre-Test	35	22.53	3.64
Non-Flipped Group Post-Test	35	28.25	5.85

Hypothesis Testing

$H_0 1$: There is no significant difference in conceptual understanding of chemical industry between students taught through flipped instructions and those taught through non-flipped instructions.

Table 9

Comparison between Flipped and Non-flipped Groups after Intervention

Group	N	Mean	SD	t-value	p	Cohen's d
Flipped	35	35.32	4.40	9.12	.000	2.18
Non- Flipped	35	24.10	5.85			

Significant at .05 level

The independent samples t-test was used to compare conceptual understanding scores of students that were taught using flipped instruction and those taught using non-flipped instruction. The findings obtained showed that there was a statistically significant difference between the experimental group (*M* = 35.32, *SD* = 4.40) and control group (*M* = 24.10, *SD* = 5.85), *t*(68) = 9.12, *p* < .001. The effect size was extremely large (*d* = 2.18), which showed that the idea of the chemical industry conceptual comprehension was significantly influenced by the use of flipped instruction among students. Hence, it rejected the null hypothesis.

$H_0 2$: There is no statistical difference between pre-test and post-test scores of students taught through flipped instructions regarding their conceptual understanding of chemical industry.

Table 10

Comparison of Flipped Group Scores Before and After Intervention (Paired Sample)

Group	N	Mean	SD	t-value	p	Cohen's d
Pre-test	35	21.47	3.73	-13.06	.000	3.40
Post-test	35	35.32	4.40			

Significant at .05 level

Paired samples t-test was applied to test the effects of flipped instruction on the conceptual knowledge of chemical industry among students. Results showed that the pre and post-test scores were significantly different (M = 21.47, SD = 3.73) and post-test scores (M = = 35.32, SD = 4.40), t(34) = -13.06, p < .001. The magnitude of the effect was very high (d = 3.40), which implied that the conceptual understanding of students was affected by flipped instruction in a significant positive way. Hence, it rejected the null hypothesis.

H_03: There is no statistical difference between pre-test and post-test scores of students taught through non-flipped instructions regarding their conceptual understanding of chemical industry.

Table 11

Comparison of Non-Flipped Group Scores Before and After Intervention (Paired Sample)

Group	N	Mean	SD	t-value	p	Cohen's d
Pre-test	35	22.53	3.64	-1.45	.155	0.27
Post-test	35	24.10	5.85			

Significant at .05 level

A paired samples t-test was conducted to determine whether traditional non-flipped instruction improved students' conceptual understanding of the chemical industry. The analysis revealed non-statistically significant difference between pre-test scores (M = 22.53, SD = 3.64) and post-test scores (M = 24.10, SD = 5.85), t(34) = -1.45, p > .05. The effect size was small (d = 0.27), indicating minimal improvement in students' conceptual understanding. Therefore, the null hypothesis was retained.

Discussion

The results of the current research indicated that the conceptual knowledge of students about the chemical industry was significantly improved though the application of flipped instruction as compared to the traditional non-flipped instruction. The results of the experiment showed that post-test scores were significantly higher in the experimental group compared to the control group, which was statistically significant, thus, proving that flipped learning establishes a more efficient setting to develop concepts in chemistry education. This finding goes in favour of the suggestion, that learner-centered instructional strategies enhance higher cognitive processing and active work in complex scientific matters. Flipped learning does not involve a lecture delivery but rather interactive problem solving and collaborative learning that will enable the learning process to be biased towards high-order thinking and conceptual understanding among secondary school students (Yu et al., 2023).

The restructuring of the learning time may be one of the reasons why students exposed to flipped instruction perform better. Flipped classroom model introduces the basic knowledge prior to the start of the lesson, using digital learning, whereas inquiry, discussion and problem-solving take place during the classroom time. This arrangement allows the students to purposefully build their knowledge, and not just have the teacher feed them with information.

It has been revealed that these learner-centered pedagogies lead to better conceptual knowledge since learners become more involved in the subject matter when they are doing the activities in the classroom (Turan, 2023).

This study also correlates with empirical studies that have shown that flipped classroom has a positive effect on the academic performance and the interest of students in the science education. As a case in point, an experimental study by Yu et al. (2023) of secondary school chemistry showed that as compared to peers receiving the traditional lecture style of teaching, students receiving a flipped teaching style performed better in all aspects of academic achievement and had better problem-solving skills. The researchers also found out that, flipped learning encourages active learning and gives the students an opportunity to utilize theoretical knowledge in practical settings, which, in the end, enhances conceptual learning.

Equally, meta-analytic findings have always revealed that flipped classroom practices end up with moderate to high positive impacts on student achievement in different fields. An integrated review of the empirical research found that flipped learning enhances both engagement and learning performance since students have increased contact with learning resources and cooperation with peers during classroom learning tasks (Abidin et al., 2024). These kinds of environments promote critical thinking and knowledge building, which are necessary in the acquisition of abstract concepts in topics such as chemistry.

The other significant meaning of the current results is connected to the fact that the students who received the flipped instruction developed critical thinking and analytical skills. According to the studies, flipped classes promote students to analyse information and question and discuss with their peers as part of the in-class activities. Indicatively, details such as Hamid and Rahmad (2025) have indicated that the flipped classroom model had a significant positive impact on students with regard to their critical thinking skills in learning chemistry due to its ability to involve them actively and engage them in reflective learning behaviours. These mental activities are crucial towards the enhancement of the conceptual sense of scientific phenomena.

The current findings are also consistent with the constructivist theory of learning, which is based on the principle that learners construct knowledge by interacting with content, peers and teachers. Flipped classrooms can assist this theoretical framework by providing the students with an opportunity to read instructional materials on their own prior to the teaching session and participate in the collaborative learning activities during the classroom sessions. As Sarwar et al. (2024) suggest, social constructivism-based flipped learning environments have a substantial positive impact on the conceptual knowledge of students since, in this case, they develop knowledge out of the discussion, experiments, and problem solving.

On the other hand, the results obtained in this study showed that the control group that had a traditional lecture-based teaching did not show statistically significant improvement in pre-test and post-test scores. This is an indication that traditional methods of teaching do not necessarily encourage conceptual learning about chemistry. Conventional learning environments can be very dependent on what the teacher tells and what students memorize and do not have much time to engage in and ask questions. Students can therefore become superficial learners instead of having a profound conceptual understanding.

The non-significant effect of the improvement in the control group is also symptomatic of more general issues regarding the role of teacher-centered pedagogies in science education. Students in most of the conventional classrooms are mere consumers of information, a fact that limits their chances of asking questions, discussing or demonstrating knowledge. The studies have shown that this kind of instructional strategy often leads to the absence of meaningful learning as students are not actively engaged in the learning process (Siyam et al., 2025).

Moreover, enhanced student engagement and motivation can also be suggested as the source of the effectiveness of flipped instruction that was observed during the current study. Digital materials, interaction, and group work are common in the flipped learning environments as they would arouse the curiosity and engagement of learners. Research has proven that learning environments that use technology will increase engagement and behavioural participation among students and eventually lead to higher learning outcomes (Consoli et al., 2024).

The other significant implication of the findings is that flipped instruction gives more flexibility and control of learning rates to students. Learners will be able to study instructional materials repeatedly prior to the lesson thus enabling them to grasp highly complicated issues like industrial chemical reactions. This individual learning process minimizes cognitive load and allows students to devote attention to correcting mistakes in the classroom during discussions with the teacher. Consequently, flipped learning facilitates better learning and comprehension of scientific ideas (Sholahuddin et al., 2023).

The research results also can be applied to the enhancement of chemistry teaching in the secondary level in the situations when students have problems with the abstract scientific concepts. The inclusion of flipped instructional strategies can be used to assist teachers in designing more interactive and learner-centered classrooms where inquiry, experimentation, and collaborative problem solving occur. When the emphasis of the teaching process is changed to active learning instead of a lecture-based teaching, it becomes possible to better support the development of the students in terms of the concepts and the development of the critical thinking skills (Styers et al., 2018).

Overall, the findings of the research serve as an empirical data that indicates that flipped instruction outperforms conventional approaches to teaching chemistry before the secondary school level in terms of enhancing the conceptual learning of the chemical industry in students. The dramatic change in the test group indicates the effectiveness of the flipped learning approach to increase the interest, stimulate active learning and deepen the understanding of the chemistry material in the students. The results can be added to the existing body of literature that recommends the incorporation of new pedagogical tools in science lessons to enhance learning.

Conclusions

The article investigated how flipped teaching can be used to improve the conceptual learning of the chemical industry by students in secondary school. The results indicated that the students who were exposed to the flipped classroom model had a much better conceptual knowledge than those whose teaching methods were using the non-flipped instructions. The findings show that offering instructional content prior to a class and using classroom time on interactive learning activities are effective in allowing students to understand more about complex concepts of industrial chemistry.

The results also imply that flipped teaching facilitates learning through engagement and engagement of students. The experimental group students engaged more in group discussions, problem solving activities and application-based learning activities in the classroom sessions. These interactions helped to gain a better conceptual insight into industrial chemical processes.

Moreover, the findings outline the pedagogical opportunities of incorporating digital learning materials in science teaching. The availability of pre-class resources, including instructional videos and multimedia explanations, helped the students' study at their pace and review challenging concepts, which enhanced their understanding of the idea. In general, the paper concludes that flipped instruction is a helpful instructional method to enhance the conceptual learning of chemistry, especially regarding the challenging subject, such as the chemical industry.

Recommendations

According to research findings the following recommendations were put forth and they included.

1. In teaching complex chemistry topics, the teachers may embrace flipped methods of teaching to improve conceptual knowledge of the students.
2. Teachers may be given professional development opportunities in learning how to design and implement flipped classroom models in educational institutions.
3. The schools may support the incorporation of digital learning materials, including video lectures and online learning systems, to enhance pre-class learning.
4. During classroom, chemistry teachers may employ collaborative learning exercises, discussions and problem-solving activities that will encourage conceptual learning.
5. To enhance the use of technology-based teaching strategies in science curricula in secondary schools, curriculum developers may include them in the science curricula.

Implications for Practice

This study has various implications in the classroom practice and science education. To begin with, flipped instruction may be a useful teaching method in learning difficult scientific topics because it can change the teacher-centered lectures to the student-centered learning tasks. Second, the incorporation of online teaching aids students to study at their pace, which can contribute to assisting in the need to overcome differences in the abilities of students to learn. Third, the flipped classroom model allows instructors to make better use of classroom time, including better use of classroom time on higher-order learning tasks like analysis, discussion and application of ideas. Such practices could help in enhancing the conceptual learning and learning of students in chemistry.

Limitations of Research

In spite of the contributions, the study has a number of limitations. First, the study was undertaken in a small educational setting with a rather small sample, limiting the application of the research. Second, the research was directed towards a particular subject in the chemistry field, that is, the chemical industry and the findings might vary when used in other areas or subjects. Third, the quasi-experimental design failed to control all the extraneous variables that have the potential of affecting the learning outcome among the students. Also, the research studied conceptual knowledge in relatively brief teaching time; thus, the long-term outcomes of learning were not studied.

Future Directions

This study can be extended in a number of ways in the future research. The researchers can implement comparable studies on bigger and more varied samples in various schools and education settings to increase the generalizability of the results. Longitudinal research may as well be conducted to investigate the long-term implications of flipped instruction on the conceptual development and academic performance of the students.

Future studies can focus on exploring how effective flipped teaching can be in various chemistry courses and in other sciences to find out whether it is more applicable. Also, it might be possible in the future to perform the research about perceptions, attitudes, and learning experiences of students in flipped classrooms through mixed-method or qualitative research. Lastly, new technologies in education, including interactive simulation, virtual laboratory, and learning systems with the help of artificial intelligence may be introduced into the flipped instructional design to advance conceptual knowledge in science education.

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