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Flipped Learning in Secondary Chemistry: Academic Achievement and E-Learning Satisfaction

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Abstract: This study seeks to examine changes in students' academic achievement after the implementation of flipped learning in secondary-level chemistry and to explore the relationship between academic achievement and e-learning satisfaction, and to investigate students' perceptions of the model. A mixed-methods research design was employed. Quantitative data were collected from 62 twelfth-grade students using a pre-test–post-test academic achievement test and an E-Learning Satisfaction Scale, while qualitative data were obtained through semi-structured interviews. Quantitative data were analyzed using a paired-samples t-test and Pearson correlation analysis, and qualitative data were analyzed through content analysis. The results indicated a statistically significant increase in students' academic achievement from pre-test ($M = 37.66$, $SD = 24.46$) to post-test ($M = 62.66$, $SD = 18.08$), $t(61) = 7.25$, $p < .001$, Cohen's $d = 0.92$. However, no significant relationship was found between students' e-learning satisfaction and their post-test academic achievement scores ($r(60) = .125$, $p = .334$). Qualitative findings revealed that students generally held positive views toward flipped learning, highlighting increased motivation, improved conceptual understanding, and more effective use of class time while also reporting challenges related to self-regulation, technological access, and the length of instructional videos. Taken together, the findings suggest that flipped learning can effectively enhance academic achievement in secondary-level chemistry education, although its effectiveness is influenced by instructional design, learner characteristics, and contextual factors. However, due to the absence of a control group, causal interpretations should be made cautiously. The study provides practical implications for the implementation of flipped learning in science education and offers directions for future research.

Keywords: flipped learning, chemistry education, academic achievement, e-learning satisfaction, mixed-methods research, secondary education, student perceptions, student-centered learning, learning engagement, digital learning

Highlights

What is already known about this topic:

- Flipped learning promotes active learning and student engagement across educational contexts.
- Evidence on its effects on academic achievement and learner satisfaction remains mixed.

What this paper contributes:

- This study offers mixed-methods evidence on flipped learning in secondary chemistry education.
- Results show increased academic achievement but no direct link with e-learning satisfaction.

Implications for theory, practice and/or policy:

- Findings emphasize the role of instructional design and self-regulation in flipped learning.
- Practical insights are provided for implementing flipped learning in science education.



Introduction

Advances in digital technologies have reshaped teaching and learning processes, particularly within distance and blended learning environments. In parallel with these developments, contemporary learner-centered approaches have increasingly emphasized flexibility, interaction, and active engagement, positioning learners as active agents in the learning process rather than passive recipients of information (Kerimbayev et al., 2023). Within this evolving landscape, technology is no longer perceived merely as a medium for content delivery; instead, it is conceptualized as a pedagogical component that facilitates meaningful and engaging learning experiences (Johnson et al., 2016). Accordingly, distance education research consistently suggests that the effectiveness of technology-supported learning environments depends less on the availability of digital tools and more on the intentional design of instructional processes that foster learner interaction, engagement, and satisfaction (Bozkurt & Sharma, 2020). Within this transformation, flipped learning has emerged as an instructional approach that reorganizes traditional classroom structures by transferring direct instruction to out-of-class digital environments and dedicating in-class time to interactive and application-based activities (Bishop & Verleger, 2013; Lo & Hew, 2017). This structure is intended to promote active engagement and foster richer student–student and student–teacher interactions.

From a distance education perspective, learners' satisfaction with e-learning environments is considered a critical indicator of instructional effectiveness, as it is closely associated with learner engagement, persistence, and learning outcomes (Martin & Bolliger, 2022). E-learning satisfaction is shaped by instructional design quality, interaction opportunities, and learner characteristics such as self-regulation and perceived support (Al-Samarraie et al., 2018; Landrum, 2020). However, the relationship between satisfaction and academic achievement remains inconclusive (Artino, 2009; Alqurashi, 2019). Accordingly, flipped learning may affect both academic achievement and students' satisfaction with digital learning environments.

Chemistry education offers a suitable context for evaluating the effectiveness of such instructional approaches. Chemistry instruction requires learners to develop higher-order cognitive skills, including conceptual understanding, analysis, and problem-solving, which necessitates the use of active and learner-centered instructional strategies (Johnstone, 2006; Taber, 2013). In this regard, empirical studies indicate that flipped learning may enhance achievement, engagement, and problem-solving skills in chemistry courses (Küpelikılınç & Kan, 2024; Yu et al., 2023), similar to its effects in other areas (Moghadam & Razavi, 2022; Nja et al., 2022). However, most existing research has been conducted in higher education settings, and empirical evidence at the secondary level remains comparatively limited (Sergis et al., 2018). Furthermore, few studies have simultaneously examined academic achievement and e-learning satisfaction within flipped secondary chemistry contexts (Öztürk Demir & Eren, 2022).

Therefore, this study aims to examine changes in academic achievement following a flipped learning implementation in secondary-level chemistry and to investigate the relationship between academic achievement and e-learning satisfaction. To provide a more comprehensive understanding of students' experiences, qualitative data were also collected. By integrating cognitive and affective dimensions, the study offers a multidimensional evaluation of flipped learning in secondary education and addresses the identified gap in the literature. In line with these aims, the study seeks to address the following research questions:

- Is there a statistically significant difference between students' pre-test and post-test academic achievement scores?
- Is there a statistically significant relationship between students' e-learning satisfaction and academic achievement (post-test) scores?
- What are students' perceptions of the flipped learning model?

Literature

Flipped Learning

Flipped learning is a learner-centered model that reorganizes the traditional sequence of teaching by moving direct instruction outside the classroom and reserving in-class time for interactive, application-based activities (Lage et al., 2000; Bishop & Verleger, 2013). In this model, students engage with digital materials prior to class, while classroom sessions focus on discussion, problem-solving, and collaborative learning (Sams & Bergmann, 2012). By reallocating instructional time, flipped learning aims to foster active engagement and deeper cognitive processing.

Empirical and meta-analytic studies generally report positive effects of flipped learning on academic achievement across disciplines (Strelan et al., 2020; van Alten et al., 2020). These effects are often attributed to increased opportunities for active learning, immediate feedback, and peer interaction. However, findings are not uniformly consistent. Some studies report no significant differences between flipped and traditional approaches (Holm et al., 2022; Topal & Akhisar, 2018), suggesting that the effectiveness of flipped learning depends on contextual and pedagogical factors rather than the model itself.

Rather than treating flipped learning as inherently effective, recent scholarship emphasizes the importance of pedagogical alignment and structured implementation (Lo & Hew, 2017). In particular, the design of pre-class materials and the purposeful organization of in-class activities play a critical role in supporting meaningful learning experiences. Thus, flipped learning should be understood not merely as a technological shift, but as an instructional design approach that requires coherence between learning objectives, digital materials, and interactive classroom practices.

Flipped Learning in Chemistry Education

Chemistry is widely recognized as a cognitively demanding subject due to its abstract concepts, multi-level representations, and emphasis on higher-order thinking skills (Johnstone, 2006; Taber, 2013). These characteristics require instructional approaches that support conceptual understanding, active engagement, and the integration of symbolic, macroscopic, and microscopic representations. Within this context, flipped learning has been proposed as a promising pedagogical framework for chemistry instruction. Empirical studies indicate that flipped learning has positive effects on students' academic achievement, engagement, and problem-solving skills in chemistry education (Küpelikılınç & Kan, 2024; Yu et al., 2023). By reallocating classroom time to application-based activities, laboratory tasks, and guided discussion, flipped learning may facilitate deeper conceptual processing and the clarification of misconceptions. Furthermore, the integration of simulations and interactive digital learning activities into flipped learning environments has been shown to enhance students' conceptual understanding of complex chemistry topics (Jere & Mpeta, 2024). From a cognitive load perspective, chemistry topics such as thermodynamics, enthalpy, reaction kinetics, and equilibrium involve high intrinsic cognitive load due to their abstract nature and the need to integrate mathematical reasoning with conceptual understanding (Johnstone, 2006; Sweller, 1988). In flipped learning contexts, distributing instructional phases across pre-class and in-class environments may allow foundational explanations to be processed individually, thereby enabling classroom time to focus on elaboration, application, and conceptual integration. When instructional materials are carefully sequenced and aligned, this structure may support schema construction and reduce unnecessary extraneous cognitive load.

Nevertheless, the literature also reports several limitations related to flipped learning in chemistry education. Inconsistent student engagement with pre-class materials, limitations in technological infrastructure, and variability in teachers' competencies in developing digital content may constrain the effectiveness of the model (Keskin et al., 2021). In addition, much of the existing evidence has been

generated in higher education settings, while empirical studies conducted at the secondary school level remain comparatively limited (Sergis et al., 2018). These gaps indicate the need for further research examining flipped learning within secondary chemistry contexts.

Students' Academic Achievement and E-Learning Satisfaction in the Context of Flipped Learning

Flipped learning promotes students' active engagement while redefining the teacher's role from a transmitter of knowledge to a facilitator and guide (Tucker, 2012). Allocating in-class time to student-centered activities it fosters collaborative learning environments and provides opportunities for students to engage in higher-order cognitive processes, which are closely associated with academic success (Bishop & Verleger, 2013). A growing body of empirical research suggests that flipped learning generally has positive effects on students' academic achievement. Studies have shown that well-designed flipped learning implementations, compared to traditional lecture-based approaches, improve academic performance across various disciplines and educational levels (ElGamal, 2022; Sergis et al., 2018; Strelan et al., 2020; van Alten et al., 2020; Zheng et al., 2020), foster deeper understanding of course content and improve knowledge retention (Dinçer & Polat, 2022; Lo & Hew, 2023; Moghadam & Razavi, 2022). However, findings are not uniformly consistent. Some studies report no significant differences compared to traditional instruction (Cabi, 2018; Holm et al., 2022; Topal & Akhisar, 2018), suggesting that learning outcomes depend less on the structural format of flipped learning and more on the quality of pedagogical implementation and students' engagement with pre- and in-class activities.

E-learning satisfaction represents an important affective dimension of technology-supported learning. It reflects learners' evaluations of instructional quality, interaction, usability, and support (Al-Samarraie et al., 2018; Sun et al., 2008). In flipped contexts, satisfaction is often linked to flexibility, self-paced learning, and interactive classroom experiences (Lo & Hew, 2023; Yalçın & Dennen, 2024). However, satisfaction is shaped not only by the instructional model but also by learner characteristics such as online learning readiness and self-regulation (Ip & To, 2025). Research indicates that flipped learning generally leads to higher levels of learner satisfaction in online and blended learning environments. Flexible access to learning materials, opportunities for self-paced learning, and the use of class time for interactive activities have been identified as key factors contributing to positive e-learning experiences (Lo & Hew, 2023; Yalçın & Dennen, 2024). In addition providing clear guidance and offering timely feedback are particularly important in enhancing learner satisfaction within flipped learning environments (Al-Samarraie et al., 2018; Lo & Hew, 2023; Martin & Bolliger, 2022). Conversely, poorly structured digital content or insufficient alignment between learning phases may diminish learners' perceived value of the model. Research emphasizes that sustaining high levels of e-learning satisfaction requires an integrated pedagogical and technological design perspective.

Despite growing research on flipped learning, limited studies have simultaneously examined academic achievement and e-learning satisfaction within secondary-level chemistry contexts. Moreover, few investigations have employed an explanatory sequential mixed-methods design to explore not only whether changes occur, but also how students' experiences may help explain quantitative outcomes. Addressing this gap, the present study integrates cognitive and affective indicators to provide a multidimensional evaluation of flipped learning in secondary chemistry education.

Methodology

Research Design

In this study, an explanatory sequential mixed-methods research design was employed to examine the relationship between students' academic achievement and their satisfaction with e-learning within a flipped learning environment in the Chemistry and Energy unit of the chemistry course. Mixed-methods

designs allow for a more comprehensive and in-depth examination of research problems by integrating quantitative and qualitative data within a single study (Creswell, 2013). In the explanatory sequential design, quantitative data are collected and analyzed first, followed by the collection and analysis of qualitative data to explain and elaborate on the quantitative findings (Creswell, 2013). In the present study, the quantitative phase constituted the primary strand of the research and aimed to determine (a) whether students' academic achievement significantly changed following the flipped learning implementation and (b) whether a statistically significant relationship existed between academic achievement and e-learning satisfaction. However, quantitative results alone were considered insufficient to explain the mechanisms underlying the observed patterns. Therefore, a qualitative phase was purposefully incorporated to provide explanatory depth, particularly regarding (a) the factors contributing to the observed increase in academic achievement and (b) the absence of a significant relationship between satisfaction and achievement. The quantitative component followed a single-group pretest–posttest quasi-experimental design to examine changes in students' academic achievement during a four-week flipped learning implementation. Although no control group was included, pre-test and post-test measurements enabled the analysis of achievement changes over time. In the qualitative phase of the study, students' emotions, thoughts, attitudes, and experiences related to the flipped learning process were examined in depth. Particular emphasis was placed on identifying themes that could account for the quantitative results, thereby strengthening the integration between the two strands of data. This analytical process enabled students' perspectives to be structured meaningfully and allowed for a deeper interpretation of the quantitative results by revealing the underlying reasons behind the observed findings.

Data Collecting Tools

Within the scope of this study, three different data collection instruments were employed to measure students' online learning processes, academic achievement, and perceptions of flipped learning.

The E-Learning Satisfaction Scale (Gülbahar, 2012) was used to examine participants' satisfaction with the e-learning process. The scale is structured around the dimensions of accessibility of online course materials, content quality, instructional process, interaction, feedback, and assessment. Consisting of a total of 29 items, the scale is formatted as a five-point Likert-type instrument ranging from Strongly Disagree to Strongly Agree. The validity and reliability of the scale have been established, with a reported Cronbach's alpha reliability coefficient of .94.

The academic achievement test was developed by the researcher based on multiple-choice questions related to the Chemistry and Energy topic from chemistry examinations administered by Student Selection and Placement Center (ÖSYM) within the past ten years. The test comprises 20 multiple-choice items selected from questions published on ÖSYM's official website and aligned with the Chemistry and Energy unit of the chemistry curriculum. Item selection was guided by criteria including alignment with instructional objectives and learning outcomes, content representativeness, coverage of different cognitive levels, and appropriateness for the target grade level. The selected items were also reviewed by an experienced chemistry teacher to ensure content accuracy and grade-level appropriateness. ÖSYM examinations follow standardized psychometric procedures, supporting the quality of the item pool. For the present sample, the internal consistency of the test was calculated using KR-20, yielding a reliability coefficient of .82.

The semi-structured interview form was developed by adapting the interview questions originally designed by Kavaz (2023). The form consists of nine main questions. To ensure content validity, the interview questions were submitted to two field experts for review, and the final version of the instrument was established based on their feedback.

Study Group

The participants of the study consisted of 62 twelfth-grade students enrolled at a private course center in Istanbul. Participants were between 17 and 19 years of age and were selected using convenience sampling, which enables the researcher to recruit individuals who are easily accessible and offers advantages in terms of time, cost, and accessibility (Büyüköztürk et al., 2018). Of the participants, 38 (61.3%) were male and 24 (38.7%) were female. In terms of school type, 34 students (54%) were from Anatolian High Schools, 7 students (12.7%) were from Science High Schools, and 21 students were from Vocational High Schools. The participants were preparing for the national university entrance examination and were therefore engaged in an academically intensive and examination-oriented study period at the time of the implementation.

Data Analysis

Adopting a mixed-methods approach, quantitative data were analyzed using a paired-samples t-test to examine whether there was a significant difference between students' pre-test and post-test academic achievement scores, and Pearson correlation analysis was conducted to investigate the relationship between students' e-learning satisfaction scores and their academic achievement (post-test) scores. Qualitative data were analyzed through content analysis to explore students' views on flipped learning, with codes, themes, and sub-themes developed to complement and enrich the quantitative findings. The analysis followed a systematic coding procedure. Two researchers independently coded the interview transcripts in the initial phase of analysis. Subsequently, the researchers compared their coding schemes and discussed discrepancies. Differences were resolved through discussion and consensus, and a final set of codes and themes was collaboratively established. This iterative process enhanced the credibility and consistency of the qualitative analysis.

Validity and Reliability

- The variables measured in the study were selected in direct alignment with the research objectives, thereby enhancing the ability of the collected data to address the research questions.
- All data collection procedures were implemented under identical conditions for all participants to minimize the potential influence of external factors. Consistency was further ensured by administering the same academic achievement test at both the pre-test and post-test stages.
- The Cronbach's alpha reliability coefficient of the E-Learning Satisfaction Scale was calculated as .94, indicating a high level of internal consistency.
- The validity and reliability of the academic achievement test were supported through the selection of items aligned with curriculum learning outcomes from questions published by ÖSYM over the past ten years, and expert approval was obtained from another teacher in the same subject area.
- For the qualitative data, reliability was ensured through the development of clearly defined themes, the use of direct quotations from participants, and the systematic execution of the analysis process, thereby enhancing the credibility and internal validity of the qualitative findings.

Research Procedures

Within the scope of the study, a four-week implementation process was conducted focusing on the Chemistry and Energy topic. Prior to the implementation, students were informed about the procedure. Three days before each class session, the teacher shared links to topic-related instructional videos with the students via the Education Informatics Network (EBA) platform. Students were asked to log into the system using their personal EBA usernames and passwords and to watch the assigned content. One day before the lesson, the teacher sent a reminder through the class communication group to ensure that students came to class prepared.

Pre-test and Preparation Process; in the initial stage of the implementation, a pre-test academic achievement test related to the topic was administered to determine students' prior knowledge levels. During the implementation process, students were supported with instructional videos and digital materials on the topics of internal energy, Hess's Law, enthalpy, refrigeration cycles, and bond energy via the EBA platform. On the day of the lesson, students attended the class prepared, based on the videos and digital materials they had previously viewed.

In-Class Activities; the activities implemented during class sessions were designed to support students' understanding of the subject from both theoretical and experimental perspectives. The activities consisted of the following stages:

- **Concept Identification Activity:** Students are provided with key concepts related to the Chemistry and Energy unit along with their definitions. They match the concepts with the correct explanations, and the teacher reinforces learning by clarifying the correct matches.
- **True–False Activity:** Students respond to true–false statements and discuss the reasons for incorrect statements, thereby identifying and addressing misconceptions.
- **Conceptual Linking Activity:** Core concepts—particularly enthalpy—are correctly linked to one another to strengthen conceptual understanding.
- **Enthalpy Calculation Activity:** Calculations related to changes in enthalpy are carried out step by step.
- **Real-Life Application Activity:** The Chemistry and Energy unit is connected to real-life contexts; students perform calculations, construct graphs, and discuss the effects of ocean acidification on living organisms.

Post-Test and Data Collection; at the end of the four-week implementation, a 20-item test developed from chemistry questions on the topics of Chemistry and Energy and enthalpy that had appeared in ÖSYM examinations over the past ten years was administered as the post-test. In addition, the E-Learning Satisfaction Scale was administered to evaluate students' digital learning experiences, and qualitative data were collected through semi-structured interviews. Participants for the interviews were randomly selected from among the students, and a total of 10 students were interviewed. During the face-to-face interviews, audio recordings were made and later transcribed for analysis.

Limitations

- The absence of a control group constitutes a primary methodological limitation of the study. Although a statistically significant increase in academic achievement was observed, the single-group pretest–posttest design limits the extent to which the improvement can be attributed solely to the flipped learning intervention. Alternative explanations, such as maturation effects, test familiarity, or external learning influences, cannot be entirely ruled out.
- The use of self-report-based measurement instruments increases the risk of bias, particularly for variables such as self-regulation and satisfaction.
- Due to the implementation period being limited to four weeks, the long-term effects of the flipped learning model could not be examined.
- The restriction of the study to a single subject area (Chemistry) and a single grade level (12th grade) reduces the generalizability of the findings.

Findings

The results of the data analysis are presented below under separate quantitative and qualitative headings.

Quantitative Findings

Table 1 presents the descriptive statistics and normality values for participants' overall e-learning satisfaction, pre-test academic achievement scores, and post-test academic achievement scores.

Table 1. Descriptive statistics and normality values

Variable	N	Min	Max	Mean	SD	Skewness	Kurtosis
E-Learning Satisfaction	62	105	131	117.11	5.86	0.16	-0.08
Pretest (Academic Achievement)	62	10	90	37.66	24.46	0.50	-0.93
Posttest (Academic Achievement)	62	30	100	62.66	18.08	0.28	-0.81

As shown in Table 1, the mean score for online e-learning satisfaction was 117.11 (SD = 5.86), the mean pre-test academic achievement score was 37.66 (SD = 24.46), and the mean post-test score was 62.66 (SD = 18.08). For all variables, skewness and kurtosis values fell within the ± 1 range, indicating that the data were normally distributed.

The difference between participants' pre-test and post-test academic achievement scores was analyzed using a paired-samples t-test (Table 2).

Table 2. Paired-samples t-test results for pre-test and post-test academic achievement scores

Variable	N	M	SD	p
Pretest	62	37.66	24.46	< .001
Posttest	62	62.66	18.08	

As presented in Table 2, post-test scores (M = 62.66, SD = 18.08) were significantly higher than pre-test academic achievement scores (M = 37.66, SD = 24.46), $t(61) = 7.25$, $p < .001$. The effect size, calculated as Cohen's d for paired samples, was 0.92, indicating a large magnitude of change according to conventional benchmarks (Cohen, 1988). The results have revealed a statistically significant increase in students' academic achievement, suggesting that the flipped learning model may contribute positively to students' learning outcomes.

Pearson correlation analysis was conducted to examine the relationship between e-learning satisfaction and academic achievement (post-test) scores. The results are presented in Table 3.

Table 3. Pearson correlation between e-learning satisfaction and academic achievement (post-test)

Variable	N	E-Learning Satisfaction	Academic Achievement
E-Learning Satisfaction	62	1	.125
Academic Achievement	62	.125	1

$p = .334$

As shown in Table 3, the relationship between e-learning satisfaction and academic achievement scores was not statistically significant ($r = .125$, $p = .334$). According to Cohen's (1988) benchmarks, this represents a small effect size, indicating a weak association between satisfaction and academic performance. The quantitative findings suggest that the flipped learning model may contribute to improvements in students' academic achievement, however, no direct association was observed between students' e-learning satisfaction and their academic achievement.

Qualitative Findings

Qualitative data were collected to address the research question, "What are students' views on the flipped learning model?" Based on students' responses, six main themes were identified: Emotional Responses and Attitudes, Academic Contributions and Learning, Self-Regulation, In-Class Interaction, Challenges and Limitations, and Suggestions for Improvement. These themes were examined in relation to the quantitative outcomes to determine how students' reported experiences might explain the observed. The identified themes and codes are presented in the table below.

Tablo 4. The themes and codes

Theme	Codes	Frequency	Participants	Sample Quotations
Emotional Responses and Attitudes	Excitement, comfort, curiosity, increased motivation, gain in self-confidence, boredom, lack of motivation, tension, indecisiveness	10	P1, P2, P3, P4, P5, P6, P7, P8, P9, P10	"While watching the videos, my curiosity increased, which helped me come to class more prepared." (P3) "I could not always maintain the same level of motivation; sometimes I felt bored." (P8)
Academic Contributions and Learning	Better understanding of the topic, focus on questions, reinforcement, deeper learning, opportunity for repetition, conceptual coherence, time efficiency	10	P1, P2, P3, P4, P5, P6, P8, P9, P10, P11	"Being able to pause and rewatch the video was a great advantage for me; I understood the topic better." (P5) "When I participated in classroom discussions, what I learned became more permanent." (P9)
Self-regulation	Pre-class preparation, self-discipline, planned studying, difficulty in independent study, willpower and focus problems	7	P1, P2, P4, P5, P6, P10, P11	"It was difficult to sit down and start the video; my focus drifted." (P11) "Preparing before the lesson helped me develop discipline." (P6)
In-Class Interaction	In-class practice, discussion of questions, efficient use of class time, asking questions to the teacher instantly	8	P1, P2, P4, P6, P8, P9, P10, P11	"Discussing our questions in class was very useful; I learned points I hadn't considered from my classmates." (P2) "Being able to ask the teacher questions immediately made learning easier." (P10)
Challenges and Limitations	Inability to ask questions immediately, internet access issues, lack of concentration, inadequate individual learning environment, long video duration, difficulty studying at home, suitability problems	8	P3, P4, P5, P6, P8, P10, P11	"It was difficult to concentrate while studying at home; I was frequently distracted." (P6) "The videos were sometimes too long, and I struggled to watch them until the end." (P4)
Suggestions for Improvement	Shorter and more engaging videos, solutions for internet access, increased problem-solving activities, enhanced in-class guidance	5	P3, P4, P8, P10, P11	"If the videos were shorter and more engaging, it would be easier for me to focus." (P10) "I would like more problem-solving activities to be done in class." (P3)

The qualitative findings presented in Table 4 indicate that students' perceptions of the flipped learning process encompass both positive contributions and certain limitations. Overall, the results reveal that the flipped learning model generated diverse emotional, cognitive, and social responses among students.

Within the theme of Emotional Responses and Attitudes, a substantial number of students reported positive emotional reactions to the flipped learning process. Students frequently stated that the model aroused their curiosity, increased their motivation, and contributed to the development of self-confidence. For instance, Participant 3 noted, "*While watching the videos, my curiosity increased, which helped me come to class more prepared,*" reflecting a positive emotional engagement with the learning process. However, some students also reported negative emotional experiences. As expressed by Participant 8, "*I could not always maintain the same level of motivation; sometimes I felt bored.*" These

findings suggest that flipped learning may evoke varying emotional responses depending on individual learner characteristics.

Regarding the theme of Academic Contributions and Learning, students emphasized that the flipped learning model helped them understand the subject matter more effectively and enabled reinforcement and deeper learning. The opportunity to pause and rewatch instructional videos emerged as one of the most frequently highlighted advantages. For example, Participant 5 stated, "*Being able to pause and rewatch the video was a great advantage for me; I understood the topic better.*" In addition, students frequently mentioned the contribution of in-class discussions to their learning. Participant 9 supported this view by stating, "*When I participated in classroom discussions, what I learned became more permanent.*" These findings suggest that flipped learning provides a supportive learning environment for cognitive development.

Under the theme of Self-Regulation, students' individual responsibilities and learning behaviors became more apparent. While some students reported that pre-class preparation fostered self-discipline, others indicated difficulties related to focus and self-control. For example, Participant 6 stated, "*Preparing before the lesson helped me develop discipline,*" whereas Participant 11 highlighted a challenge by noting, "*It was difficult to sit down and start the video; my focus drifted.*" These findings indicate that flipped learning may encourage self-regulation skills; however, differences in students' readiness for self-directed learning may create challenges for some learners.

The theme of In-Class Interaction reflects students' perceptions of increased efficiency and interaction during class time. Students emphasized that class sessions were used more productively and that opportunities for interaction increased, particularly through peer learning and immediate access to the teacher. Participant 2 noted, "*Discussing our questions in class was very useful; I learned points I hadn't considered from my classmates,*" highlighting the role of peer interaction. Similarly, Participant 10 stated, "*Being able to ask the teacher questions immediately made learning easier,*" emphasizing the value of teacher–student interaction. These findings suggest that flipped learning supports not only individual learning but also social learning processes.

The Challenges and Limitations theme reveals obstacles encountered during the implementation of the flipped learning model. Students frequently mentioned issues related to internet access, lack of concentration, and difficulties studying in the home environment. Participant 6 explained, "*It was difficult to concentrate while studying at home, I was frequently distracted.*" Additionally, the length of instructional videos was identified as a common challenge. As Participant 4 noted, "*The videos were sometimes too long, and I struggled to watch them until the end.*" These findings highlight the importance of technical infrastructure, instructional design, and students' individual study environments in the effective implementation of flipped learning.

Finally, within the Suggestions for Improvement theme, students offered various recommendations to enhance the effectiveness of the flipped learning process. Common suggestions included preparing shorter and more engaging videos, addressing internet access issues, and increasing the number of problem-solving activities conducted in class. Participant 10 stated, "*If the videos were shorter and more engaging, it would be easier for me to focus,*" reflecting expectations regarding instructional design. Likewise, Participant 3 expressed a desire for more in-class practice by stating, "*I would like more problem-solving activities to be done in class.*" Overall, these suggestions provide valuable insights for improving the design and implementation of flipped learning environments.

Taken together, the qualitative findings demonstrate that the flipped learning model has multidimensional effects on students. While emotional, cognitive, and social benefits are prominent,

technical and individual factors may limit the effectiveness of the model. Students' suggestions for improvement offer important implications for the more effective and sustainable implementation of flipped learning practices.

Discussion

The findings of the present study provide converging evidence from quantitative and qualitative data regarding the effects of the flipped learning model on students' learning experiences in secondary-level chemistry education. Quantitative results revealed a statistically significant increase in students' academic achievement from pre-test to post-test, indicating that the flipped learning model can effectively enhance students' academic performance in the Chemistry and Energy unit. This finding aligns with previous meta-analytic and empirical research demonstrating that flipped learning approaches generally yield positive, though context-dependent, effects on academic achievement when compared to traditional instructional methods (Küpelikılınç & Kan, 2024; Tekin & Kabapınar, 2023; Strelan et al., 2020; van Alten et al., 2020). At the same time, the literature also reports mixed findings, suggesting that the effectiveness of flipped learning varies according to instructional design quality, implementation duration, subject matter, and learner characteristics (Buhl-Wiggers et al., 2023; Eltahir, 2018). For instance, some experimental studies have found no significant difference in academic achievement between flipped learning and traditional instruction (Cabi, 2018; Holm et al., 2022), while others have shown that effect sizes are sensitive to implementation duration and instructional structuring (van Alten et al., 2020). These findings suggest that flipped learning should be understood not merely as a method but as a pedagogical approach shaped by implementation quality and contextual factors. Although the absence of a control group prevents attributing the observed improvement solely to the flipped learning intervention, qualitative findings shed light on the mechanisms underlying the observed achievement gains; structured in-class interaction and flexible access to digital materials appear to have supported cognitive processing during the implementation. Participants particularly emphasized increased motivation, enhanced conceptual understanding, and more efficient use of class time. The opportunity to pause and rewatch instructional videos, along with participation in interactive in-class discussions, was perceived as a key factor supporting deep learning and knowledge retention. These findings are consistent with prior research emphasizing the role of active learning, peer interaction, and immediate feedback as central mechanisms through which flipped learning supports academic achievement (Strelan et al., 2020). Additionally, the use of the same academic achievement test as both pre-test and post-test raises the possibility of a testing effect. Students' familiarity with item formats or prior exposure to the content may have partially contributed to score increases. Although the time interval and instructional intervention likely influenced performance, this potential testing effect should be considered when interpreting the magnitude of the observed achievement gains. Indeed, Zheng et al. (2020), in their meta-analysis, reported that medium-term interventions (5–8 weeks) were more effective than short-term (less than five weeks) and long-term (more than eight weeks) interventions. Such an approach may also help reduce potential testing effects.

With respect to the relationship between e-learning satisfaction and academic achievement, the quantitative findings indicated no statistically significant association between students' satisfaction scores and their post-test academic achievement scores. This result is consistent with previous studies reporting that learner satisfaction does not necessarily predict academic success in flipped or blended learning environments (Korkmaz et al., 2015; Öztürk Demir & Eren, 2022). These findings suggest that academic achievement in flipped learning contexts may be influenced more strongly by cognitive engagement, instructional alignment, and learning strategies than by satisfaction alone, supporting arguments in the literature that satisfaction and achievement represent related but distinct dimensions of the learning experience (van Alten et al., 2020). Nevertheless, qualitative data revealed notable challenges related to self-regulation, technological access, and instructional design. While some students reported that pre-class preparation fostered discipline and responsibility, others experienced

difficulties with focus, motivation, and independent study. In addition, issues such as limited internet access and lengthy instructional videos were identified as factors that negatively influenced students' learning experiences. This variability in students' participation patterns provides a plausible explanation for the weak and statistically non-significant correlation between satisfaction and academic achievement. Although many students expressed positive perceptions of the flipped model, differences in self-regulated learning behaviors and contextual constraints may have influenced academic performance independently of overall satisfaction levels. Similar challenges have been documented in the literature and highlight that the benefits of flipped learning are not automatic but depend on learners' readiness for self-directed learning and the availability of supportive technological and instructional conditions (van Alten et al., 2020).

In light of these findings, flipped learning model can effectively enhance students' academic achievement in secondary-level chemistry education, even when students' levels of e-learning satisfaction vary. While flipped learning supports students' cognitive, emotional, and social learning experiences, its effectiveness is shaped by multiple interrelated factors, including instructional design quality, students' self-regulation skills, and access to technological resources. These results underscore the importance of evaluating flipped learning not only in terms of achievement outcomes but also through a multidimensional perspective that considers learners' experiences and contextual conditions.

Conclusion and Suggestions

The findings of this study indicate that the flipped learning model can effectively enhance students' academic achievement in the Chemistry and Energy unit of secondary-level chemistry education. Although a significant improvement was observed in students' post-test achievement scores, no direct relationship was found between e-learning satisfaction and academic achievement. Qualitative findings revealed that flipped learning supports students' cognitive, emotional, and social learning experiences; however, challenges related to self-regulation, instructional design, and technological access remain.

Based on these findings, several recommendations can be offered for researchers and practitioners. Teachers may be encouraged to incorporate the flipped learning model into their instructional planning, and future studies may explore its effectiveness across different chemistry topics and subject areas. Further research is also needed to examine factors influencing e-learning satisfaction, such as motivation, digital content quality, interaction, and learning strategies. Additionally, instructional videos should be designed to be shorter, engaging, and visually supported in order to promote effective pre-class preparation. Consideration should also be given to students' access to technological resources, and measures should be taken to reduce digital inequalities that may limit the effectiveness of flipped learning. The duration of the implementation may also be extended in future studies to examine the sustainability of its outcomes over a longer period. Finally, adapting the flipped learning model to different types of courses, particularly those with strong visual or verbal components, may further enhance student engagement and learning outcomes. Moreover, future research may adopt experimental designs with control and experimental groups to more rigorously examine the effectiveness of the flipped learning model.

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Kübra Arda: Conceptualization, Methodology, Investigation, Visualization, Writing –original draft, Writing –review & editing; Güneş Akça: Conceptualization, Writing –review & editing. All authors have read and agreed to the published version of the manuscript

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This study is linked to the following SDG(s): Quality education (SDG 4)

Data Accessibility Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethics and Consent

Participation in the study was voluntary. No personal or identifiable information was collected from the participants. The data were used solely for research purposes, and the study was conducted in accordance with ethical research principles.

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