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# From preparation to performance: How a flipped classroom promotes conceptual learning and problem-solving in inorganic chemistry

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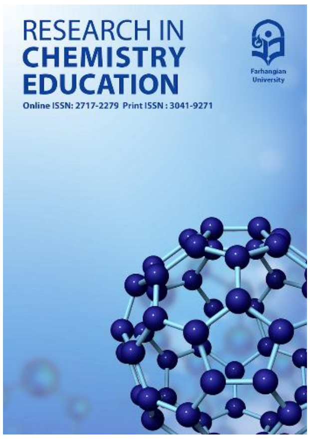

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## Abstract:

**Background and Objective:** Inorganic chemistry is widely recognized as a conceptually rigorous and experimentally intensive discipline, for which traditional lecture-based instruction frequently affords limited opportunities for structured reasoning and collaborative engagement. Flipped pedagogy reallocates initial content acquisition to the pre-class phase, thereby transforming in-class time into an interactive environment dedicated to higher-order problem-solving, peer discourse, and formative assessment. This study investigates the effects of flipped instruction on undergraduate students' academic performance and the development of their problem-solving competencies in an inorganic chemistry course. **Methods:** A convergent mixed-methods, quasi-experimental design was implemented involving 88 pre-service science teachers across four intact classes. Two classes were exposed to flipped instruction, while the remaining two received conventional lecture-based teaching over the course of one semester under the guidance of the same instructor to ensure instructional consistency. Academic achievement was evaluated using a pre-knowledge test, as well as midterm and final examinations. Problem-solving skills were assessed at three time points—at the beginning, midpoint, and conclusion of the semester—through a validated questionnaire. Qualitative data derived from open-ended questionnaire responses were subjected to inductive coding and thematic analysis. **Findings:** The groups were comparable at baseline. The flipped cohort exhibited a modest advantage on the midterm that did not remain statistically significant after correction; however, they achieved significantly higher scores on the final examination, with the performance gap widening by the end of the semester. Moreover, they demonstrated greater gains in problem-solving skills at the final assessment. Qualitative findings converged with these results, indicating deeper conceptual understanding, enhanced multistep reasoning, more substantive peer collaboration, and increased motivation. Reported challenges included a substantial pre-class workload, stress associated with readiness checks, uneven levels of preparation, and limited internet access. **Conclusion:** Flipped instruction can strengthen achievement and problem-solving in inorganic chemistry when pre-class tasks are manageable, and in-class activities are carefully scaffolded. Given the single-institution setting and technology constraints, replication across diverse universities and learning conditions is needed.

**Keywords:** Flipped Classroom, Inorganic Chemistry, Problem-Solving Skills, Mixed-Methods, Self-Regulated Learning.

## Introduction

Chemistry education has progressively reoriented from lecture-dominated instruction toward learner-centered approaches that foreground conceptual understanding, multistep problem-solving, and collaborative knowledge construction. This reorientation is driven by a persistent instructional challenge in chemistry: many university-level courses are highly abstract, representation-intensive, and cognitively demanding, yet conventional lecture-based instruction affords limited structured opportunities for students to engage in sustained reasoning, integrate multiple chemical representations, and receive feedback on the validity of their solution strategies (Hamdan et al., 2013). The flipped classroom (FC) has therefore been advanced as a strategic instructional approach that redistributes learning time in a manner consistent with the cognitive and epistemic demands of chemistry. In flipped classroom (FC) models, students engage with foundational content prior to class through videos, readings, or interactive materials, whereas in-class sessions are dedicated to guided problem-solving, peer discussion, inquiry-based activities, and formative assessment (Baig & Yadegaridehkordi, 2023; Sizemore et al., 2024). This functional redistribution is consistent with meta-analytic findings indicating that flipped learning yields its strongest effects when face-to-face sessions are explicitly organized around active problem-solving and guided practice (Låg & Sæle, 2019; Shi et al., 2020). From constructivist and socio-cultural perspectives, the potential contribution of FC lies in its sequencing of learning experiences. Pre-class engagement supports preliminary schema formation and reduces extraneous cognitive load, whereas in-class activity enables elaboration, monitoring, and transfer through scaffolded dialogue and immediate feedback (Anand, 2021; Lai, 2023). Moreover, from a constructivist perspective, engaging with concepts before class and subsequently reconstructing them through classroom interaction renders learning a process of meaning-making and stabilization—an explanation frequently emphasized in flipped classroom scholarship as a driver of deeper understanding (Al-Samarraie et al., 2020; Låg & Sæle, 2019). In chemistry education research, the flipped classroom (FC) is framed not as a substitute for active learning but as a structural framework that enables systematic implementation of active-learning strategies. Likewise, studies in higher-education chemistry have described flipped instruction as a scaffold that promotes student engagement and facilitates deeper conceptual understanding of chemical phenomena (Anand, 2021). Empirical evidence in general chemistry indicates that flipped sections can outperform traditional formats on achievement measures and reduce withdrawal or failure rates, with particularly robust effects among students entering with weaker prior preparation (Castillo-Cruz et al., 2025). Comparable findings are reported in organic chemistry, where FC implementations yield equal or higher learning outcomes and strengthen students perceived preparedness and confidence in addressing non-routine problems (Dehghan et al., 2022; Holloway et al., 2024). Recent investigations in physical and analytical chemistry similarly show that when pre-class work is coherently aligned with feedback-rich, activity-centered class sessions, FC supports both achievement gains and collaborative problem-solving (Wang et al., 2023; Belmonte & Bopegedera, 2025). Overall, the findings suggest that students' learning within a flipped environment is shaped by intersecting cognitive, social, and motivational processes, while remaining contingent on implementation quality and learners' self-regulatory readiness. Nevertheless, the flipped literature in chemistry underscores that benefits are contingent rather than inherent. Meta-analyses across disciplines report small-to-moderate average effects alongside substantial heterogeneity, indicating sensitivity to contextual variables and design fidelity (Akçayır & Akçayır, 2018; Bredow et al., 2021). Chemistry-focused reviews converge on similar conclusions: negligible or contradictory outcomes occur when pre-class workload is excessive or poorly targeted, readiness accountability is weak, technological access is uneven, or class time does not sustain genuinely active learning but instead reproduces mini-lecture practices (Aidoo et al., 2022; Anand, 2021; Eichler, 2022). This interpretation is consistent with systematic reviews indicating that the impact of flipped learning is not simply a function of reallocating instructional time; rather, it depends on the design quality of pre-class materials, the pedagogical rigor of in-class activities, and the degree to which learners' preparation and self-regulated learning are explicitly supported (Akçayır

& Akçayır, 2018; Eichler, 2022). An additional, frequently cited mechanism concerns students limited self-regulated learning capacity; without explicit scaffolds for planning, monitoring, and sustaining preparation, pre-class engagement deteriorates and undermines the intended in-class cognitive work (Akçayır & Akçayır, 2018; Anand, 2021). Collectively, these findings caution that FC is neither a universal remedy nor a sufficient condition for improved chemistry learning; rather, it is a conditional design whose effectiveness depends on coherent integration of pre-/in-class components and contextual feasibility.

Recent research on flipped instruction in chemistry education increasingly highlights that its effectiveness depends on contextual factors and the deliberate design of learning sequences. Studies conducted in environments facing infrastructure and learner-readiness challenges—including Iranian higher-education settings—indicate that flipped classrooms can improve conceptual understanding and student engagement. However, they also reveal persistent obstacles, such as students' limited experience with autonomous pre-class learning, time-management difficulties, unequal internet access, and instructors' need for professional support to coordinate coherent pre-class and in-class activities (Hojjati Siyamakani & Rashtizadeh, 2024). Complementary empirical work in Iran further indicates that, when these design and readiness issues are addressed, flipped learning can positively influence key affective and metacognitive foundations of chemistry learning: it has been linked to higher academic self-efficacy and achievement (Ebrahimi Orang et al., 2024) and to stronger metacognitive strategies, particularly self-monitoring and self-control (Rezaei et al., 2024). Theoretically, these outcomes can be interpreted through the lens of learner agency and its relation to self-efficacy. In flipped settings, students often perceive that substantial aspects of learning are under their control—from pre-class preparation and self-paced study to active participation in in-class tasks and group decision-making. Collectively, this body of evidence stresses that such outcomes are not automatic; they depend on sustained scaffolding of students' preparation and on providing equitable technological conditions for participation (Hojjati Siyamakani & Rashtizadeh, 2024; Rezaei et al., 2024). These considerations are especially pertinent for Inorganic Chemistry, a high-stakes gateway course in teacher-education programs. Inorganic chemistry requires students to coordinate abstract theoretical models (e.g., bonding theories, symmetry, coordination and crystal chemistry) with multistep qualitative and quantitative reasoning. Pre-service science teachers often encounter this course with elevated cognitive load and reduced confidence, conditions that can restrict engagement and compromise long-term retention. A well-scaffolded FC environment may, therefore, be advantageous by offering repeated self-paced access to foundational explanations before class and reserving classroom time for guided reasoning, peer comparison of alternative problem-solving routes, and corrective feedback. However, compared with general and organic chemistry, rigorous FC research in inorganic chemistry remains limited, with extant studies often focused on laboratory settings or short-term interventions (Anand, 2021; Song et al., 2023). Moreover, much of the prior literature prioritizes course grades or general satisfaction, whereas current chemistry education research calls for broader outcome sets that include problem-solving proficiency, critical thinking, and collaborative learning capacities (Eichler, 2022; Wang et al., 2023). When students engage with problems during class, they are compelled to analyze reasoning pathways, interrogate underlying assumptions, and evaluate alternative answers. These demands align with the upper tiers of the revised Bloom's taxonomy—analysis, evaluation, and creation—since pre-class engagement predominantly targets lower-order processes, such as recall and basic comprehension, while in-person sessions are designed to foster higher-order cognitive skills. From an inquiry- and question-based learning perspective, flipped instruction also appears to foster a learning environment that is inherently 'question-producing.' Students encounter content before class, develop preliminary uncertainties and questions, and then bring these issues into classroom dialogue where they are examined through discussion and argumentation (Anand, 2021; Li & Yang, 2021). Accordingly, this study utilized a convergent mixed-methods design to investigate the effectiveness of a flipped classroom in an undergraduate inorganic chemistry course for pre-service science teachers at Farhangian University, Iran. Using a quasi-experimental nonequivalent control-group approach, two intact classes received flipped instruction (n = 46), and two parallel classes received traditional lecture-based instruction (n = 42) across one semester. The quantitative strand compared the groups' academic achievement—assessed via a pre-knowledge test, midterm, and final exam—and problem-solving skills across three time points, whereas the qualitative strand examined students lived experiences to illuminate the cognitive, metacognitive, social, and motivational mechanisms underlying the observed outcomes.

## Methodology

### Participants

The study was carried out at Farhangian University in Iran during the Spring 2025 semester. A convergent mixed-methods design was adopted; whereby quantitative and qualitative data were gathered concurrently and merged at the interpretation stage. The target population comprised pre-service science teachers (student teachers) majoring in Experimental Sciences who were enrolled in the undergraduate Inorganic Chemistry course. Because participants were recruited from intact, readily accessible course sections and neither individual randomization nor reallocation of students across classes was practicable, convenience sampling was employed. The course instructor, who had 14 years of teaching experience, taught all four parallel Inorganic Chemistry sections during the same semester. To minimize instructor-related confounding, both the flipped and traditional conditions were implemented by the same instructor. Overall, 91 pre-service teachers took part in the study. Two of the four intact classes were allocated to the experimental flipped learning condition, while the remaining two served as the control group receiving traditional instruction. Initially, the flipped classroom group comprised 49 students (28 males, 21 females), while the control group included 42 students (23 males, 19 females). Inclusion criteria required (a) official enrollment and regular attendance in the Inorganic Chemistry course during the study semester and (b) participation in all three assessment waves (pre-test, midterm, and post-test). Students who missed any measurement occasion or were absent for extended periods were excluded. Consequently, only participants with complete data across all three waves were retained for analysis; three students from the flipped group were removed due to incomplete data, resulting in final sample sizes of n = 46 (experimental) and n = 42 (control). All participants were informed of the study aims and procedures and were assured that data would be collected and analyzed anonymously and confidentially. Following this explanation, verbal informed consent was obtained from all students.

### Research Design

The study utilized a quasi-experimental nonequivalent control-group design. Owing to administrative and instructional constraints at the university, together with the fixed structure of official course sections, random assignment of students to experimental conditions was not possible. Accordingly, the four parallel inorganic chemistry classes were maintained as intact groups, with two classes assigned to the experimental flipped learning condition and the other two to the traditional-instruction control condition. To minimize potential instructor-related confounds, both conditions were implemented by the same course instructor. The instructional intervention ran from February to September 2025, with one two-hour session delivered each week. At the start of the semester, a chemistry pre-knowledge test was administered to determine students' baseline content knowledge in both groups. Group means at pre-test were calculated and compared to assess initial equivalence and to mitigate potential selection bias. In parallel, students' problem-solving ability was assessed at three measurement points (beginning of the semester, midterm, and end of the semester). These pre-, mid-, and post-intervention datasets were used to examine learning trajectories over time and to compare the relative effectiveness of flipped learning and traditional instruction. Because enrollment in the official course sections determined participant numbers, the final sample size was necessarily dependent on the number of students registered in the intact classes.

### Course Structure

According to the approved Inorganic Chemistry curriculum for pre-service science teachers majoring in Experimental Sciences, the course was designed around the following learning objectives:

1. To explain core concepts in inorganic chemistry, including the quantum model, bonding theories, periodic properties of elements, and the structure of crystalline solids.
2. To examine and interpret the structures and properties of inorganic substances and to analyze the relationships between structure and properties.
3. To use acquired inorganic chemistry knowledge to solve chemical problems, interpret related phenomena, and propose scientifically grounded solutions to relevant tasks.

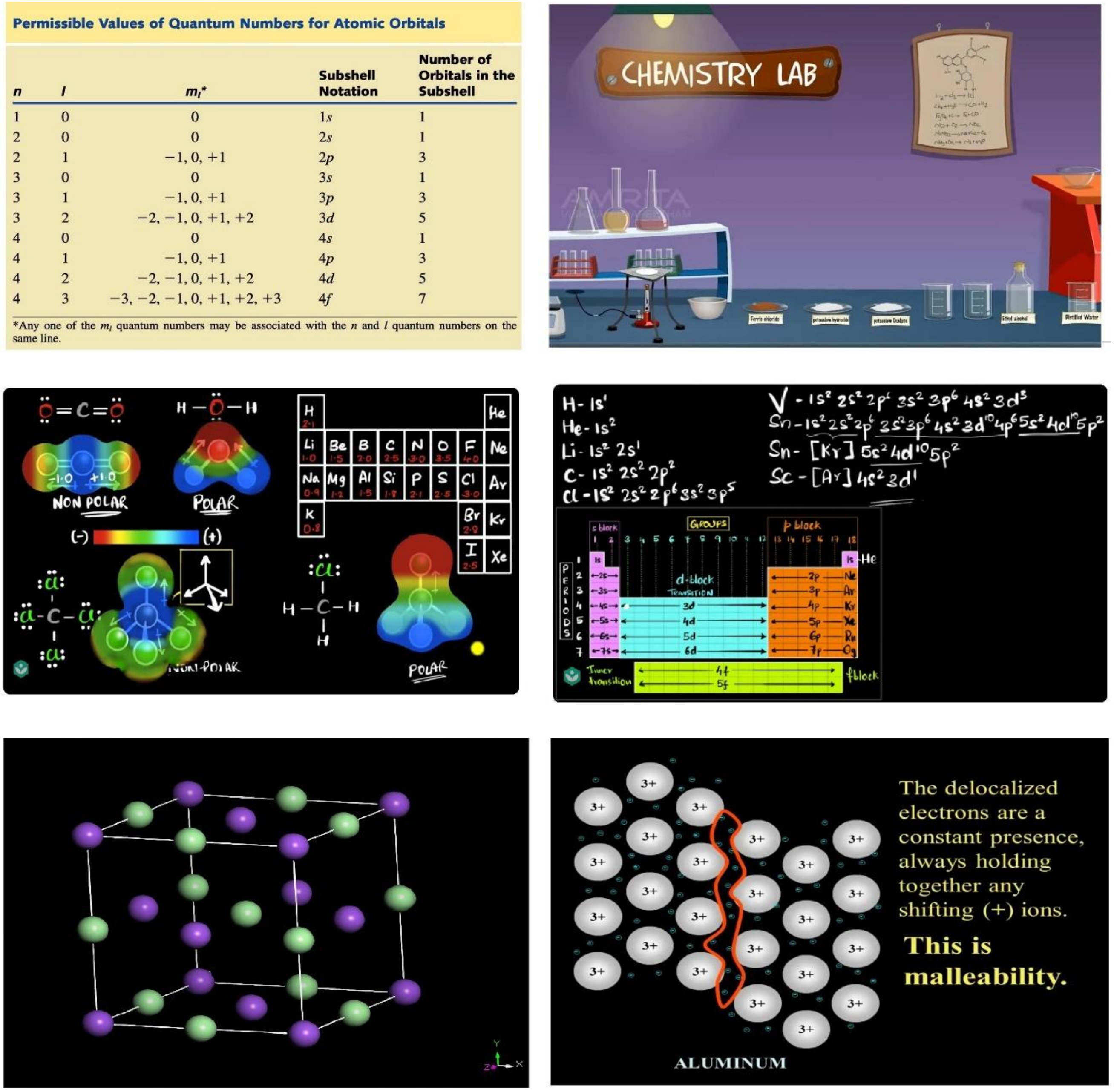
The instructional content of the course was organized into five chapters:

1. Atomic structure and its fundamental properties
2. Chemical bonding
3. Transition-element chemistry
4. Bioinorganic chemistry
5. Solid-state inorganic chemistry (including inorganic pigments and semiconductor chemistry)

The instructional intervention was designed in accordance with the four pillars of the FLIP model and implemented throughout the semester:

- Flexible Environment: establishing flexible learning conditions by providing students with online access to a variety of instructional resources;
- Learning Culture: promoting an active, student-centered culture of learning;
- Intentional Content: purposefully selecting and delivering pre-class materials and structuring in-class activities to facilitate deeper understanding;
- Professional Educator: emphasizing the instructor’s central role in orchestrating learning, offering timely feedback, and addressing misconceptions as they arise.

Operationally, the flipped classroom intervention was carried out through three sequential phases: pre-class, in-class, and post-class learning activities. During the pre-class phase, students engaged in self-directed preparation prior to attending face-to-face sessions. All preparatory materials were provided through the course learning management system (LMS). For each weekly session, pre-class content consisted of two primary types of multimedia resources: instructor-produced lecture videos and curated visual and multimedia materials from reputable online sources, including animations, infographics, instructional videos, and electronic handouts. Fig. 1 shows the overall structure of the flipped-classroom intervention in the Inorganic Chemistry course across the pre-class phase. All resources were uploaded to the LMS, and students were expected to review them before the in-person class meeting. To promote accountability for preparation and to consolidate pre-class learning, a short readiness quiz was administered at the beginning of each face-to-face session (see the in-class phase). The LMS was selected because it enabled the uploading of diverse content formats, supported online assessment, and allowed monitoring of students’ learning activity. Lecture videos were delivered in 10–15-minute segments, totaling approximately 45 minutes per session on average, and were made available three days prior to each class meeting.



**Permissible Values of Quantum Numbers for Atomic Orbitals**

| n | l | $m_l$* | Subshell Notation | Number of Orbitals in the Subshell |
|---|---|---|---|---|
| 1 | 0 | 0 | 1s | 1 |
| 2 | 0 | 0 | 2s | 1 |
| 2 | 1 | −1, 0, +1 | 2p | 3 |
| 3 | 0 | 0 | 3s | 1 |
| 3 | 1 | −1, 0, +1 | 3p | 3 |
| 3 | 2 | −2, −1, 0, +1, +2 | 3d | 5 |
| 4 | 0 | 0 | 4s | 1 |
| 4 | 1 | −1, 0, +1 | 4p | 3 |
| 4 | 2 | −2, −1, 0, +1, +2 | 4d | 5 |
| 4 | 3 | −3, −2, −1, 0, +1, +2, +3 | 4f | 7 |

*Any one of the $m_l$ quantum numbers may be associated with the n and l quantum numbers on the same line.

The delocalized electrons are a constant presence, always holding together any shifting (+) ions.

**This is malleability.**

**Figure 1-** Schematic overview of the flipped-classroom intervention in the inorganic chemistry course, structured according to the FLIP pillars and implemented via a self-paced pre-class preparation phase.

Each class session began with a short readiness quiz (3–5 items) covering the assigned pre-class materials. Based on students' quiz performance, the instructor first targeted recurring misconceptions and then provided a focused synthesis of the session's key concepts. The majority of in-class time was dedicated to active problem-solving and interactive learning activities. Students collaborated in small groups of 2–5 to address inorganic chemistry problems, while the instructor supported learning by posing strategic questions, clarifying conceptual uncertainties, and providing timely corrective feedback. Core in-class learning activities included:

- solving complex and conceptually demanding inorganic chemistry problems;
- structured small-group collaboration (2–5 students);
- conceptual discussion and critical analysis of alternative solution strategies;

- scaffolding learning toward higher-order cognitive engagement.

In the post-class phase, students completed online assessments and supplementary learning activities designed to reinforce understanding and provide additional practice. These tasks included items targeting theoretical knowledge as well as simulation-based problem-solving exercises delivered through virtual chemistry tools. Specifically, ChemCollective, PhET Interactive Simulations, and Quizizz were employed for this purpose (Fig. 2). Through virtual laboratory activities, reaction simulations, and interactive quizzes, students were afforded repeated opportunities to practice, review, and extend the concepts addressed during the face-to-face sessions. The instructor offered feedback on students' post-class work, and the recorded outcomes were utilized in subsequent sessions to identify learning difficulties and support further synthesis and clarification. Table 1 summarizes the key features of the pre-class, in-class, and post-class phases of the flipped classroom, including learning objectives, activities, instructional roles, and digital tools.

**Table 1-** Overview of the flipped-classroom instructional phases in the Inorganic Chemistry course

| Phase | Main Purpose | Student Activities | Instructor Role | Tools & Resources |
|---|---|---|---|---|
| **Pre-class** | Initial exposure to core concepts and preparation for in-class learning | • Watching short lecture videos (10–15 min segments)<br>• Reviewing curated multimedia materials<br>• Self-paced note-taking and concept review | • Design and curate pre-class materials<br>• Upload resources to LMS<br>• Monitor students' engagement | LMS, instructor-produced videos, animations, infographics, electronic handouts |
| **In-class** | Deep conceptual understanding and guided problem-solving | • Completing readiness quizzes<br>• Solving complex inorganic chemistry problems in small groups<br>• Participating in conceptual discussions and peer explanations | • Diagnose misconceptions<br>• Facilitate group work<br>• Provide immediate feedback and scaffolding | Readiness quizzes, problem-solving worksheets, board, peer discussion |
| **Post-class** | Reinforcement, practice, and transfer of learning | • Completing online assessments<br>• Engaging with simulations and virtual labs<br>• Reviewing feedback and correcting errors | • Provide formative feedback<br>• Analyze student performance<br>• Adjust subsequent instruction | ChemCollective, PhET simulations, Quizizz, LMS |

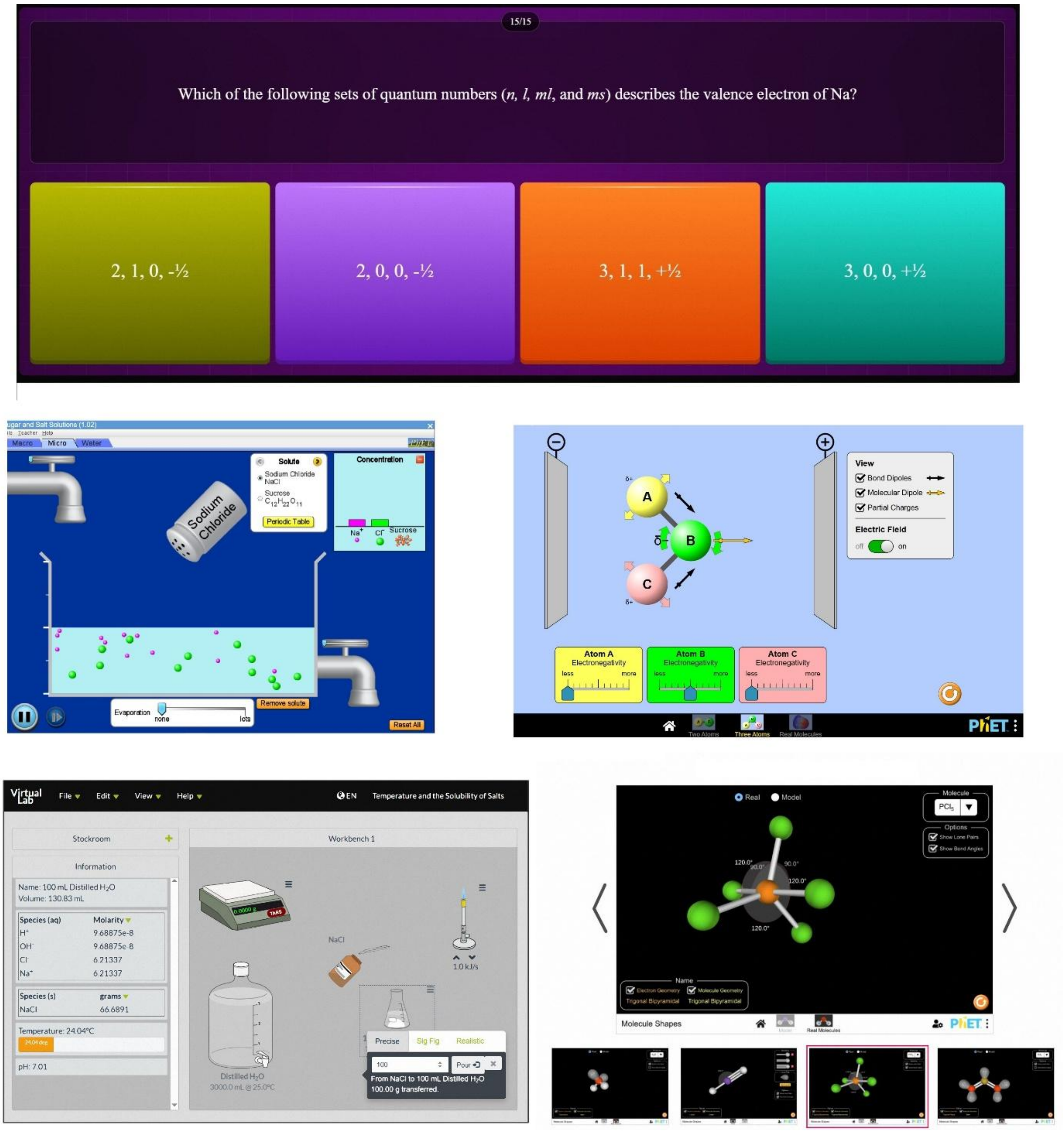


**Figure 2-** Examples of post-class digital learning tools used to reinforce and extend Inorganic Chemistry concepts, including ChemCollective virtual laboratory tasks, PhET interactive simulations, and Quizizz formative quizzes.

### Control Group (Traditional Instruction)

Instruction in the control condition was delivered through a conventional lecture-based format. In each session, the instructor presented Inorganic Chemistry content face-to-face using the board, while students simultaneously recorded notes. Class time was devoted primarily to direct explanation of concepts and instructor-worked examples, and related exercises were assigned for individual completion as homework. Students completed these tasks outside of class and, when necessary, addressed questions during the subsequent session. No pre-class multimedia resources (e.g., videos or online materials) were provided to the control group, and the course did not include game-based interactive activities or virtual simulation tools.

Consequently, the key distinction between the two instructional conditions was that the flipped format integrated structured pre-class learning with guided, interactive in-class problem-solving, whereas the traditional format relied on in-class lecturing followed by individual homework assignments.

### Assessing Students' Perceptions of the Flipped Classroom

To assess students' perceptions and attitudes toward the flipped classroom experience, a researcher-developed questionnaire was constructed and administered to the experimental group at the conclusion of the intervention. The instrument comprised two components .The first component consisted of Likert-type items rated on a five-point scale ranging from 1 (strongly disagree) to 5 (strongly agree). Item scores were assigned from 1 to 5, and an overall perception index was calculated as the mean of item responses, with higher values reflecting more favorable attitudes toward the flipped classroom. Content validity was established through expert review: four specialists in science education and curriculum planning evaluated the items, leading to refinement and revision where necessary. The internal consistency of this section was examined using Cronbach's alpha and demonstrated satisfactory reliability ($\alpha = 0.88$). The second component of the questionnaire consisted of five open-ended prompts aimed at eliciting students' lived experiences and more nuanced perspectives regarding the flipped classroom. The qualitative questions were:

1. Describe your experience of participating in the flipped classroom. In what ways did this approach facilitate or impede your learning?
2. From your perspective, what are the main advantages and disadvantages of the flipped classroom?
3. How has the flipped classroom affected your problem-solving ability, critical thinking, group collaboration, and social skills?
4. What challenges, barriers, or difficulties did you encounter while experiencing the flipped classroom?
5. What suggestions would you offer for improving the flipped classroom? What changes could make learning more effective?

Responses to these open-ended items were analyzed through thematic analysis. An inductive, data-driven approach was employed, such that codes and themes were derived from the dataset rather than predetermined. Initially, all responses were read multiple times and examined line-by-line to achieve thorough familiarization. Preliminary open codes were then generated, followed by clustering conceptually related codes into subthemes and broader thematic categories. Emerging themes were subsequently reviewed and refined to ensure internal consistency and comprehensive representation of the data. To strengthen analytic credibility, two researchers conducted independent coding, and disagreements regarding coding decisions or thematic structure were resolved through discussion until consensus was reached. Analysis proceeded to the point of thematic saturation, defined as the stage where additional responses no longer yielded new themes but instead elaborated on established ones. Trustworthiness was addressed through Lincoln and Guba's criteria: credibility was enhanced via double-coding and iterative review; dependability was supported by systematic documentation of analytic procedures and maintenance of an audit trail; confirmability was ensured by grounding interpretations in the data and avoiding imposed meanings; and transferability was facilitated by providing detailed descriptions of the instructional setting, flipped classroom procedures, and participant characteristics.

Students' problem-solving skills were assessed through the Problem-Solving Questionnaire developed by Yang and Zhang (2017). The original instrument was translated into Persian and then subjected to minor cultural and contextual adaptations to ensure alignment with the educational setting of the present study. The adaptation process involved an initial forward translation, followed by linguistic and conceptual review to confirm clarity, appropriateness, and relevance of items within the context of the Inorganic Chemistry course. The finalized Persian version was subsequently evaluated, refined, and approved by four experts in science education and curriculum studies. The questionnaire contains four subscales:

1. Problem Understanding (5 items; e.g., “I can clearly understand the causes and consequences of a problem.”)

2- Problem Representation/Expression (4 items; e.g., “Others can clearly understand what I express about a problem.”)

3. Solution Implementation (6 items; e.g., “I always propose solutions for different problems.”)

4. Reflection (5 items; e.g., “After solving a problem, I check whether a better solution exists.”)

The questionnaire was administered collectively during a regular class session. Before distribution, the researcher explained the study’s objectives and completion procedure, emphasizing that responses would remain confidential and would not affect course grades. Participants were instructed to read each statement carefully and respond independently—without consulting peers—based on their personal perceptions and experiences. After the instructions, questionnaires were distributed and completed individually in a calm classroom environment under the researcher’s supervision. The administration required approximately 5–7 minutes. Throughout the process, the researcher ensured uniform testing conditions across students and, when clarification was needed, addressed only procedural issues without shaping response content. This protocol was intended to minimize response bias, improve accuracy, and strengthen the validity of the resulting data. All items were rated on a five-point Likert scale ranging from 1 (“Strongly Disagree”) to 5 (“Strongly Agree”). Subscale scores were calculated by summing responses to relevant items, and the total problem-solving score ranged from 20 to 100, where higher values indicate stronger perceived problem-solving competence. Internal consistency reliability was examined using Cronbach’s alpha and indicated excellent reliability for each subscale ($\alpha\_understanding = 0.893$, $\alpha\_expression = 0.902$, $\alpha\_execution = 0.921$, $\alpha\_reflection = 0.885$). These coefficients confirm that the adapted questionnaire provides a reliable measure of problem-solving skills for the present sample. Following coding, all quantitative data were entered into SPSS (Version 26). Prior to conducting inferential analyses, key statistical assumptions were examined. Normality of score distributions within each group was evaluated using the Shapiro–Wilk test, which indicated no significant departures from normality ($p > .05$). Homogeneity of variances between the flipped and traditional groups was assessed via Levene’s test, and the equal-variance assumption was satisfied across all comparisons ($p > .05$).

To compare academic achievement and problem-solving skills between groups, independent-samples t-tests were performed at three measurement occasions (pre-test, midterm, and final exam). This analytic strategy was selected because intact classes were used, and the study focused on cross-sectional group differences at each time point under baseline equivalence. Given that multiple comparisons were conducted over time, the potential inflation of Type I error was addressed. Accordingly, a Bonferroni-adjusted alpha level was applied for the three comparisons within each outcome ($\alpha\_adj = .05/3 = .0167$), and statistical inferences were interpreted against this adjusted criterion. In addition to statistical significance testing, effect sizes were calculated using Cohen’s d to estimate the magnitude of instructional effects. Because group assignment was quasi-experimental and class-based, baseline equivalence was confirmed through pre-test comparisons and all analyses were conducted at the student level; therefore, findings should be interpreted in relation to the study design. With respect to missing data, three participants were removed from the analyses due to incomplete participation (absence/incomplete questionnaire/missing one measurement). Consequently, only students with complete data across all waves were retained. At study onset, the flipped group comprised 49 participants and the control group 42 participants; after excluding three students from the flipped condition, final analyses included 46 students (26 males, 20 females) in the experimental group and 42 students in the control group. p-values are reported based on α = .05, while statistical significance for comparisons across time points was determined using the Bonferroni-adjusted threshold (α_adj = .0167).

## Results

To evaluate the impact of the flipped classroom on academic achievement, group mean scores on the pre-knowledge test (semester outset), midterm examination, and final examination were compared using independent-samples t-tests (Table 2). At the pre-test stage, the flipped and traditional groups demonstrated comparable achievement levels (Flipped: M = 57.8, SD = 6.3; Traditional: M = 58.2, SD = 6.5). The between-group difference was not statistically significant, t (86) = 0.312, p = 0.756, MD = −0.40, 95% CI [−3.12, 2.32], indicating baseline equivalence prior to the intervention. At midterm (Week 8), mean performance favored the flipped group (Flipped: M = 70.9, SD = 5.9; Traditional: M = 68.1, SD = 6.2). This difference reached statistical significance under the conventional alpha level, t (86) = 2.145, p = 0.036, d = 0.46, MD = 2.80, 95% CI [0.23, 5.37], reflecting a medium effect size. However, given the Bonferroni adjustment for multiple comparisons (α_adj = 0.0167), this midterm effect should be interpreted as marginal and therefore warrants cautious inference. By the final examination (Week 16), the achievement difference widened in favor of the flipped group (Flipped: M = 76.4, SD = 5.8; Traditional: M = 72.5, SD = 6.2). The between-group gap was statistically significant and remained robust under the Bonferroni-adjusted criterion, t (86) = 3.012, p = 0.003, d = 0.64, MD = 3.90, 95% CI [1.35, 6.45]. The medium-to-large effect size suggests a stable and cumulative advantage for flipped instruction over the course of the semester.

To examine the influence of flipped instruction on problem-solving skills, mean scores from the problem-solving questionnaire were compared between the flipped and traditional groups at the beginning of the semester, midterm, and final assessment points (Table 3). At pre-test, the two groups demonstrated comparable levels of problem-solving ability (Flipped: M = 54.1, SD = 7.1; Traditional: M = 53.6, SD = 6.8). The between-group difference was not statistically significant, t (86) = 0.337, p = 0.737, MD = 0.50, 95% CI [−2.45, 3.45], confirming baseline equivalence in problem-solving skills. At midterm, the flipped group again obtained higher mean scores; however, the difference did not reach statistical significance (Flipped: M = 61.7, SD = 6.5; Traditional: M = 59.2, SD = 6.9), t (86) = 1.734, p = 0.089, d = 0.37, MD = 2.50, 95% CI [−0.35, 5.35]. The small-to-medium effect size and confidence interval spanning zero are consistent with the non-significant finding at this stage. By the final measurement, problem-solving scores in the flipped group were significantly higher than those of the traditional group (Flipped: M = 68.5, SD = 6.2; Traditional: M = 65.1, SD = 6.6), t (86) = 2.489, p = 0.015, d = 0.53, MD = 3.40, 95% CI [0.68, 6.12]. This difference remained statistically meaningful under the Bonferroni-adjusted criterion (p < α_adj), indicating a moderate and progressively emerging improvement in problem-solving skills attributable to the flipped approach over the semester.

**Table 2-** Independent-samples t-test comparing academic achievement between groups across three time points.

| Time point | Flipped classroom (n = 46) M ± SD | Traditional (n = 42) M ± SD | t(86) | p | Cohen's d | 95% CI for mean difference (MD) | Sig (α_adj = 0.0167) |
|---|---|---|---|---|---|---|---|
| **Pre-test** | 57.8 ± 6.3 | 58.2 ± 6.5 | 0.312 | 0.756 | — | [−3.12, 2.32] | ns |
| **Midterm** | 70.9 ± 5.9 | 68.1 ± 6.2 | 2.145 | 0.036 | 0.46 | [0.23, 5.37] | ns |
| **Final exam** | 76.4 ± 5.8 | 72.5 ± 6.2 | 3.012 | 0.003 | 0.64 | [1.35, 6.45] | * |

**Table 3-** Independent-samples t-test comparing problem-solving skills between groups across three time points

| Time point | Flipped classroom (n = 46) M ± SD | Traditional (n = 42) M ± SD | t(86) | p | Cohen's d | 95% CI for mean difference (MD) | Sig (α_adj = 0.0167) |
|---|---|---|---|---|---|---|---|
| **Pre-test** | 54.1 ± 7.1 | 53.6 ± 6.8 | 0.337 | 0.737 | — | [−2.45, 3.45] | ns |
| **Midterm** | 61.7 ± 6.5 | 59.2 ± 6.9 | 1.734 | 0.089 | 0.37 | [−0.35, 5.35] | ns |
| **Final exam** | 68.5 ± 6.2 | 65.1 ± 6.6 | 2.489 | 0.015 | 0.53 | [0.68, 6.12] | * |

Note. df = 86 for all tests. Sig (α_adj) indicates significance after Bonferroni correction for three comparisons (α_adj = 0.05/3 = 0.0167). *p < α_adj; ns = not significant. MD = mean difference (Flipped − Traditional).

Thematic analysis of students' responses to the open-ended questions indicated that their experiences of the flipped classroom in Inorganic Chemistry were characterized by an interplay of cognitive, social, and motivational affordances, alongside several implementation-related constraints. Overall, participants portrayed flipped instruction as a format that redistributed learning opportunities across pre-class and in-class spaces, thereby enabling face-to-face sessions to focus on higher-order engagement and scientific interaction. From students' perspectives, this restructuring supported deeper and more durable learning. Within the theme of deeper learning and conceptual understanding, students repeatedly emphasized the value of self-paced preparation. They reported that the ability to view and revisit pre-class videos and resources multiple times reduced ambiguity surrounding abstract inorganic concepts and facilitated movement away from rote memorization toward grasping underlying rationales and conceptual relations. In-class engagement with complex exercises was described as a stabilizing process that consolidated and clarified conceptual learning. In relation to growth in problem-solving skills and enhanced critical thinking, students noted that the readiness quizzes at the start of sessions, followed by multistep problem-solving in small groups, compelled them to analyze solution pathways, compare alternative strategies, and identify errors in reasoning. Participants further highlighted the role of immediate instructor feedback in refining their approaches. They also described simulations and authentic problem contexts as supportive of scientific inference and as encouraging more critical evaluation of proposed answers. The theme of social learning and collaboration reflected students' perceptions that flipped instruction created conditions for substantive teamwork. They referred to role distribution within groups, peer teaching, scientific discussion, and the need to articulate and defend ideas as central learning experiences. Such processes were viewed as enhancing not only disciplinary understanding but also broader competencies, including scientific communication, concise presentation, and constructive engagement with diverse viewpoints.

Under affective–motivational outcomes, students reported increased confidence, self-efficacy, and sustained motivation to participate in a demanding course. They associated active involvement and timely feedback with more positive attitudes toward difficult chemistry topics and with greater willingness to persist in learning. Despite these benefits, the distinct theme of implementation challenges and barriers revealed that perceived effectiveness was strongly contingent on students' pre-class preparation and self-regulatory capacity. Participants identified pre-class workload and time pressure, stress related to the opening quizzes, uneven readiness among group members, and limitations in internet access or digital tools as salient obstacles. Some students also expressed concern about equity and fairness in evaluating classroom participation. Collectively, these findings suggest that optimizing flipped classroom implementation requires maintaining concise and purposefully targeted pre-class materials, employing low-pressure yet accountability-oriented readiness structures, organizing heterogeneous groups with role rotation, and ensuring offline or alternative access to preparatory resources.

**Table 4-** Main Themes, Subthemes, and Initial Codes Extracted from Students' Open-Ended Responses.

| Initial Codes | Subtheme | Main Theme |
|---|---|---|
| • **Controlling study pace**<br>• **Pausing and replaying content**<br>• **Watching videos multiple times**<br>• **Learning at a preferred time** | Self-paced and reviewable learning | Deeper Learning and Conceptual Understanding |
| • **Clarifying ambiguities before class**<br>• **Making prerequisites clearer**<br>• **Greater mental readiness for class** | Reduced confusion about abstract concepts | |
| • **Understanding reasons behind phenomena**<br>• **Explaining why reactions occur**<br>• **Conceptual learning** | Shift from memorization to understanding 'why' | |
| • **Linking across chapters**<br>• **Building a coherent mental model**<br>• **Categorizing concepts** | Connecting concepts | |
| • **Applying concepts**<br>• **Guided practice**<br>• **Immediate correction of errors** | Consolidation of learning in class | |
| • **Correcting solution paths**<br>• **Explaining common errors**<br>• **Socratic guidance** | Immediate instructor feedback | Social Learning and Collaboration |
| • **Solving complex problems**<br>• **Continuous practice**<br>• **Using data in solutions** | Practice with multi-step problems | Growth in Problem-Solving Skills |
| • **Learning multiple methods**<br>• **Comparing solutions**<br>• **Selecting better strategies** | Diverse solution strategies | |
| • **Smoother calculations**<br>• **Fewer errors**<br>• **Time management** | Improved accuracy/speed | |
| • **Asking why/how questions**<br>• **Skepticism toward ready-made answers** | Questioning | Critical and Scientific Thinking |
| • **Evaluating reasoning**<br>• **Identifying faulty assumptions**<br>• **Defending answers** | Critiquing solution paths | |
| • **Changing variables**<br>• **Observing outcomes**<br>• **Evidence-based inference** | Analyzing simulations | |

| | | |
|---|---|---|
| • Analyzing articles<br>• Applying concepts to real problems | Linking to reality/research | |
| • Stable groups<br>• Taking on roles<br>• Shared responsibility | Role distribution | Social Learning and Collaboration |
| • Explaining concepts to peers<br>• Learning through teaching | Peer teaching | |
| • Conceptual dialogue<br>• Reaching agreement<br>• Tolerating opposing views | Scientific discussion | |
| • Brief presentations<br>• Public defense of solutions | Presentation skills | |
| • Sense of capability<br>• Courage to ask questions<br>• Reduced fear of mistakes | Confidence and self-efficacy | Affective–Motivational Outcomes |
| • Regular course engagement<br>• Interest<br>• Sense of progress | Motivation to follow the course | |
| • Long study time<br>• Pressure due to overlap with exams | Pre-class workload | Implementation Challenges and Barriers |
| • Need for discipline<br>• Falling behind quickly<br>• Time management | Dependence on self-regulation | |
| • Anxiety from frequent assessments<br>• Fear of being unprepared | Quiz-related stress | |
| • Different readiness levels<br>• Slower group work | Group heterogeneity | |
| • Weak internet<br>• Difficult downloads<br>• Studying on a phone | Internet/device problems | |
| • Subjectivity of participation grades<br>• Disadvantaging quieter students | Concerns about assessment fairness | |

## Discussion

The present study investigated the effectiveness of flipped instruction on pre-service teachers' academic achievement and problem-solving skills in an undergraduate Inorganic Chemistry course, and further examined participants' perceptions and lived experiences of this instructional approach. Quantitative results demonstrated that the experimental and control groups were equivalent at the outset of the semester in terms of both chemistry pre-knowledge and problem-solving skills, with no statistically significant baseline differences. As the semester progressed, students in the flipped condition achieved significantly higher academic performance at both midterm and final assessments, with effect sizes ranging from moderate to moderately high. This trajectory implies that the benefits of flipped learning accumulated over time rather than reflecting a transient performance boost. Regarding problem-solving skills, although midterm mean scores favored the flipped group, the difference was not statistically significant; however, by the end of the semester, a significant and stable advantage emerged, indicating a progressively developing effect of flipped instruction on problem-solving competence. Qualitative findings provided an explanatory layer for these quantitative patterns. Students primarily framed their flipped classroom experiences in terms of deeper conceptual learning, development of higher-order cognitive capacities (particularly problem-solving and critical thinking), strengthened teamwork and communication skills, and enhanced motivation and confidence. At the same time, they identified practical constraints—including pre-class time pressure, the reliance of success on self-regulation, and technological limitations—that moderated the effectiveness of the approach. Each of these quantitative and qualitative outcomes is elaborated in the following sections.

The achievement gains observed in the flipped classroom group can be interpreted through mechanisms related to the redistribution of learning activities across pre-class and in-class phases. By shifting initial content engagement to the pre-class space, classroom time was freed for active knowledge use, guided practice, and timely feedback—processes that are central to mastering complex inorganic chemistry concepts. Students' accounts indicated that pre-class preparation enabled them to approach classroom activities with greater familiarity and confidence, allowing in-class time to be used for elaboration, clarification, and consolidation rather than first-time comprehension. Self-paced pre-class learning also appeared to support achievement by helping students manage the cognitive demands of the course. In this respect, pre-class engagement helped students construct an initial conceptual framework and enter class with greater mental readiness. Once this framework was in place, classroom activities emphasized higher-order cognitive processes, such as analyzing complex cases and integrating conceptual relationships. The routine use of brief quizzes followed by targeted clarification of common errors established a continuous formative-feedback cycle. This structure promoted regular preparation and enabled instructional emphasis to be adjusted in response to students' needs. Finally, the structure of in-class tasks—particularly multistep collaborative problem-solving—required students to apply concepts across varied contexts. These combined mechanisms provide a plausible explanation for why the performance difference between groups was more pronounced at the final assessment than at midterm.

The development of problem-solving skills followed a gradual trajectory, with significant between-group differences emerging only at the end of the semester. This pattern is educationally plausible given that problem-solving in chemistry is a complex competence that develops through repeated practice rather than immediate exposure to instructional content. Problem-solving requires learners to interpret problem conditions, select strategies, execute multistep solutions, and evaluate outcomes—processes that stabilize over time. In the present study, students in the flipped condition engaged regularly in collaborative problem-solving, with the instructor adopting a facilitative role that emphasized questioning and strategic guidance. Qualitative evidence suggested that students gradually improved in articulating reasoning, identifying errors, and revising solution approaches. The initially non-significant midterm results may also reflect an adjustment period during which students acclimated to the demands of flipped learning, particularly the expectation of consistent pre-class preparation. As preparation routines stabilized, the instructional affordances of the flipped approach became more fully realized, resulting in stronger problem-solving performance by the end of the semester.

Qualitative evidence indicated that flipped instruction supported the development of critical thinking and scientific reasoning. Students described engaging more actively with problems during class, requiring them to justify assumptions, evaluate solution pathways, and reflect on alternative approaches. In inorganic chemistry, where conceptual relationships are often reduced to memorization under passive instruction, these practices contributed to deeper conceptual engagement. In this sense, gains in critical thinking may operate as a mediating mechanism linking flipped instruction to improved achievement and problem-solving outcomes.

Collaboration emerged as a central feature of students' flipped classroom experiences. Participants described group work as facilitating the exchange of ideas, comparison of solution strategies, and shared responsibility for learning. These interactions were perceived as reducing anxiety and increasing willingness to participate. Beyond cognitive outcomes, flipped instruction influenced students' affective and motivational experiences. Students associated increased confidence and self-efficacy with regular engagement in problem-solving activities and with observing incremental progress over time. The classroom climate, which treated errors as opportunities for learning, encouraged participation and persistence. Students' experiences highlighted several challenges associated with flipped instruction, particularly the time demands of pre-class preparation and the strong dependence of in-class activities on learner readiness. Disparities in preparation within groups, technological limitations, and initial resistance to reduced lecturing were also noted. These findings underscore the importance of balancing pre-class workload, providing accountability structures that support preparation, and clearly communicating the pedagogical rationale for flipped instruction.

## Conclusion

Employing a convergent mixed-methods design, the present study demonstrates that implementing a flipped classroom in an undergraduate Inorganic Chemistry course can produce meaningful gains in students' learning outcomes, provided that instructional components are coherently designed and students' pre-class readiness is actively supported. Quantitative evidence showed that the flipped group outperformed the traditional group on both midterm and, more substantially, final-exam achievement, with the performance gap widening by semester end. This pattern suggests a gradual and cumulative influence of flipped instruction on conceptual learning and success in problem-based assessments. In parallel, results from the problem-solving scale indicate that flipped learning enhanced not only final performance indicators but also the quality of students' learning processes and their capacity to engage with complex chemical tasks. Qualitative findings offered an explanatory complement to these outcomes, indicating that students experienced the flipped classroom as a setting for deeper and more active learning. Participants reported that self-paced preparation and repeated engagement with pre-class resources reduced confusion surrounding abstract concepts and enabled them to enter face-to-face sessions with stronger cognitive readiness. During class, sustained attention to multistep problem-solving, conceptual dialogue, and immediate feedback was perceived as central to the development of problem-solving competence and to cultivating a more critical orientation toward solution pathways. Students also highlighted the contribution of social learning—particularly collaborative work and peer explanation—as well as affective–motivational gains such as heightened self-efficacy and confidence. Taken together, these converging strands of evidence indicate that the value of flipped instruction does not lie merely in relocating content delivery outside class, but in transforming classroom time into a context for higher-order reasoning and scaffolded practice. At the same time, qualitative results underline that flipped learning does not yield benefits automatically; its effectiveness is conditioned by implementation constraints. Students identified pre-class workload pressure, anxiety associated with readiness quizzes, uneven preparedness within groups, and limited internet or device access as factors that can impede learning. Accordingly, flipped instruction is likely to be most effective when pre-class materials remain concise, purposeful, and manageable; readiness assessments are low-stakes and diagnostic rather than punitive; group collaboration is structured through transparent, rotating roles; and flexible access options—including low-bandwidth or offline resources—are available to all learners. Continuous support for self-regulation and time management across the semester is likewise essential to prevent students from falling behind in the preparatory phase. From a teacher-education perspective, the findings suggest that experiencing flipped learning in a conceptually demanding course such as Inorganic Chemistry may extend beyond subject-matter achievement and contribute to pre-service teachers' professional development as active, forward-looking learners. In addition to strengthening disciplinary understanding, students in flipped environments gain practice in key 21st-century competencies—problem-solving, scientific interaction, teamwork, and confidence in articulating chemical ideas—that are foundational for designing learner-centered classrooms in their future teaching careers. Finally, future research with broader samples and across other chemistry or foundational science courses is recommended to examine the long-term sustainability of flipped effects (retention and transfer) and to investigate individual-difference moderators such as self-regulation, digital literacy, and learning approaches. Such work can refine evidence-based models for effective flipped classroom implementation in higher education and teacher-preparation settings.

## Conflict of Interest

The authors have declared no conflicts of interest.

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