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# A FLIPPED CLASSROOM MODEL IMPLEMENTATION TOWARDS PROFESSIONAL DEVELOPMENT IN BIOLOGY TEACHING

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**Abstract**

This study, conducted at Shymkent University, evaluated the effectiveness of the Flipped Classroom (FCR) paradigm compared to Conventional Lecture-based Learning (CLL) in teaching biology to third-year clinical pedagogy students. A total of 109 students participated in the study. The FCR model incorporated pre-class preparation, collaborative group projects, and reflective discussions to foster critical thinking, independent problem-solving, and learner autonomy. Initial assessments revealed that students in the FCR group significantly outperformed their CLL counterparts in exam performance, analytical reasoning, and communication skills. Furthermore, FCR students demonstrated stronger application of foundational knowledge in subsequent, practice-oriented courses. While long-term knowledge retention did not differ significantly between groups, the FCR cohort expressed higher levels of engagement and satisfaction. Despite challenges—such as the reliance on GPA for group formation and insufficient evaluation of lifelong learning skills—the findings underscore the transformative potential of FCR in pedagogy education. By promoting active learning and equipping students for professional and lifelong development, the FCR model offers a robust framework for modernizing teacher training in the clinical sciences.

***Keywords –*** Flipped classroom, Professional development, Biology teaching and conventional learning.

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## 1. Introduction

To address the evolving interdisciplinary demands of contemporary education, there is a growing need for paradigm shifts in teaching methodologies. Traditional lecture-based learning (CLL), which primarily relies on the passive transmission of information from teacher to student, often fails to cultivate critical competencies such as active engagement, independent thinking, and self-directed learning. These limitations are particularly evident in professional and laboratory-based education, where the integration of theoretical knowledge with practical application is essential for skill development and professional readiness (Ji et al., 2022; Shen et al., 2022; Tang et al., 2017)

In response to these challenges, the flipped classroom (FC) paradigm has emerged as a promising pedagogical approach. By inverting the conventional lecture–homework structure, the FC model allows students to engage with instructional content independently before class, thereby freeing classroom time for higher-order learning activities such as applied problem-solving, discussion, and collaborative projects (Hossain, 2020; Oudbier et al., 2022). Empirical research suggests that this approach fosters deeper student engagement, enhances intrinsic motivation, and promotes active participation in the learning process (Barral et al., 2018; Nguyen & Oudeyer 2012).

The effectiveness of the flipped classroom model is further amplified when combined with collaborative learning (CL). Collaborative learning emphasizes shared responsibility, teamwork, and peer interaction, fostering both cognitive development and essential soft skills such as communication, leadership, and cooperation, while reinforcing personal accountability (Reinoso-Tapia et al., 2024; Kang & Kim, 2021). The integration of FC and CL gives rise to the Flipped Classroom with Reflection and Collaboration (FCR) model, which is particularly well suited to disciplines such as biology, where experimentation, data analysis, and interdisciplinary problem-solving are fundamental components of professional practice (Ji et al., 2023; Gopalan & Klann, 2017; Kibble et al., 2016).

In biology education—especially at the professional level—equal emphasis must be placed on conceptual understanding and practical application. Laboratory-based courses provide an ideal environment for implementing student-centered approaches, as they inherently require critical thinking, experimentation, and active engagement. The FCR model addresses these demands by fostering inquiry, collaboration, and analytical reasoning within the learning process (Johnson, 2024; Malekigorji & Hatahet, 2020).

Moreover, biology laboratory curricula often involve complex technical procedures, including electrophoresis, polymerase chain reaction (PCR), and nucleic acid extraction. Mastery of these techniques requires not only hands-on skills but also a deep understanding of the underlying theoretical principles. The FCR approach enables students to familiarize themselves with theoretical and procedural aspects of laboratory methods prior to class, allowing in-class time to be devoted to collaborative experimentation, data interpretation, and real-time problem solving. This active learning structure enhances scientific reasoning and better prepares students for clinical and research-oriented careers (Dehghanzadeh & Jafaraghaee, 2018; Gopalan & Klann, 2017; Kibble et al., 2016).

Although the flipped classroom model itself is not new, the novelty of the present study lies in the systematic integration of structured collaboration and guided reflection as core, interdependent components of the instructional design. Unlike many existing flipped classroom implementations, where collaboration and reflection are treated as supplementary or optional activities, the proposed FCR model intentionally embeds these elements throughout the pre-class, in-class, and post-class phases. This integrated design explicitly targets metacognitive development, cooperative learning, and professional competencies, thereby extending traditional flipped classroom approaches and offering a more holistic framework for biology and pedagogy education (Lin & Lin 2023; Kang & Kim, 2021).

A growing body of research provides empirical support for the effectiveness of the FCR approach. Previous studies demonstrate that FCR-based instruction improves students' critical thinking, collaborative skills, and overall academic performance, particularly in professional and laboratory-based training contexts (Nguyen & Oudeyer, 2012; Reinoso-Tapia et al., 2024). Longitudinal evidence further indicates that students exposed to FCR instruction show stronger retention of knowledge and perform better in subsequent courses that build upon foundational competencies, which is especially relevant in cumulative disciplines such as biology and medical sciences (Ji et al., 2023; Malekigorji & Hatahet, 2020; Joseph et al., 2021; Della-Rata, 2015).

In parallel, broader STEM education research highlights the importance of contextual and instructional factors in determining learning outcomes. A large-scale meta-analysis of STEM interventions shows that while cognitive outcomes often improve substantially, gains in practical and non-cognitive skills vary depending on factors such as academic level, instructional approach, duration of intervention, and class size (Cao et al., 2025). Similarly, research on multiple external representations in STEM learning suggests that appropriately designed combinations of visual and textual materials can enhance learning efficiency, though their effectiveness depends on learner characteristics and instructional support (Rexigel et al., 2024).

Further insights are provided by studies employing learning analytics, which emphasize the multifaceted nature of student persistence and performance in STEM education. These studies highlight the role of motivational, self-regulatory, and institutional factors in shaping learning trajectories and underscore the need for adaptive, data-informed instructional strategies (Li et al., 2022). Complementary evidence from meta-analyses on computer-based scaffolding demonstrates consistent positive effects on cognitive performance during problem-centered learning tasks in STEM contexts, regardless of scaffold type or adaptation strategy (Belland et al., 2017).

In the context of rapid scientific and technological development, STEM education has gained increasing importance due to its focus on interdisciplinary knowledge, critical thinking, and real-world problem solving. Digital technologies play a growing role in enhancing educational quality and student motivation. Among these, augmented reality (AR) has attracted particular attention for its potential to integrate virtual objects into real learning environments, thereby enriching instructional experiences. Research indicates that AR can support deeper conceptual understanding, increased engagement, and improved learning outcomes, particularly in science and engineering education, while also presenting implementation challenges related to technical infrastructure and teacher preparedness (Sırakaya & Alsancak-Sırakaya, 2022; Li et al., 2020; Xu & Ouyang, 2022; Kayan-Fadlelmula et al., 2022; Oudbie et al., 2022**)**.

Taken together, these findings highlight the evolving demands of modern educational systems, which increasingly emphasize lifelong learning, adaptability, and professional competence. In this regard, the FCR model aligns closely with contemporary educational priorities by fostering active engagement, self-directed learning, and collaborative problem solving. These competencies are especially valuable for students preparing for careers in biology, medicine, and other knowledge-intensive fields. The subsequent sections of this paper present the methodology, results, and discussion in detail, outlining the implementation of the FCR and CLL models, the evaluation of learning outcomes, and the implications of the findings for professional education (Hamdan et al., 2013; Hew & Lo, 2018; Han & Klein, 2019).

## 2. Purpose of the Research

The primary aim of this research is to assess the effectiveness of the Flipped Classroom with Reflection and Collaboration (FCR) model in fostering professional development among students enrolled in a biology laboratory course.

Specific Objectives:

- To compare the FCR model with the traditional Conventional Lecture-based Learning (CLL) approach by analyzing key indicators of immediate learning outcomes, including test scores and laboratory skill performance.
- To evaluate students' retention of learned material and their performance in subsequent, conceptually related courses following exposure to the FCR model.
- To investigate students' perceptions of the FCR model, particularly regarding its impact on classroom engagement, analytical thinking, and collaborative learning.

An important aspect of the originality of this study lies in the implementation of the Flipped Classroom with Reflection and Collaboration (FCR) model within the context of biology education in Kazakhstan. This context is characterized by a predominantly teacher-centered instructional tradition and limited systematic use of reflective and collaborative learning practices. Investigating the FCR model under these conditions extends existing flipped classroom research beyond commonly studied educational settings and provides insight into how student-centered pedagogies function in non-Western higher education environments.

### 2.1. The Research's Importance

This study contributes to the growing body of literature on innovative pedagogical practices in higher education, particularly within the context of STEM and laboratory-based instruction. While much of the existing research has focused on theoretical courses or non-STEM disciplines, this study addresses a critical gap by evaluating the effectiveness of the Flipped Classroom with Reflection and Collaboration (FCR) model in biology laboratory settings (Joshi & Deshpande, 2010). The findings not only offer practical insights into adapting flipped classroom methodologies for experimental and applied sciences, but also provide broader implications for professional education.

Supporting evidence from recent scholarship reinforces the relevance of this work. For example, a systematic review and meta-analysis by Cao et al. (2025) synthesizes 66 experimental and quasi-experimental studies published between 2000 and 2024, concluding that STEM education has a moderately positive effect on learning outcomes overall. However, the strength of this effect varies considerably depending on contextual factors. The most substantial improvements occur in cognitive outcomes—especially among high school students—whereas gains in non-cognitive outcomes and practical skills are smaller. Effectiveness is also mediated by sample size, academic level, subject area, duration of intervention, and instructional approach, with problem-oriented learning and small class sizes generating the strongest results. The authors emphasize that a single aggregated effect size masks important differences and that successful STEM initiatives require tailoring to learner needs and educational contexts (Cao et al., 2025).

Similarly, the meta-analysis by Rexigel et al. (2024) examines how the use of more than two external representations in STEM education (e.g., graphs, diagrams, formulas, images, and text) influences learning and problem-solving. The findings indicate that, under appropriate conditions, multiple complementary representations—up to a limit of about six—can significantly enhance learning efficiency without increasing instructional time, with four representations often yielding the strongest improvement. Nonetheless, the benefits depend on moderating variables such as learners' academic level, the nature of the representations, informational redundancy, and the degree of instructional support, suggesting that multiple representations can either facilitate or hinder learning depending on the educational context (Rexigel et al., 2024).

Further research using learning analytics offers another perspective on effective STEM instruction. A systematic review of 59 empirical studies demonstrates that learning analytics is predominantly used to predict academic performance, identify at-risk students, and forecast dropout risk using institutional learning data and, occasionally, self-report measures such as motivation, self-efficacy, and self-regulation. The review identifies seven categories of factors that influence persistence in STEM, underscoring the complex and multidimensional nature of student retention. The authors argue that learning analytics can meaningfully support universities in improving retention, but call for more studies exploring the interactions among retention factors and refining predictive model features (Li et al., 2022).

Complementing these insights, a comprehensive meta-analysis of 144 experimental studies (333 outcomes) on computer-based scaffolding demonstrates that scaffolding consistently yields substantial positive effects on students' cognitive performance (overall Hedges' $g = 0.46$) during ill-structured, problem-centered learning tasks in STEM education. The strongest effects are observed at the principles-level of assessment and among adult learners. Importantly, no significant variation was found based on whether scaffolding was faded, added, or left unchanged over time, nor between generic and context-specific scaffolds—suggesting broad flexibility in scaffold design. Overall, computer-based scaffolding emerges as an effective and adaptable instructional intervention across learner characteristics and pedagogical contexts (Belland et al., 2017).

In the context of the rapid development of science and technology, STEM education (Science, Technology, Engineering, and Mathematics) has gained particular importance, as it aims to develop students' interdisciplinary knowledge, critical thinking skills, and ability to solve complex real-world problems. Modern educational systems increasingly turn to digital technologies as tools for improving the quality of education and enhancing student motivation. Among these technologies, augmented reality (AR) occupies a special place, as it allows virtual objects to be integrated into real learning environments, thereby enriching the educational process.

Research indicates that the use of augmented reality in STEM education contributes to a deeper understanding of abstract concepts, increased student engagement, and improved learning outcomes. A systematic review of scientific publications on this topic demonstrates a growing interest in AR technologies in recent years, particularly in school education, where they are predominantly applied in natural science and engineering disciplines. At the same time, despite the identified advantages, the literature also highlights certain challenges and limitations associated with the implementation of AR, including technical difficulties and teachers' readiness to adopt new technologies.

In this regard, further investigation of the potential of digital technologies in STEM education is highly relevant, as well as the analysis of existing studies in order to identify key trends, benefits, and challenges related to their application in educational practice (Sırakaya & Alsancak-Sırakaya 2022; Li et al., 2020; Xu & Ouyang, 2022; Kayan-Fadlelmula et al., 2022; Oudbier et al., 2022).

Taken together, these research findings highlight the evolving demands of modern educational systems, which increasingly emphasize lifelong learning and professional adaptability. In this regard, the FCR model aligns well with current priorities by fostering essential competencies such as active engagement, self-directed learning, and collaborative problem solving. These skills are especially valuable for undergraduates preparing for careers in medicine, biology, and other knowledge-intensive fields. The subsequent sections of this paper outline the methodology, results, and discussion in detail. The methodology section describes the selection of participants, the structure and implementation of the FCR and CLL models, and the evaluation tools used to assess learning outcomes. The results section presents comparative data on academic performance, skill acquisition, and knowledge retention. Finally, the discussion critically examines the implications of the findings, highlights both the strengths and limitations of the FCR approach, and proposes recommendations for its application in professional education (Hamdan et al., 2013; Hew & Lo 2018).

Through its focus on biology curricula, this research aims to advance the discourse on evidence-based, student-centered teaching strategies and support the evolution of educational practices that meet the needs of future professionals (Han & Klein, 2019).

## 3. Methodology

To improve the clarity of the instructional design, a schematic representation of the Flipped Classroom with Reflection and Collaboration (FCR) model is provided in Figure 1. The diagram illustrates the structure of the model across the pre-class, in-class, and post-class phases and highlights the integration of collaborative learning and reflective activities as core components of the learning process.

### 3.1. Study Participants

The study involved a total of 109 third-year pedagogy students enrolled in the College of Basic Medical Sciences at Shymkent University. The participants were undertaking a sixth-semester biology laboratory course and were recruited to compare the effectiveness of two instructional approaches: Conventional Lecture-based Learning (CLL) and the Flipped Classroom with Reflection and Collaboration (FCR) model.

Participants ranged in age from 19 to 21 years and comprised 61% women and 44% men. Students were randomly assigned to either the CLL group (n = 54) or the FCR group (n = 55). Baseline academic performance was assessed using Grade Point Average (GPA) on a 4-point scale. The mean GPA for students in the CLL group was 3.45 ± 0.26, and for the FCR group, it was 3.42 ± 0.23. Statistical analysis revealed no significant difference between the groups in terms of prior academic performance (P = 0.585), ensuring comparability.

The study was conducted in accordance with ethical standards. Participants were assured of anonymity, and informed consent was obtained voluntarily from all students prior to their inclusion in the study.

The experimental (FCR) and control (CLL) groups were organized under comparable instructional conditions in terms of curriculum content and total instructional time. Both groups completed the same biology topics; however, the instructional design differed significantly.

The experimental group followed the FCR model, which combined pre-class independent study with in-class collaborative activities and structured reflective tasks. The control group was taught using conventional lecture-based learning (CLL), with limited student interaction and no systematic reflection component.

In both groups, the number of instructional and laboratory hours was equivalent, ensuring that differences in learning outcomes could be attributed to the instructional approach rather than time-on-task.

### 3.2. Study Design

The biology laboratory course was composed of four core units: nucleic acid extraction, quantitative analysis, polymerase chain reaction (PCR), and electrophoresis. Each unit was designed to reinforce students' theoretical understanding, develop hands-on laboratory skills, and enhance their capacity for scientific problem-solving.

Both instructional groups—CLL and FCR—received identical course content, learning objectives, instructors, and instructional materials to ensure pedagogical consistency. All students followed a standardized course outline and used the same prescribed textbook throughout the study.

The course was delivered over a four-week period, with one 180-minute laboratory session per week. This uniform structure allowed for a reliable comparison of outcomes between the two instructional methods, isolating the influence of the teaching model as the primary variable.

To further guarantee internal validity, the study controlled for instructor effects, task complexity, and assessment methods across groups. Both groups completed the same laboratory assignments, performed the same experimental procedures, and were evaluated with identical rubrics. Students were not allowed to switch groups, and cross-group interaction related to laboratory content was discouraged to minimize treatment contamination. Attendance was monitored to ensure all participants were fully exposed to their assigned instructional condition.

### 3.3. Structure of FCR

The structure of the Flipped Classroom with Reflection and Collaboration (FCR) model is illustrated in Figure 1. Participants in the FCR group were organized into eight collaborative teams, each consisting of six to seven students. Teams were formed to ensure balanced distribution of gender and Grade Point Average (GPA), thereby promoting equity and minimizing group performance variability.

Prior to each class session, students accessed preparatory materials—including instructional videos, slideshows, reading texts, and discussion prompts—via the "Flip Classroom" application. This pre-class phase also included an Individual Readiness Assurance Test (IRAT), designed to assess students' understanding of the materials.

In class, one team was randomly selected to present their prepared content during the first 15 minutes. This was followed by a Team Readiness Assurance Test (TRAT), also lasting 15 minutes, to foster collaborative problem-solving and knowledge synthesis. Subsequently, the instructor facilitated a 30-minute guided discussion, during which key concepts were clarified, experimental procedures were explained, and critical learning points were reinforced.

Students then engaged in a 60-minute laboratory session, conducting hands-on experiments related to the weekly topic. Following the experiments, teams were given 5 minutes to analyse their findings collaboratively, followed by 5 minutes of feedback from the instructor to promote reflective learning and continuous improvement.

Post-class activities were supported via a WeChat group and the Flip Classroom app, through which students could submit laboratory reports, access supplemental materials, and participate in extended academic discussions. The proposed model framework is detailed in Figure 2, which depicts the sequential and integrative elements of the FCR learning cycle.

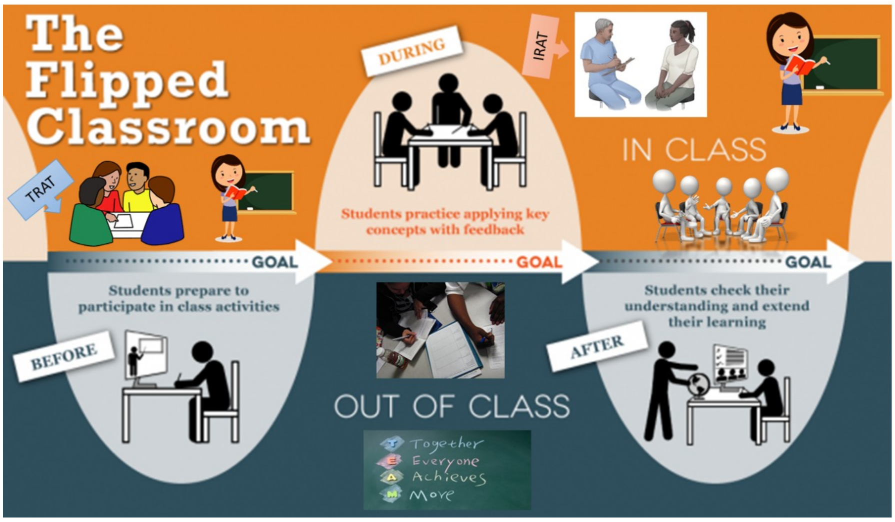


*Figure 1. Flipped class room model structure*

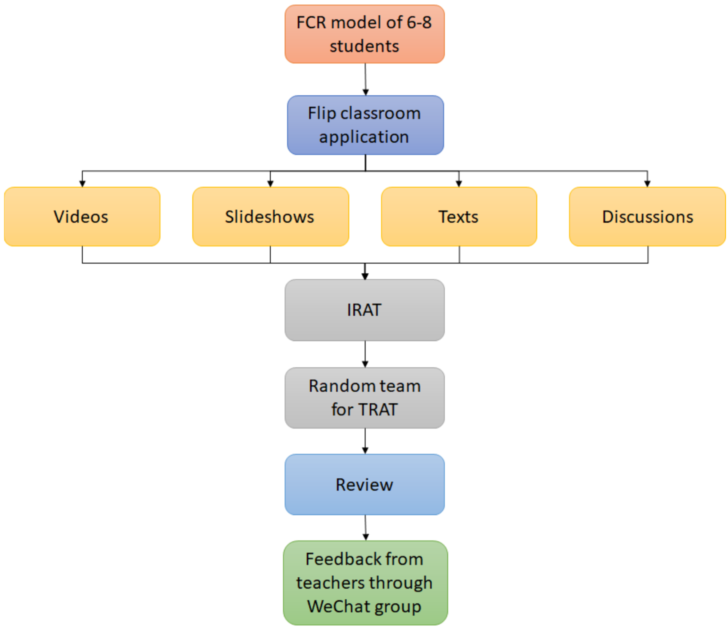


*Figure 2. FCR model architecture*

To further enhance understanding of the instructional process, an additional schematic overview of the Flipped Classroom with Reflection and Collaboration (FCR) model was developed and incorporated into the study as Figure X. The schematic summarizes the full learning cycle and its interdependent components across three stages: (1) Pre-class preparation, (2) In-class collaboration and laboratory engagement, and (3) Post-class reflection and consolidation.

The pre-class phase visualizes the flow from accessing digital learning materials to completing the Individual Readiness Assurance Test (IRAT). The in-class section depicts team presentations, the Team Readiness Assurance Test (TRAT), instructor-guided clarification, and application of knowledge during laboratory activities. The post-class stage illustrates the submission of laboratory reports, participation in reflective discussions, and ongoing interaction via the learning platform.

Figure 3 serves as a consolidated visual summary of learning objectives, cognitive processes, assessment checkpoints, and communication pathways, enabling clearer conceptualization of the instructional intervention and distinguishing the FCR method from the traditional CLL structure.

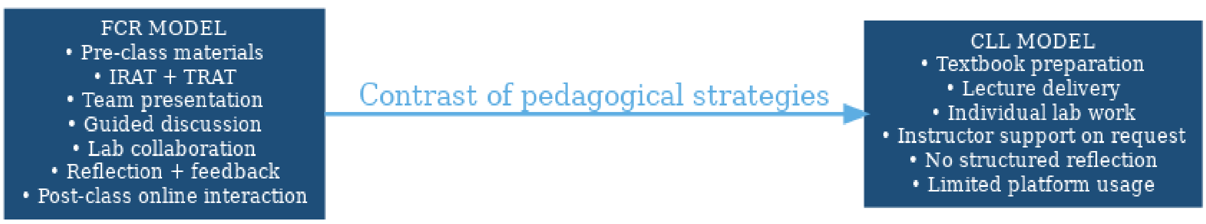


*Figure 3. Comparative diagram of the Flipped Classroom with Reflection and Collaboration (FCR) model and the Conventional Lecture-based Learning (CLL) approach, highlighting differences in instructional design, learner engagement, and feedback mechanisms.*

### 3.4. Structure of CLL

The Conventional Lecture-Based Learning (CLL) group followed a traditional instructional approach. Unlike the FCR model, students in this group engaged in independent pre-class study, reviewing the assigned textbook chapters and PowerPoint slides without structured group collaboration.

At the beginning of each laboratory session, the instructor delivered a comprehensive lecture that outlined the theoretical background, experimental procedures, and relevant safety protocols. This teacher-centered instruction served as the primary mode of knowledge delivery. Following the lecture, students conducted laboratory experiments individually or in ad-hoc pairs, without the use of formalized teams.

To mirror the time-on-task of the FCR group, the duration of the lecture and laboratory activities was equivalent across both groups. However, students in the CLL condition did not receive readiness assurance tests, did not participate in structured in-class presentations or group reflections, and received instructor guidance only when requested. No formative feedback mechanisms were embedded during experimentation, meaning reflection and collaboration occurred informally rather than intentionally.

Each session concluded with the submission of laboratory results, which were reviewed by the instructor. Although students in the CLL group did not participate in any pre-class team activities or structured discussions, they had access to the "Flip Classroom" application to review materials and ask questions. However, use of the platform in this group was limited to passive interaction, primarily for clarification of lecture content or procedural instructions.

### 3.5. Evaluation Methodology

The effectiveness of the instructional methods was evaluated using a combination of quantitative and qualitative assessment tools. At the conclusion of the course, all participants completed a final examination, which assessed their comprehension of core concepts, practical laboratory skills, and ability to apply theoretical knowledge. This exam served as a primary indicator of the immediate learning outcomes associated with the FCR and CLL models.

Additionally, students were asked to complete an anonymous post-course survey, designed to capture their levels of satisfaction, engagement, and perceived effectiveness of the instructional approach. The survey included Likert-scale and open-ended items to allow for both structured and narrative feedback.

To evaluate the long-term impact of the instructional methods, a follow-up assessment was conducted seven months after course completion. This second examination measured knowledge retention and the ability to apply previously learned material to advanced topics covered in later coursework, such as medical biotechnology and genetic diagnostics. This longitudinal approach provided insights into the sustained effectiveness of the FCR model in fostering durable learning and professional readiness.

### 3.6. Data Analysis

Statistical analysis was performed using IBM SPSS Statistics version 21. Descriptive statistics were reported as mean ± standard deviation (SD) for continuous variables, including GPA and examination scores. Independent t-tests were used to compare differences between the FCR and CLL groups. Statistical significance was set at $P < 0.05$.

Survey data were analyzed using a 5-point Likert scale, and internal consistency was assessed using Cronbach's alpha coefficient to ensure the reliability of the questionnaire. Additionally, chi-square ($\chi^2$) tests were employed to evaluate categorical survey responses and compare levels of satisfaction, engagement, and participation between groups, also applying a significance level of $P < 0.05$.

By providing a controlled comparison with conventional lecture-based methods, this study aimed to illustrate how the flipped classroom model may enhance the development of professional competencies in biology education.

# 4. Results

## 4.1. Evaluation of Test Results

The results of the final examination, as presented in Table 1, demonstrate significant differences in student performance between the Flipped Classroom with Reflection and Collaboration (FCR) model and the Conventional Lecture-Based Learning (CLL) approach. The differing instructional strategies had a notable impact on learning outcomes.

Students in the FCR group achieved higher average test scores, reflecting a deeper understanding of the course material. This outcome can be attributed to the model's emphasis on pre-class preparation, collaborative problem-solving, and iterative feedback mechanisms, all of which promote the development of both analytical and practical skills. The integration of real-world applications into in-class discussions and laboratory activities further enhanced their capacity to synthesize and apply knowledge.

In contrast, students in the CLL group, who primarily engaged with material through lecture-based delivery, tended to adopt a more surface-level approach to learning, often relying on rote memorization. This method may contribute to lower performance, particularly on assessment items that require higher-order thinking, conceptual integration, or the application of theoretical knowledge to novel scenarios.

Overall, the comparative analysis suggests that the FCR model offers a more effective instructional framework for developing critical thinking, content mastery, and durable knowledge retention, making it especially advantageous in biology education settings.

| Stage | FCR | CLL |
|---|---|---|
| Pre-Class | **Teacher Activities** | **Teacher Activities** |
| | Offer curated educational resources, including articles, videos, and assignments. | Develop reading assignments and lecture presentations. |
| | Develop team exercises and the Individual Readiness Assurance Test (IRAT). | Distribute pre-class study guides or reading materials. |
| | Develop activities and discussions that are team-oriented. | Develop a strategy for the delivery of lecture content. |
| | **Student Activities** | **Student Activities** |
| | Independently review the materials provided. | Evaluate textbooks and assigned readings. |
| | Finish any pre-class exams or assignments. | In preparation for subsequent instructor-led lectures, passively examine the content. |
| | Determine the areas in which there is a lack of knowledge to facilitate in-class discussions. | Emphasize the rote memorization of pre-class materials. |
| In-Class | **Teacher Activities** | **Teacher Activities** |
| | Lead team discussions and problem-solving exercises. | Deliver lectures to convey content. |
| | Conduct the IRAT and Team Readiness Assurance Test (TRAT). | Conduct the class in a one-way presentation format. |
| | Offer feedback and address any misunderstandings. | Respond to infrequent inquiries from students. |
| | **Student Activities** | **Student Activities** |
| | Participate in team discussions to resolve issues. | Follow the lecture by taking notes. |
| | Engage in TRAT and group exercises. | Respond to the instructor's inquiries. |
| | Work together to apply theoretical concepts to real-world situations. | Information is passively absorbed without active engagement. |

| Stage | FCR | CLL |
|---|---|---|
| Post-Class | **Teacher Activities** | **Teacher Activities** |
| | Evaluate the performance of the team and offer feedback. | Evaluate assessments or assignments. |
| | Create additional assignments or activities that are contingent upon the results of the class. | Develop the subsequent lecture in accordance with the syllabus's advancement. |
| | **Student Activities** | **Student Activities** |
| | Evaluate the feedback received and identify areas in which knowledge deficits exist. | Review lecture notes and prepare for examinations. |
| | Finalize any assignments or research that were assigned after the class. | Finish any assignments that have been assigned. |
| | Develop inquiries for forthcoming team meetings. | Conduct individual research without the assistance of a peer. |

*Table 1 Differences in structure between the traditional lecture-based model of instruction and the flipped classroom approach that uses collaborative learning for students*

### 4.2. Examining Student Competencies in Comparison

The Flipped Classroom with Reflection and Collaboration (FCR) and Conventional Lecture-Based Learning (CLL) models foster fundamentally different learning environments, which in turn shape student competencies in distinct ways.

During the pre-class phase, the FCR model encourages students to engage actively with a variety of curated educational resources, including articles, instructional videos, and guided assignments. This autonomous engagement supports self-directed learning and knowledge exploration, while formative assessments such as the Individual Readiness Assurance Test (IRAT) help students identify gaps in their understanding prior to class. In contrast, students in the CLL group typically prepare for lessons through passive review of lecture slides and textbook materials, which often emphasizes memorization and recitation over critical thinking or conceptual analysis.

The in-class phase further differentiates the two models. In the FCR group, interactive components such as the Team Readiness Assurance Test (TRAT) and collaborative problem-solving exercises foster the development of analytical reasoning, teamwork, and applied problem-solving skills. These activities promote an active learning environment centered on student engagement and discussion. Conversely, the CLL approach relies heavily on didactic lectures, with students primarily listening and taking notes. Opportunities for peer interaction or real-time application of knowledge are limited, which may hinder the development of higher-order thinking skills.

In the post-class phase, FCR students engage in reflective learning, revisiting feedback, clarifying misconceptions, and collaborating on reports or project-based tasks. This iterative process reinforces learning and supports the development of inquiry-based thinking and knowledge retention. In contrast, post-class engagement in the CLL model is typically confined to individual assignments and review, offering minimal opportunities for collaborative exploration or in-depth investigation.

Overall, the structured, student-centered environment of the FCR model appears to be more effective in cultivating key professional competencies, particularly in applied scientific fields such as biology, where critical thinking, collaborative learning, and practical application are essential.

| Competency | Teaching Strategy | Agree (n) | Neutral (n) | Disagree (n) | Cronbach's Alpha | P-Value |
|---|---|---|---|---|---|---|
| Critical Thinking Skills | FCR | 43 | 7 | 5 | 0.82 | 0.023 |
| | CLL | 31 | 10 | 13 | | |
| Teamwork and Collaboration | FCR | 49 | 4 | 2 | 0.84 | 0.012 |
| | CLL | 35 | 9 | 10 | | |
| Analytical Abilities | FCR | 46 | 6 | 3 | 0.83 | 0.019 |
| | CLL | 33 | 11 | 10 | | |
| Self-Directed Learning | FCR | 45 | 8 | 2 | 0.85 | 0.005 |
| | CLL | 30 | 12 | 12 | | |
| Communication Skills | FCR | 48 | 5 | 2 | 0.88 | 0.017 |
| | CLL | 36 | 8 | 10 | | |
| Practical Application of Concepts | FCR | 47 | 5 | 3 | 0.86 | 0.01 |
| | CLL | 34 | 10 | 10 | | |

*Table 2. Examining the skills that students in the two groups learnt through FCR and CLL lessons*

### 4.3. Students' Opinions on the FCR Method of Instruction

Student perceptions of the instructional approaches were evaluated through an anonymous post-course survey, and the results strongly favored the Flipped Classroom with Reflection and Collaboration (FCR) model across multiple professional competency domains. The findings, summarized in Table 2, indicate that students were more satisfied with the FCR model's capacity to enhance critical skills required for both academic success and future professional practice.

In the domain of critical thinking, 43 students in the FCR group agreed that the model helped them develop this competency effectively, compared to only 31 students in the CLL group. This difference was statistically significant ($p = 0.023$), with a strong reliability score (Cronbach's $\alpha = 0.82$), suggesting a consistent and meaningful advantage of the FCR model in promoting higher-order thinking.

Collaborative and teamwork skills were also rated more favorably in the FCR group, with 49 students expressing agreement, versus 35 in the CLL group ($p = 0.012$, $\alpha = 0.84$). This reinforces the model's strength in facilitating peer interaction and cooperative learning.

For analytical ability, 46 students in the FCR group reported positive development, supported by a significant p-value (0.019) and Cronbach's $\alpha = 0.83$. This suggests that the iterative and application-oriented nature of FCR promotes better analytical reasoning and problem-solving capacity.

The FCR model also excelled in supporting self-directed learning, with 45 students acknowledging this benefit, compared to fewer in the CLL group. The statistical analysis showed a highly significant difference ($p = 0.005$, $\alpha = 0.85$), affirming the model's emphasis on learner autonomy and independent engagement with course materials.

When evaluating communication skills, 48 students endorsed the FCR model as an effective tool for improving their ability to express ideas and collaborate, compared to 36 in the CLL group. This category achieved the highest internal reliability (Cronbach's $\alpha = 0.88$, $p = 0.017$), underscoring the FCR model's success in fostering verbal articulation and interpersonal interaction.

Finally, in terms of practical application of theoretical knowledge, 47 students in the FCR group reported a positive experience, significantly higher than in the CLL group ($p = 0.010$, $\alpha = 0.86$). This confirms the FCR model's effectiveness in bridging the gap between classroom theory and real-world practice, especially in applied scientific fields like biology.

Overall, the survey results demonstrate that the FCR model provides a more robust and holistic learning environment, effectively cultivating both academic and professional competencies in students.

### 4.4. A Flipped Classroom Model for Professional Development in Biology Teaching

The findings of this study reaffirm the Flipped Classroom with Reflection and Collaboration (FCR) model as a transformative instructional strategy, particularly within biology education. As presented in Table 2, the FCR model outperformed the Conventional Lecture-Based Learning (CLL) approach in developing a wide range of professional competencies essential for students' academic success and workforce preparedness.

In biology education, the ability to engage in critical thinking is paramount. The FCR model, through its active, student-centered learning environment, fosters deeper engagement with complex biological concepts. The significantly higher levels of student agreement and strong statistical reliability indicators suggest that this participatory structure facilitates more meaningful cognitive processing compared to passive lecture-based approaches.

Moreover, the FCR model strongly supports the development of collaboration and teamwork, skills that are indispensable in both academic and scientific research settings. Its emphasis on interactive group tasks and cooperative problem-solving reflects real-world practices in biological and medical sciences, thereby enhancing students' preparedness for future professional environments.

The FCR framework also enhances analytical competencies, particularly in evaluating and interpreting experimental data—an essential aspect of laboratory-based biology education. The combination of pre-class theoretical exploration and in-class discussions enables students to develop a more nuanced understanding of scientific methods and outcomes.

Importantly, self-directed learning, a cornerstone of lifelong scientific literacy, is notably reinforced in the FCR environment. By encouraging students to engage with instructional materials before class, the model promotes autonomy, initiative, and curiosity—qualities that align with the goals of modern biology instruction and continuing education.

In addition, communication skills are more effectively cultivated through the FCR model. Students are given multiple opportunities to articulate findings, discuss biological processes, and explain complex ideas clearly and confidently—key skills for both academic and professional success.

Finally, the FCR model excels at bridging the gap between theory and practice, a critical aim in biology education. Through hands-on experimentation paired with reflective learning, students are better able to apply conceptual knowledge in practical settings, reinforcing their understanding and skill development.

In sum, the FCR model not only improves immediate learning outcomes but also aligns more closely with the professional competencies demanded in biology-related careers. Its emphasis on interaction, application, and reflection makes it a valuable pedagogical framework for enhancing student engagement and educational quality in the life sciences.

### 4.5. Impact on Subsequent Courses

The effectiveness of the FCR model extended well beyond the immediate course, as evidenced by student performance across subsequent biology-related subjects during the seventh and eighth semesters. Students who had participated in the FCR-based biology laboratory course consistently outperformed their peers in advanced modules such as *Medical Biotechnology and Applications*, *Gene Diagnosis and Gene Therapy*, and *Introduction to Pedagogical Science Research*. These findings suggest that the FCR model not only supports short-term content mastery but also fosters deeper understanding and transferable skills that enhance learning in more complex and interdisciplinary courses.

This sustained academic success highlights the FCR model's strength in promoting long-term retention, conceptual integration, and application of biological knowledge. The ability to transfer foundational understanding to advanced coursework is a critical indicator of professional preparedness and academic maturity—further validating FCR as an effective pedagogical strategy for cultivating high-level competencies in biology education.

### 4.6. Advantages of the FCR Model

At South Kazakhstan Pedagogical University, undergraduate education emphasizes the development of creativity and independent thinking—objectives that are often unmet by traditional, instructor-centered teaching methods. Such methods, which rely heavily on passive information delivery, have proven less effective in fostering student engagement, critical thinking, and problem-solving skills. In contrast, the Flipped Classroom with Reflection and Collaboration (FCR) model empowers students by encouraging pre-class preparation, team-based learning, and reflective practice.

This student-centered approach not only enhances learning outcomes but also increases motivation and learning efficiency by blending flexibility with collaborative inquiry. The results of this study, particularly from clinical and laboratory-based biology courses, demonstrate that the FCR model significantly improves academic performance and competency development. These findings suggest that FCR represents a transformative shift in biology education, offering a scalable and effective framework for professional training in the life sciences.

### 4.7. Promoting Lifelong Learning

The Flipped Classroom with Reflection and Collaboration (FCR) model is particularly well-suited to preparing future doctors and healthcare professionals, for whom lifelong learning is an essential habit. By integrating pre-class assignments, interactive class discussions, and problem-solving tasks, the FCR approach systematically cultivates critical academic and professional competencies—namely analytical reasoning, critical thinking, and effective communication.

These competencies not only enhance students' academic performance but also equip them to confront real-world challenges in clinical practice and biomedical research. The long-term benefits of the FCR model were evident in this study, as students exposed to FCR demonstrated stronger performance in advanced coursework. This improvement was largely due to their ability to form deeper connections between theoretical concepts and practical applications, underscoring the model's effectiveness in fostering transferable, high-level skills essential for health professions.

### 4.8. Student Feedback and Challenges

Student feedback regarding the Flipped Classroom with Reflection and Collaboration (FCR) model was largely positive, as summarized in Table 3. A majority of respondents (70%) reported that the strategy increased their interest in learning, and 65% found the pre-class preparation helpful in enhancing their readiness for in-class activities.

| Survey Question | Agree (%) | Neutral (%) | Disagree (%) |
|---|---|---|---|
| The method enhanced my interest in learning. | 70% | 18% | 12% |
| Pre-class preparation was effective. | 65% | 22% | 13% |
| Collaborative discussions improved understanding. | 74% | 16% | 10% |
| The pace of the classroom was suitable. | 60% | 24% | 16% |
| Feedback from peers and teachers was helpful. | 78% | 14% | 8% |
| I contributed significantly to group activities. | 68% | 20% | 12% |
| The approach improved my independent learning. | 72% | 18% | 10% |
| I would choose this teaching method again. | 76% | 16% | 8% |

*Table 3. Feedback from FCR students*

Furthermore, 74% of students stated that collaborative discussions improved their understanding of course content, while 78% valued the feedback received from both peers and instructors. These findings highlight the perceived benefits of peer interaction and ongoing formative feedback in promoting comprehension and active engagement. Notably, 76% of students expressed willingness to use the FCR model in future courses, and 72% felt it promoted self-directed learning, reflecting alignment with the core goals of modern pedagogy in higher education.

However, some areas for improvement were identified. Approximately 24% of students expressed neutrality and 16% disagreed with the appropriateness of the classroom pace, indicating a need for better time management and adaptability to individual learning speeds. Additionally, 20% were ambivalent and 12% disagreed that all team members contributed meaningfully during group activities, suggesting a need for more structured facilitation of equitable participation.

Overall, the feedback indicates a high level of student satisfaction, with clear benefits in engagement, comprehension, and independent learning. Nonetheless, optimizing classroom pacing and ensuring **balanced team dynamics** will be essential for maximizing the effectiveness of FCR in future implementations.

## 5. Discussion

The role of reflection and collaboration within the FCR model should be interpreted in relation to the educational context in which the study was conducted. For many participants, reflective activities represented a shift from passive knowledge acquisition to active self-evaluation and metacognitive engagement. Likewise, collaborative tasks required students to assume shared responsibility for learning, which contrasted with their prior experience in lecture-based environments. These findings suggest that the effectiveness of the FCR model is partly explained by students' adaptation to new learning roles, rather than instructional design alone.

One of the primary objectives of ongoing reforms in South Kazakhstan's pedagogical education system is to nurture creative, research-oriented, and independent thinkers (Kirdasinova et al., 2016). Undergraduate pedagogy students are particularly well-positioned to develop critical thinking and scientific inquiry skills during their training. At South Kazakhstan Pedagogical University, laboratory-based courses serve as a vital platform for encouraging creativity and inquiry. However, the conventional structure of laboratory education, which often revolves around verification experiments and teacher-led procedures, tends to restrict student autonomy, creativity, and engagement (Wilson, Aronson, & Carlsmith, 2010).

The need for innovative pedagogical models in laboratory instruction is therefore urgent. Compared to traditional lecture-based methods, models such as the Flipped Classroom (FC) and Collaborative Learning (CL) promote greater student autonomy and motivation by providing flexible pre-class learning opportunities and encouraging team-based interaction (Garcia-Allen, 2020). By shifting content acquisition to the pre-class phase and dedicating classroom time to application, collaboration, and reflection, the FCR model restructures learning in a way that supports deeper conceptual processing while preserving laboratory rigor. Prior research has shown that FCR improves comprehension, retention, and performance in biomedical and clinical courses (Qu et al., 2024).

Our findings are consistent with this trend while adding nuance to it. Students taught using the FCR model demonstrated significant gains in both cognitive and practical competencies relative to the CLL group. These benefits appear to derive not simply from content reallocation, but from structured collaborative reflection (IRAT/TRAT and post-class feedback), which strengthens metacognitive awareness and knowledge integration. This supports the broader argument that cognitive and emotional engagement act synergistically in laboratory learning environments (Sikhymbaev et al., 2023).

Although many studies focus on short-term learning outcomes, our long-term assessment suggests that the durability of learning depends on the quality of conceptual grounding rather than the instructional model alone. While the final retention test did not reveal statistically significant group differences, students exposed to FCR demonstrated more coherent recall of foundational concepts and greater confidence in advanced subjects such as Gene Diagnosis, Gene Therapy, and Medical Biotechnology (Hilton & Pellegrino, 2012; Lawrence, 1992). These observations reinforce the idea that FCR contributes not only to immediate academic performance but also to students' readiness for more complex coursework.

Students reported high levels of satisfaction with the FCR method, noting the independence of pre-class preparation, the value of peer-supported discussion, and the motivational role of continuous formative feedback. This is consistent with the broader literature emphasizing the importance of social presence and active participation in shaping STEM learning experiences.

Despite the promising results, this study has limitations. Group formation based solely on GPA may have overlooked interpersonal and communication dynamics relevant to collaborative learning. Retention was evaluated primarily through exam performance, which does not fully capture skills such as creativity or problem-solving. Additionally, the limited sample size and study duration constrain the generalizability of the findings. Future studies should examine variables such as optimal video length, team composition, self-regulation strategies, and cognitive load to refine the design of FCR environments.

### 5.1. Limitations and Future Research

Although reflective practices were an integral component of the FCR model, the present study primarily relied on quantitative data. The qualitative inputs collected during implementation were limited and not intended for in-depth qualitative analysis. Future research may expand on the current findings by incorporating qualitative methods, such as reflective journals or interviews, to further explore the reflective dimension of the FCR framework

In conclusion, the FCR model offers a compelling framework for fostering active participation, critical thinking, and lifelong learning competencies among pedagogy students. The addition of a schematic visual representation of the FCR process (see Figure X) enhances conceptual transparency and supports replication of the model in future studies. Continued refinement and cross-context implementation remain essential for unlocking the full pedagogical potential of FCR in laboratory-based STEM education (Elrayies, 2017).

## 6. Conclusion

This study demonstrates that implementing the Flipped Classroom with Reflection and Collaboration (FCR) model can significantly transform biology laboratory instruction by shifting the learning emphasis from passive knowledge reception to active, student-driven engagement. Essential competencies for the academic and professional development of pedagogy students—critical thinking, problem-solving, collaboration, and autonomous learning—were effectively cultivated through structured pre-class preparation, collaborative group activities, and reflective discussions integrated into laboratory sessions.

Compared to the traditional Lecture-Based Learning (CLL) model, the FCR approach yielded higher examination scores and more advanced analytical and communication skills, confirming its capacity to improve immediate learning outcomes. Furthermore, the advantages of the model extended beyond the duration of the course: students who completed the FCR-based program demonstrated superior performance in subsequent advanced subjects, suggesting that the model strengthens the ability to transfer theoretical knowledge to practical and research-oriented contexts.

Although long-term knowledge retention did not differ significantly between the two groups, students exposed to FCR reported greater motivation, engagement, and satisfaction with the learning process. These qualitative benefits underscore the central role of active participation and self-directed pre-class study in shaping positive attitudes toward laboratory-based learning. At the same time, limitations such as group formation based solely on GPA and the absence of indicators related to lifelong learning, creativity, and metacognitive development suggest the need for further research and methodological refinement.

Overall, the findings indicate that the FCR model represents a robust and forward-looking instructional strategy that not only enhances academic performance, but also supports competencies essential for lifelong learning and professional adaptability. With continued refinement—such as more nuanced team-formation criteria, integration of digital learning analytics, and expanded evaluation metrics—the FCR approach has the potential to become a foundational pedagogical model across laboratory-based STEM disciplines, contributing to the modernization of higher education and the training of future educators and scientists.


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## Institutional Review Board Statement

The study was conducted in accordance with ethical standards, and all procedures involving human participants were approved by the academic council of South Kazakhstan Pedagogical University.

## Informed Consent Statement

Informed consent was obtained from all participants prior to their inclusion in the study.

## Declaration of Conflicting Interests

The authors declare that there are no known financial or personal conflicts of interest that could have appeared to influence the content or conclusions of this study.


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## Authors' contributions

Saltanat Zhaiynbayeva: conceptualization, methodology, investigation, writing – original draft preparation, supervision.

Asiya Maimataeva: data processing, methodology, validation, writing – review and editing.

Azhar Abubakirova: investigation, data curation, project administration.

Gulmira Khalikova: formal analysis, interpretation of data, visualization.

Gulzhakhan Utegenova: acquisition of funding, resources, supervision, writing – review and editing.

## Data availability

No data were generated or analyzed during this study.

## Use of Artificial Intelligence

The authors declare that they have used artificial intelligence for linguistic correction and style improvement. The software used was ChatGPT (OpenAI).

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