THE EFFECTIVENESS OF FLIPPED CLASSROOM TECHNOLOGY IN TEACHING THE TOPIC OF DISPERSE SYSTEMS IN CHEMISTRY EDUCATION

Gulzar U. Kaipnazarova

Chemistry Teacher, Secondary School No. 13

Phone: +998990411040; E-mail: qaypnazarovagulzar80@gmaul.ru

Abstract: The rapid digitalization of higher education has intensified interest in innovative pedagogical technologies capable of increasing student engagement and learning outcomes. This study examines the effectiveness of the flipped classroom model in teaching the topic of “Disperse Systems,” a foundational and conceptually demanding unit of general and colloid chemistry, to undergraduate chemistry students. A quasi-experimental comparative design was employed with thirty students divided into two intact groups of fifteen: a traditional lecture-based group and a flipped classroom group. In the flipped classroom, students studied theoretical material asynchronously at home through instructor-prepared video lectures, freeing classroom time for hands-on, competition-based laboratory experiments, virtual laboratory work in the “Unreal Chemist” simulator, and interactive exercises on the Learning Apps platform. Learning outcomes were assessed with a five-item multiple-choice test scored on a ten-point scale and evaluated through two standard pedagogical indicators: academic performance (the percentage of students achieving a passing score) and quality of knowledge (the percentage achieving a high score). The flipped classroom group demonstrated markedly higher results, with an academic performance rate of 93.3% and a knowledge quality rate of 66.7%, compared with 80.0% and 33.3%, respectively, in the traditionally taught group. These findings suggest that combining asynchronous video-based instruction with active, technology-supported classroom practice meaningfully improves both the pass rate and the depth of understanding among students learning disperse systems. Implications for chemistry curriculum design and recommendations for broader implementation are discussed.

Keywords: flipped classroom, innovative educational technology, disperse systems, colloid chemistry, chemistry education, academic performance, quality of knowledge

INTRODUCTION. Contemporary society is defined by continuous modernization and dynamism, and the education sector is no exception: sustainable development in any sphere of public life now presupposes the introduction of innovation into teaching and learning. In higher education specifically, the accelerating development of computer technology and telecommunication networks has created an entirely new environment for acquiring knowledge, shifting the traditional teacher-centered lecture toward more flexible, learner-centered, and technology-mediated formats. Innovative pedagogical methods are introduced primarily to help students adapt quickly to a rapidly changing world and to actively master knowledge rather than passively receive it; in doing so, they simultaneously cultivate critical thinking, creativity, collaborative skills, and stronger motivation for learning.

Among the innovative educational technologies that have gained the most traction internationally over the last two decades, the flipped classroom model occupies a prominent place. First developed in 2007 by two American high-school teachers, Jonathan Bergmann and Aaron Sams, as a way of supporting student-athletes who frequently missed class, the flipped classroom has since evolved into one of the leading pedagogical technologies of the twenty-first century [3]. Unlike purely distance-learning formats, the flipped classroom preserves face-to-face interaction between instructor and student while allowing learners to revisit recorded video material as many times as needed until a concept is understood, supplemented by additional communication channels such as email. Global search-interest data (e.g., Google Trends) confirm a steady increase in the number of educators adopting this model, reflecting its growing recognition as a response to international standards that call for greater use of technological tools in the classroom, the cultivation of learners’ critical thinking and digital literacy, and the development of independent problem-solving skills that go beyond rote memorization of material presented by the teacher.

The topic of “Disperse Systems” was selected as the content focus of this study because it represents one of the more conceptually demanding units within the general and colloid chemistry curriculum. Disperse systems require students to grasp an abstract quantitative concept (the degree of dispersion), to correctly classify heterogeneous systems — such as

aerosols, foams, emulsions, suspensions, and colloidal solutions — according to the aggregate states of their dispersion medium and dispersed phase, and to connect this classification to an observable optical phenomenon, the Tyndall effect. Because the topic combines abstract theory with phenomena that are best appreciated through direct observation and experimentation, it is particularly well suited to a pedagogical comparison between a traditional, lecture-centered approach and an approach that reallocates classroom time toward hands-on demonstration and inquiry.

Although a substantial body of international literature documents the benefits of the flipped classroom model for student engagement and achievement, comparatively few empirical studies have examined its application to specific, content-dense topics within colloid chemistry in the context of Kazakhstani higher education. Existing research on educational technology in Kazakhstan has tended to focus on the broader digitalization of higher education and on general barriers to and trends in e-learning adoption [8, 12, 13], leaving a gap with respect to topic-level, outcome-based evidence for specific chemistry subjects. The present study addresses this gap.

The aim of this study was to evaluate the effectiveness of flipped classroom technology, relative to traditional lecture-based instruction, in teaching the topic of “Disperse Systems” to undergraduate chemistry students, as measured by two standard indicators of learning outcomes: academic performance (the proportion of students attaining a passing test score) and quality of knowledge (the proportion of students attaining a high test score). It was hypothesized that students taught using the flipped classroom model would demonstrate higher academic performance and a higher quality of knowledge than students taught through the traditional format.

LITERATURE REVIEW. Innovation in Higher Education. The term “innovation” first entered scholarly discourse in the 1930s through the work of the Austrian economist Joseph Schumpeter and was subsequently developed by German scholars, initially in an economic sense denoting the introduction of new technology [6]. The concept migrated into educational theory only in the 1950s internationally, and did not enter post-Soviet pedagogical discourse until the late 1970s, making pedagogical innovation, relative to many

other applied fields, a comparatively young area of scholarship. In an educational context, innovation is best understood not as a wholesale replacement of existing practice but as the deliberate introduction of new methods, approaches, and skills capable of producing a genuinely new and beneficial result for the learner [1]. Educational innovation processes are frequently modeled as passing through a sequence of stages, from the emergence of an idea, typically arising from fundamental or applied research, through its transformation into a concrete product or model, its trial implementation and refinement, its dissemination across the wider educational community, and finally its maturation into an established, fully developed practice [7].

Researchers examining innovative methods in the university classroom have consistently emphasized that innovative and traditional approaches are not mutually exclusive but complementary: the task of the modern educator is to identify the optimal balance between the two, retaining the strengths of established, teacher-led instruction while incorporating the flexibility and learner autonomy that innovative technologies afford [2]. This principle of complementarity, rather than replacement, underlies the design of the present study, in which the flipped classroom model was not used to eliminate direct instructor contact but to relocate the delivery of theoretical content outside the classroom so that class time itself could be devoted to active, teacher-guided practice.

The Flipped Classroom Model. The flipped classroom inverts the conventional sequence of instruction: rather than encountering new material for the first time during a lecture and completing practice exercises independently at home, students engage with foundational theoretical content — most commonly through instructor-produced video lectures — before class, while classroom time is reserved for the application, discussion, and practical consolidation of that material under the teacher’s direct supervision [3]. This restructuring is intended to shift the locus of lower-order cognitive work, such as the initial acquisition of facts and definitions, to the home environment, where students may proceed at their own pace and revisit difficult segments as needed, while reserving scarce, high-value classroom time for higher-order tasks — experimentation, problem-solving, and collaborative discussion — that benefit most from immediate instructor feedback.

Within the growing literature on educational technology in Central Asia, several studies have documented both the momentum behind, and the obstacles to, digital and blended learning adoption in Kazakhstani higher education. Yerzhanova and Nurgaliyeva [12] examined the integration of technology into Kazakhstani classrooms and highlighted both the opportunities that digital tools present for student engagement and the infrastructural and training-related barriers that can limit their effective use. Ospanova and Mussina [8] similarly documented emerging trends in the application of information and communication technologies within Kazakhstani higher education, while Zhumabayeva and Zhaparova [13] catalogued the practical challenges universities face when implementing e-learning formats. Taken together, this body of work suggests that while the conditions for innovative, technology-supported pedagogy such as the flipped classroom are increasingly favorable in Kazakhstan, subject-specific empirical evidence of its effectiveness — particularly at the level of individual chemistry topics — remains limited, motivating the topic-focused approach adopted in the present study.

Theoretical Background: Disperse Systems. A disperse system consists of two essential components: the dispersed phase, the finely divided substance, and the dispersion medium, the substance throughout which the dispersed phase is distributed. Depending on the size of the particles constituting the dispersed phase, disperse systems are conventionally classified into coarse (macroscopic) systems, in which the number of atoms per particle exceeds 10^{18}; microheterogeneous systems, with particle atom counts above 10^{9}; and colloidal systems, in which particle atom counts fall within the intermediate range of roughly 10^{3} to 10^{9} [4, 11]. Systems in which the dispersed phase is broken down to the level of individual molecules or ions constitute true solutions, which, while representing the theoretical limit of dispersion, are traditionally treated as lying outside the object of study of colloid chemistry proper [5].

Colloidal systems are further classified according to the aggregate states of their dispersion medium and dispersed phase. Aerosols consist of solid or liquid particles dispersed in a gaseous medium, exemplified by fog and by smoke or dust. Foams consist of a gas dispersed in a liquid, as in an aqueous soap solution. Emulsions consist of one liquid

dispersed in another immiscible liquid, milk being the classic example. Suspensions consist of solid particles dispersed in a liquid, such as sand suspended in water, while colloidal solutions, or sols, occupy the upper boundary of dispersion at which the dispersed phase, though solid, no longer settles readily under gravity, protargol being a representative example [14]. Lyophobic sols of this kind can be produced either by dispersion — the mechanical breakdown of larger particles through grinding or ultrasonic treatment — or by condensation, the aggregation of molecules or ions into particles of colloidal dimensions [10].

A defining optical property of colloidal systems is the Tyndall effect — the visible scattering of a beam of light passing through a heterogeneous medium, which appears as a luminous cone in an otherwise dark colloidal solution. This phenomenon arises because the dispersed particles in a colloidal system are smaller than the wavelength of visible light and possess a refractive index different from that of the surrounding medium, causing incident light to scatter rather than pass through undisturbed [9]; the effect is named after the nineteenth-century physicist John Tyndall, who first characterized it, and its presence or absence provides students with an immediate, visually striking criterion for distinguishing colloidal systems from true solutions — a property that made it a natural centerpiece for the hands-on, competition-based classroom activities described below.

MATERIALS AND METHODS. **Research Design**. The study employed a quasi-experimental, comparative-group design conducted under real classroom conditions at L.N. Gumilyov Eurasian National University. Two intact student groups were assigned, respectively, to a traditional, lecture-based instructional format and to a flipped classroom format, and their learning outcomes on the “Disperse Systems” topic were subsequently compared.

Participants. Participants were thirty undergraduate students enrolled in group B053-5306-23-01 of the educational program 6B05306 “Chemistry of Organic Substances and Polymers” at L.N. Gumilyov Eurasian National University. Students were divided into two groups of fifteen, matched for comparable prior academic performance: Group 1 was taught

using the traditional lecture format, and Group 2 was taught using the flipped classroom model. All materials required for the laboratory demonstrations — standard laboratory glassware, mixing rods, filter paper, and reagent-grade salts for the true solutions; sand and chalk for the suspensions; protargol and ethanol (obtained from a pharmacy) for the colloidal solution; and household surfactants such as soap and shampoo as examples of surface-active substances — were readily available through the university’s existing laboratory infrastructure and posed no safety risk to student participants.

Procedure. **Traditional group.** Instruction in Group 1 followed a conventional lecture structure of approximately forty-five minutes: (1) a brief warm-up and review (5–7 minutes) revisiting the concepts of a pure substance, a mixture, and a true solution; (2) presentation of new material (20 minutes), in which the instructor orally explained the concept of a disperse system and its two components, the classification of disperse systems, illustrative examples, and the Tyndall effect, accompanied by teacher-led demonstrations — including the preparation of a suspension from sand and the demonstration of the Tyndall effect — with students taking notes; (3) initial consolidation of the material through a short test (10 minutes); and (4) assignment of homework (3–5 minutes) consisting of reading the corresponding textbook section, answering the questions at the end of the section, and completing a written classification exercise.

Flipped classroom group. Instruction in Group 2 was divided into an asynchronous home stage and a synchronous in-class stage. During the home stage (approximately 15 minutes), students independently reviewed instructor-prepared video lectures and accompanying notes covering the definition and components of a disperse system, its classification, and the Tyndall effect, made available through two pre-recorded video links, in preparation for the in-class session.

The in-class stage (50 minutes) opened with a brief organizational and motivational segment introducing the laboratory-based format of the lesson, followed by seven minutes of oral questioning to activate students’ prior, home-acquired knowledge (for example, asking students to identify the dispersion medium in a mayonnaise emulsion given that its

dispersed phase is oil, and to explain why a laser beam is not visible when directed through salt water). Because the theoretical groundwork had already been completed at home, the bulk of class time — twenty minutes — was allocated to hands-on practical work, in which students were divided into competing teams for three laboratory tasks: Experiment 1 required teams to prepare the maximum possible number of distinct suspensions from materials available in the laboratory; Experiment 2 required teams to prepare systems that did and did not exhibit the Tyndall effect, reinforcing the distinction between colloidal and non-colloidal systems; and Experiment 3 made use of the “Unreal Chemist” virtual chemistry laboratory, in which students prepared true solutions from salts such as sodium chloride, potassium chloride, and manganese(II) chloride, as well as acid and base solutions, in a safe, simulated environment. The lesson concluded with a ten-minute consolidation stage in the form of a knowledge test.

Complementing the core laboratory activities, students in the flipped classroom group also completed interactive matching exercises created on the Learning Apps platform, including a “find the pair” activity requiring students to match given substances with their correct disperse-system category (emulsion, suspension, or colloidal system).

Assessment Instrument. Student knowledge of the “Disperse Systems” topic was evaluated using a five-item multiple-choice test, each item offering four response options, administered through the Google Forms platform to both groups under identical conditions. The test items addressed the definition of the dispersed phase, the identification of an emulsion from a set of examples, the criterion used to classify coarse-dispersed, colloidal, and true-solution systems, the identification of a system exhibiting light scattering, and the identification of a gas-in-solid system. Each test was scored on a ten-point scale.

Data Analysis. Consistent with standard pedagogical assessment practice in the post-Soviet educational tradition, two summary indicators were calculated for each group from the distribution of ten-point test scores: academic performance (uspevaemost), defined as the percentage of students scoring above the minimum passing threshold (i.e., scoring 6, 8, or 10 points out of 10), and quality of knowledge (kachestvo znaniy), defined as the more

stringent percentage of students attaining a high score (8 or 10 points out of 10). These two indicators together capture, respectively, the breadth of minimal topic mastery across the group and the depth of higher-order understanding achieved by the group’s strongest performers.

RESULTS. Table 1 presents representative examples of the disperse systems covered in the lesson, organized according to the aggregate states of the dispersion medium and dispersed phase.

Table 1. Examples of disperse systems used in the curriculum

Disperse System	Dispersion Medium	Dispersed Phase	Example
Aerosol	Gas	Liquid	Fog
Aerosol	Gas	Solid	Dust and smoke
Foam	Liquid	Gas	Aqueous soap solution
Emulsion	Liquid	Liquid	Milk
Suspension (coarse-dispersed)	Liquid	Solid	Sand + water
Colloidal solution / sol (ultra-high dispersed)	Liquid	Solid	Protargol

Table 2 presents the distribution of test scores obtained by the traditional and flipped classroom groups on the “Disperse Systems” assessment.

Table 2. Test score distribution: traditional vs. flipped classroom teaching of “Disperse Systems”

Score (points)	Traditional Group (n = 15)	Flipped Classroom Group (n = 15)
10	0	2
8	5	8
6	7	4
4	3	1
2	0	0
0	0	0

As shown in Table 2, no student in the traditional group achieved the maximum score of ten points, whereas two students in the flipped classroom group did so. The traditional group’s scores clustered most heavily around six and eight points (seven and five students,

respectively), whereas the flipped classroom group’s scores clustered more heavily around eight points (eight students). Three students in the traditional group scored only four points, compared with a single student in the flipped classroom group.

Applying the performance and quality indicators described above, the flipped classroom group achieved an academic performance rate of 93.3% and a quality-of-knowledge rate of 66.7%, compared with 80.0% and 33.3%, respectively, in the traditional group. The flipped classroom group’s performance rate was therefore 13.3 percentage points higher than that of the traditional group, and its quality-of-knowledge rate was more than double that of the traditional group — a difference of 33.4 percentage points.

DISCUSSION. The results indicate a clear and consistent advantage for the flipped classroom format in teaching the topic of “Disperse Systems,” an advantage that is considerably more pronounced on the quality-of-knowledge indicator than on the academic performance indicator. This pattern suggests that the flipped classroom model’s principal benefit in this context was not merely helping more students to pass the topic (a comparatively high 80.0% of the traditionally taught group already did so), but rather moving a substantially larger share of students from adequate, minimal understanding into the higher tier of secure, confident mastery — precisely the outcome one would predict from a model that frees classroom time for guided practice and immediate feedback rather than passive note-taking.

Several features of the flipped classroom implementation plausibly contributed to this advantage. First, relocating the initial delivery of theoretical content to the asynchronous home stage allowed the entire fifty-minute class session to be devoted to active engagement — competitive, team-based laboratory experiments, virtual laboratory practice, and interactive digital exercises — rather than being divided, as in the traditional format, between lecture delivery and only a brief period of consolidation. Second, the competitive team structure of the in-class experiments is likely to have increased student engagement and time-on-task relative to a purely observational, teacher-demonstrated experiment. Third, the “Unreal Chemist” virtual laboratory allowed students to safely and repeatedly manipulate reagents, such as manganese(II) chloride and various acids and bases, that might

otherwise be handled only briefly, or not at all, by students themselves in a physical laboratory setting for reasons of safety or time, thereby extending the range of hands-on practice available within the lesson.

These findings are broadly consistent with the international literature on flipped learning, which has consistently identified increased student engagement, more effective use of classroom time, and stronger conceptual mastery as key benefits of the model [3], and they extend this literature to the specific and conceptually demanding domain of colloid chemistry within a Kazakhstani higher education setting — a context in which subject-specific outcome data have to date been limited [8, 12].

Several limitations of the present study should be acknowledged. The sample size was modest — thirty students across two groups — and both groups were drawn from a single institution and a single student cohort, which limits the statistical power and generalizability of the findings. The intervention was also limited to a single topic taught over a single lesson cycle, so the durability of the observed gains over time, and their transferability to other chemistry topics, cannot be established from this study alone; a companion investigation of the “Surface Phenomena” topic within the same broader thesis project offers one step toward addressing this question. Finally, because the two groups were intact, pre-existing classes rather than randomly assigned individuals, the possibility that unmeasured differences between the groups, rather than the instructional format alone, contributed to the observed outcomes cannot be entirely excluded, nor can a novelty effect associated with the introduction of new digital tools be ruled out.

Despite these limitations, the consistency and magnitude of the observed differences, particularly on the quality-of-knowledge indicator, support the practical value of incorporating flipped classroom elements — asynchronous video instruction paired with active, technology-supported classroom practice — into the teaching of conceptually dense colloid chemistry topics such as disperse systems.

CONCLUSION. This study evaluated the effectiveness of flipped classroom technology, relative to traditional lecture-based instruction, in teaching the topic of “Disperse Systems” to undergraduate chemistry students. Students taught using the flipped

classroom model — in which theoretical content was studied asynchronously at home through video lectures and classroom time was devoted to competitive laboratory experiments, virtual laboratory practice in the “Unreal Chemist” simulator, and interactive Learning Apps exercises — achieved a substantially higher academic performance rate (93.3% versus 80.0%) and, especially, a substantially higher quality-of-knowledge rate (66.7% versus 33.3%) than students taught through the traditional format. These findings support the integration of flipped classroom methodology into chemistry curricula, particularly for topics that combine abstract conceptual content with observable, experimentally demonstrable phenomena, and point to the value of pairing asynchronous instruction with interactive digital tools and virtual laboratory platforms in future course design. Further research with larger and more diverse samples, and across a broader range of chemistry topics, is recommended to confirm and extend these findings.

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