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The Effectiveness of Flipped Classroom Technology in Teaching the Topic of Surface Phenomena in Chemistry Education

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Abstract

Surface phenomena - the physicochemical processes that occur at the boundary between two phases - underlie a wide range of everyday and industrial contexts, from the cleaning action of soap to the function of medical adsorbents and industrial gas purification, yet the topic is frequently perceived by students as abstract and difficult to visualize. This study investigated whether flipped classroom technology could improve learning outcomes for this topic relative to traditional, lecture-based instruction. Using a quasi-experimental comparative design, thirty undergraduate chemistry students were divided into two groups of fifteen: a traditionally taught group and a flipped classroom group. Students in the flipped classroom group studied core theoretical material - surface tension, surfactants, and adsorption - at home through instructor-provided video lectures before attending a class session built around Learning Apps interactive matching exercises, real-world demonstrations of surface phenomena drawn from nature and daily life, and a collaborative mind-mapping exercise conducted on the Miro online whiteboard in which students generated and developed an applied design concept. Learning outcomes, scored on a ten-point scale, were evaluated using two standard indicators: academic performance and quality of knowledge. The flipped classroom group achieved an academic performance rate of 100% and a knowledge quality rate of 73.3%, compared with 73.3% and 26.7%, respectively, in the traditionally taught group. Every student in the flipped classroom group achieved a passing score, and none scored in the lowest passing band, in contrast to the traditional group. These results, consistent in direction with those obtained for a parallel colloid-chemistry topic within the same broader study, suggest that flipped classroom instruction is particularly effective for topics such as surface phenomena that lend themselves to abundant real-world illustration and applied, creative synthesis. Pedagogical implications and directions for future research are discussed.

Keywords: flipped classroom, innovative educational technology, surface phenomena, adsorption, colloid chemistry, chemistry education, academic performance

1. Introduction

Surface phenomena - the physicochemical processes that take place specifically at the interface between two phases - constitute one of the most pervasive yet least visually intuitive domains of physical and colloid chemistry. Surface tension explains why a water strider can stand on the surface of a pond and why mercury spilled from a broken thermometer gathers into rounded droplets on a tabletop; adsorption explains why activated carbon and silica gel can purify water and air, and why a common medicinal preparation based on colloidal silica (marketed as Polysorb) can absorb toxins in the digestive tract; and capillarity explains how water and dissolved minerals rise from the soil through the narrow channels of plant roots even in dry conditions. Despite this rich and immediately relatable set of real-world manifestations, students frequently encounter the formal vocabulary of surface phenomena - terms such as adsorbent, adsorbate, adsorption isotherm, adhesion, and cohesion - as an abstract and disconnected list of definitions to be memorized rather than as a coherent framework for understanding phenomena they already observe daily. This gap between the abstractness of the formal terminology and the concreteness of the underlying phenomena makes surface phenomena a particularly instructive test case for pedagogical approaches, such as the flipped classroom, that emphasize active engagement and real-world grounding over passive transmission of definitions.

As in the parallel investigation of the “Disperse Systems” topic conducted within the same broader thesis project, the flipped classroom model examined here was first developed in 2007 by Jonathan Bergmann and Aaron Sams as a solution for students who frequently missed class, and has since become one of the most widely discussed innovative pedagogical technologies of the twenty-first century [3]. The model relocates the initial delivery of theoretical content to an asynchronous, self-paced home stage, typically through recorded video lectures, so that classroom time can instead

be devoted to the application, discussion, and consolidation of that material under the direct guidance of the instructor. Where the disperse-systems study emphasized competitive, hands-on laboratory experimentation as the principal in-class activity, the design of the present study capitalized on the abundance of everyday, easily observable examples of surface phenomena by building the in-class stage around real-world demonstration, interactive digital matching exercises, and a creative, applied mind-mapping task, testing whether the flipped model's benefits extend to a topic whose pedagogical strength lies less in laboratory manipulation than in connecting abstract theory to lived experience.

The aim of this study was therefore to evaluate the effectiveness of flipped classroom technology, relative to traditional lecture-based instruction, in teaching the topic of "Surface Phenomena," as measured by academic performance and quality of knowledge, and to compare the pattern of results with that obtained for the disperse-systems topic in order to assess the consistency of the flipped classroom's effect across two distinct areas of the colloid chemistry curriculum.

2. Literature Review

2.1. Innovative Pedagogy and the Flipped Classroom

The concept of innovation entered educational scholarship only in the mid-twentieth century, considerably later than in economics, where the term originated in the work of Schumpeter in the 1930s [5], and post-Soviet pedagogy did not begin to engage systematically with innovation until the late 1970s. Contemporary scholarship emphasizes that innovative and traditional teaching methods should be viewed as complementary rather than competing, with the instructor's task being to identify an optimal balance that preserves the strengths of direct instruction while incorporating the flexibility and active engagement that innovative methods, including the flipped classroom, can provide [2]. The flipped classroom itself inverts the conventional order of instruction, moving the initial transmission of theoretical content to an asynchronous home stage, typically via recorded video lectures, so that class time can be reserved for application, practice, and discussion under the instructor's direct supervision [3].

In the Kazakhstani higher education context specifically, several studies have documented both growing interest in, and continuing barriers to, the adoption of digital and blended learning technologies. Yerzhanova and Nurgaliyeva [12] examined technology integration in Kazakhstani classrooms, while Ospanova and Mussina [6] documented broader trends in the use of information and communication technologies in Kazakhstani higher education, and Zhumabayeva and Zhaparova [13] catalogued practical implementation challenges for e-learning in the country's universities. Together, this body of work underscores the need for concrete, topic-level evidence of the kind this study seeks to provide.

2.2. Theoretical Background: Surface Tension and Surfactants

Within a liquid, any given molecule is surrounded on all sides by neighboring molecules of the same substance, and the attractive forces it experiences are, on average, balanced in every direction. A molecule located at the liquid's surface, however, has neighboring molecules only below and to the sides, and none above; the resulting imbalance of attractive forces draws surface molecules inward, toward the bulk liquid phase, causing the surface to contract to the minimum area consistent with the liquid's volume and giving rise to the phenomenon of surface tension, experienced physically as an elastic, film-like layer at the liquid's surface [7].

Surface-active substances, more commonly known as surfactants, are chemical compounds that concentrate at the interface between two phases (for example, between a liquid and a solid, between two immiscible liquids, or between a liquid and a gas) and thereby reduce the surface tension at that interface. Surfactants are classified according to the nature of the ionic species they form in solution: anionic surfactants (such as sodium laureth sulfate) dissociate into negatively charged ions; cationic surfactants (such as benzalkonium chloride) dissociate into positively charged ions; amphoteric surfactants (such as betaines) display cationic character in acidic solution and anionic character in alkaline solution; and non-ionic surfactants (such as fatty alcohols) do not ionize at all [8]. All surfactant molecules share a characteristic amphiphilic structure, comprising a hydrophobic segment and a hydrophilic segment, which together allow the molecule to interact simultaneously with both water-soluble and oil-soluble residues - the physicochemical basis of soap's cleaning action.

At low concentrations, surfactant molecules adsorb at an available interface, progressively lowering the surface tension there; however, above a substance-specific threshold known as the critical micelle concentration, additional surfactant molecules can no longer further reduce surface tension and instead self-assemble in the bulk solution into structures called micelles - spherical or lamellar aggregates in which the hydrophobic tails of dozens or hundreds of surfactant molecules orient inward, away from the surrounding water, while the hydrophilic heads orient outward,

toward it [10]. This micellar structure allows non-polar contaminants to be solubilized within the hydrophobic interior of the micelle - the molecular mechanism underlying detergency.

2.3. Theoretical Background: Adsorption, Wetting, and Capillarity

Adsorption is the spontaneous process by which a solid or liquid surface accumulates a gas, vapor, or dissolved substance, manifesting as an increase in the concentration of that substance specifically at the interface between the two phases, as opposed to absorption, in which the substance is taken up throughout the volume of the absorbing material [4]. The substance that performs the adsorbing is termed the adsorbent, the substance that becomes adsorbed onto the surface is termed the adsorbate, and the substance available in the surrounding volume for potential adsorption is termed the adsorptive. Adsorption is further distinguished into physical adsorption (physisorption), which arises from comparatively weak van der Waals forces and is generally reversible, and chemisorption, which involves the formation of a genuine chemical bond between adsorbate and surface and is typically far less readily reversed [11].

Common adsorbents - including activated carbon, zeolites, and silica gel - share a highly porous, microstructured architecture that maximizes surface area per unit mass, and are widely employed in petrochemical processing, industrial air purification, gas drying, and water treatment, as well as, in the case of finely divided colloidal silica, in medicinal preparations designed to bind toxins, allergens, and pathogenic bacteria within the digestive tract [9]. The reverse process, in which a previously adsorbed substance is released back from the surface into solution, is termed desorption, and the relationship between the equilibrium quantity of adsorbate held on a surface and its concentration in the surrounding phase, at constant temperature, is described by an adsorption isotherm, most classically the Langmuir isotherm [8].

Wetting and capillarity represent a further category of surface phenomena arising at the boundary between a liquid and a solid. Wetting describes the interaction between a liquid and a solid surface, and its extent depends on the relative strengths of cohesive forces (holding molecules of the liquid together) and adhesive forces (attracting liquid molecules to the solid surface). Capillarity - the rise or fall of a liquid within a narrow tube or channel relative to the surrounding liquid level - is itself a consequence of the balance between these cohesive and adhesive forces acting at a curved liquid surface, and it accounts for the passive upward transport of water and dissolved minerals through the fine channels of soil and, subsequently, through plant root systems [7, 11].

3. Materials and Methods

3.1. Research Design and Participants

This study employed the same quasi-experimental, comparative-group design and the same participant pool as the parallel investigation of the “Disperse Systems” topic within the broader thesis project: thirty undergraduate students from group B053-5306-23-01 of the educational program 6B05306 “Chemistry of Organic Substances and Polymers” at L.N. Gumilyov Eurasian National University, divided into a fifteen-student traditional group and a fifteen-student flipped classroom group, matched for comparable prior academic performance. Conducting both topic investigations with the same two groups allowed the effect of instructional format to be examined across two distinct chemistry topics while holding the student population, group composition, and institutional context constant.

3.2. Procedure

Traditional group. Instruction in the traditional group opened with a brief organizational stage (1-2 minutes) and a short assessment of students’ prior preparation and of the conceptual link between physics and chemistry (5-7 minutes), introduced through a problem-based question inviting students to explain why a drop of water spreads across a clean glass surface but does not spread on a paraffin-coated surface. Presentation of new material (20-25 minutes) then covered, in sequence, surface tension; surface-active substances and their classification, including the critical micelle concentration; and adsorption, delivered through direct oral explanation and lecture notes emphasizing key definitions. The lesson concluded with an initial consolidation exercise (10 minutes) in which students applied the material just presented to explain the cleaning action of soap, followed by a review of the lesson and assignment of homework based on the provided lecture notes.

Flipped classroom group. During the asynchronous home stage (7-10 minutes), students in the flipped classroom group prepared independently using instructor-provided lecture notes and three recorded video lectures covering surface tension, surfactants, and adsorption, and completed a preparatory task requiring them to identify everyday examples of adsorption - such as household water filters and the silica gel packets found in footwear packaging - and to name the substance functioning as the adsorbent in each case.

The synchronous in-class stage centered on active learning. A blitz oral-and-digital quiz was conducted using interactive exercises built on the Learning Apps platform, including a matching-table exercise requiring students to pair images with the correct designation of "surface phenomenon" or "not a surface phenomenon," and several "find the pair" games requiring students to match examples with categories such as the four classes of surfactant (anionic, cationic, amphoteric, and non-ionic) and adsorption-related terminology (adsorbent, adsorbate, physisorption, chemisorption, desorption, and the adsorption isotherm). To ground the topic's terminology in direct experience, the instructor incorporated a series of real-world illustrations of surface phenomena drawn from nature and daily life, including the water strider's ability to stand on the surface of still water, the formation of rounded mercury droplets from a broken glass thermometer, the beading of dew on a leaf surface, and the capillary rise of moisture through soil to a plant's root system.

The lesson concluded with a collaborative synthesis activity conducted on the Miro online whiteboard, structured as a three-stage mind-mapping process: an initial brainstorming stage in which students generated candidate product ideas; a selection stage in which each student identified their preferred idea from those generated; and a realization stage in which students articulated how their chosen idea could be developed into a socially useful product. In one illustrative example produced during this activity, a student proposed a self-cleaning solar panel design that would exploit surface tension together with the lotus effect - the naturally occurring combination of microscale surface roughness and low surface energy that allows certain plant leaves to shed water and accumulated dirt - to keep the panel's surface clean without manual intervention.

3.3. Assessment

Student learning outcomes for the "Surface Phenomena" topic were assessed using a multiple-choice knowledge test scored on the same ten-point scale employed for the "Disperse Systems" module, preserving methodological consistency across the two topic-level investigations conducted within the broader study.

3.4. Data Analysis

As in the companion investigation, two summary indicators were computed from each group's distribution of ten-point scores: academic performance, the percentage of students scoring above the minimum passing threshold (6, 8, or 10 points), and quality of knowledge, the percentage of students achieving a high score (8 or 10 points).

4. Results

Table 3 lists the key terms and definitions covered in the "Surface Phenomena" lesson, which were presented to students in accessible language alongside the demonstrations and digital exercises described above.

Table 3. Key terms and definitions used in the "Surface Phenomena" topic

Term	Definition
Adsorption	Spontaneous accumulation of a substance at the interface between two phases
Adsorbent	The substance on whose surface adsorption occurs
Adsorbate	The substance adsorbed from a gas or liquid
Physical adsorption	Adsorption occurring through van der Waals forces
Chemisorption	A chemical reaction occurring between the adsorbate and the surface
Surface phenomenon	Physicochemical processes occurring at the interface between phases
Adhesion	The joining of the surfaces of two different bodies
Cohesion	The bonding of molecules within a single substance
Wetting	The interaction between a liquid and a solid surface
Adsorption isotherm	The relationship between the quantity of adsorbate and its concentration, at constant temperature

Table 4 presents the distribution of test scores obtained by the traditional and flipped classroom groups.

Table 4. Test score distribution: traditional vs. flipped classroom teaching of "Surface Phenomena"

Score (points)	Traditional Group (n = 15)	Flipped Classroom Group (n = 15)
10	0	3
8	4	8

Score (points)	Traditional Group (n = 15)	Flipped Classroom Group (n = 15)
6	7	4
4	4	0
2	0	0
0	0	0

As shown in Table 4, no student in either group scored zero or two points, and no student in the flipped classroom group scored below six points, whereas four students in the traditional group scored only four points. At the upper end of the scale, three students in the flipped classroom group achieved the maximum score of ten points, compared with none in the traditional group, while eight students in the flipped classroom group scored eight points, compared with four in the traditional group.

Applying the academic performance and quality-of-knowledge indicators, the flipped classroom group achieved a performance rate of 100%, meaning that every student in the group achieved a passing score, and a quality-of-knowledge rate of 73.3%. The traditional group achieved a performance rate of 73.3% and a quality-of-knowledge rate of 26.7%. The flipped classroom group's performance rate thus exceeded that of the traditional group by 26.7 percentage points, and its quality-of-knowledge rate exceeded that of the traditional group by 46.6 percentage points.

5. Discussion

The results provide clear evidence of the flipped classroom model's effectiveness in teaching the "Surface Phenomena" topic, with every measured indicator favoring the flipped classroom group over the traditionally taught group. Notably, the magnitude of the advantage observed here exceeds that observed for the parallel "Disperse Systems" topic conducted within the same broader study, in which the flipped classroom group's performance and quality-of-knowledge rates exceeded the traditional group's by 13.3 and 33.4 percentage points, respectively, compared with 26.7 and 46.6 percentage points for surface phenomena. The perfect 100% passing rate achieved by the flipped classroom group, with not a single student scoring below the passing threshold, is a particularly striking result given that four students - more than a quarter of the traditionally taught group - failed to reach that same threshold.

Several features of the surface phenomena lesson design may help explain why the flipped classroom's advantage was even more pronounced for this topic than for disperse systems. First, surface phenomena lend themselves unusually well to illustration through commonplace, easily relatable examples: the water strider resting on a pond's surface, mercury droplets on a tabletop, dew on a leaf, and the capillary movement of water through soil are phenomena that most students have already observed in daily life, even if they had not previously connected them to a shared underlying physicochemical principle. Anchoring the abstract vocabulary of adsorbents, adsorbates, and adsorption isotherms to this kind of lived experience - an approach made possible by the classroom time freed up under the flipped model - appears to have been an effective route to durable understanding, consistent with the broader emphasis in the innovative-pedagogy literature on building genuine functional literacy rather than the rote memorization of definitions [1]. Second, the collaborative Miro mind-mapping exercise, culminating in applied product concepts such as the lotus-effect self-cleaning solar panel proposed by one student, required learners to synthesize and transfer their newly acquired knowledge to a novel design problem - a demanding cognitive task that is only feasible once foundational definitions have already been secured, in this case through the preceding asynchronous home stage - and that plausibly contributed to moving a large share of students into the highest-scoring band on the subsequent assessment.

These findings are consistent with, and extend, the results obtained for the disperse-systems topic within the same broader thesis project, and together the two topic-level investigations offer convergent evidence that the flipped classroom's advantage over traditional instruction, in this setting, is not confined to a single content area but generalizes across at least two substantively distinct areas of the colloid chemistry curriculum - one weighted more heavily toward hands-on laboratory manipulation and one weighted more heavily toward real-world illustration and applied synthesis. This pattern also aligns with the broader international literature on flipped learning [3] and with the documented momentum behind digital and blended learning approaches in Kazakhstani higher education [6, 12].

The limitations noted in the companion study apply equally here: the sample was limited to thirty students from a single institution and student cohort, the intervention spanned a single lesson on a single topic, and the use of intact, non-randomly assigned groups means that pre-existing group differences and a possible novelty effect associated with the introduction of new digital tools cannot be fully excluded as alternative explanations for the observed differences. Future research employing larger, randomly assigned samples across multiple institutions, and tracking the retention of

learning gains over a longer time horizon, would help to establish the robustness and durability of the effects reported here.

6. Conclusion

This study evaluated the effectiveness of flipped classroom technology, relative to traditional lecture-based instruction, in teaching the topic of "Surface Phenomena" to undergraduate chemistry students. Students taught using the flipped classroom model - which combined asynchronous video-based instruction with in-class real-world demonstrations, interactive Learning Apps exercises, and a collaborative Miro-based mind-mapping and applied design task - achieved a 100% academic performance rate and a 73.3% quality-of-knowledge rate, compared with 73.3% and 26.7%, respectively, among students taught through the traditional lecture format. Considered alongside the parallel results obtained for the "Disperse Systems" topic within the same broader study, these findings suggest that the benefits of flipped classroom instruction are consistent - and may be especially pronounced - for chemistry topics such as surface phenomena that offer rich opportunities to connect abstract terminology to directly observable, everyday phenomena. Chemistry instructors are encouraged to consider flipped classroom designs that pair asynchronous foundational instruction with in-class activities emphasizing real-world grounding, interactive digital practice, and applied, creative synthesis, particularly for topics of comparable conceptual character.

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