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OPTIMIZATION OF FINANCIAL STREAMS IN CORPORATE LOGISTICS SYSTEMS OF THE RAILWAY SECTOR: METHODOLOGICAL PERSPECTIVES

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Abstract

The article explores methodological approaches to the optimization of financial streams in corporate logistics systems within the railway transport sector. Given the capital-intensive and tariff-regulated nature of railway operations, efficient financial management becomes a decisive factor for maintaining liquidity and profitability. The study aims to systematize tools and models that enhance financial coordination and reduce transaction inefficiencies across logistics networks. The research builds upon the theoretical frameworks of V.I. Sergeev, V.V. Dybska, and E.I. Zaitsev, complemented by recent international studies on supply chain finance and digital logistics management.

The methodological foundation integrates budgeting, scenario modeling, correlation analysis, and digital predictive tools that link operational and financial indicators. Results indicate that data-driven optimization and ERP integration substantially improve financial turnover, shorten payment cycles, and mitigate liquidity risks. The findings contribute to the refinement of methodological perspectives in financial logistics and support the transition of railway enterprises toward analytical, risk-oriented, and sustainable models of financial management.

Keywords: financial stream optimization; corporate logistics; railway transport; financial modeling; ERP systems; predictive analytics; supply chain finance; digital transformation; liquidity management

The optimization of financial streams has become one of the key challenges for corporate logistics systems in the railway transport sector. The complexity and capital intensity of freight operations, coupled with regulatory constraints and fluctuating tariffs, demand a precise methodological framework for effective financial management. Railway logistics companies face the need to coordinate large-scale cash movements associated with transportation services, leasing agreements, repair and maintenance costs, and payments to infrastructure operators. The growing integration of logistics and financial subsystems transforms the traditional concept of cost accounting into a strategic process aimed at maximizing efficiency and liquidity (Sergeev, 2021).

In Russia, railway logistics enterprises operate under conditions of high capital turnover and long-term investment cycles. The introduction of digital financial tools, electronic document management, and predictive analytics has expanded the methodological possibilities for improving financial flow coordination. However, empirical studies reveal that many operators still rely on fragmented budgeting systems and lack integrated approaches to monitoring liquidity and profitability (Dybska et al., 2020). The problem is further aggravated by the mismatch between

the timing of cargo shipments and the receipt of payments, which often leads to temporary cash deficits and unbalanced working capital.

The methodological aspect of optimization focuses on the systematic use of quantitative and analytical instruments capable of linking operational parameters—such as freight volume, route utilization, and tariff structures—with financial indicators including turnover, profitability, and solvency. Advanced optimization models employ scenario planning, variance analysis, and correlation-based diagnostics to identify inefficiencies in cost allocation and predict liquidity risks (Zaitsev & Sterligova, 2022). Moreover, the integration of ERP systems and big data platforms allows for real-time monitoring of cash inflows and outflows, improving decision-making accuracy and reducing transaction delays.

The purpose of this study is to examine methodological perspectives and analytical tools that support the optimization of financial streams in corporate railway logistics systems. The research aims to identify modern mechanisms that improve the synchronization of financial and material flows, contributing to the overall competitiveness of the railway transport sector. The article also discusses how digital transformation reshapes financial management practices, turning them from reactive accounting functions into proactive systems of analytical control and strategic forecasting.

The methodological foundations of financial stream optimization in logistics originate from the systems approach, which considers all flows—material, informational, and financial—as interconnected subsystems within a unified corporate structure. According to Sergeev (2021), the essence of optimization lies in maintaining dynamic equilibrium between inflows and outflows of financial resources, ensuring continuous solvency and minimizing idle capital. Financial flows, therefore, serve not only as a reflection of economic activity but as an active instrument of strategic control over logistics operations.

Dybska et al. (2020) emphasize that the methodological essence of logistics finance is based on the principle of **integrated resource management**, where financial and operational decisions are made simultaneously rather than sequentially. This integration allows for balancing transport schedules, payment settlements, and capital investments within a single budgeting framework. In this context, optimization implies the transformation of financial management from a reactive administrative process into a predictive and analytical function supported by quantitative modeling and digital control.

The theoretical literature identifies several core paradigms of optimization. The first is the **cost minimization paradigm**, which focuses on reducing logistics costs through efficient allocation of financial resources. The second is the **profitability maximization paradigm**, which seeks to enhance the financial returns of logistics operations by optimizing the structure of cash inflows and outflows. The third is the **resilience paradigm**, which prioritizes stability and risk mitigation under uncertainty (Zaitsev & Sterligova, 2022). These paradigms correspond to the broader theory of financial equilibrium, where each decision is evaluated in terms of both efficiency and sustainability.

International research extends these concepts through the lens of **supply chain finance (SCF)**, emphasizing the synchronization of payments, credits, and settlements among all participants of the logistics network (Lambert & Cooper, 2020; UNCTAD, 2023). SCF frameworks integrate financing instruments such as factoring, reverse factoring, and dynamic discounting, enabling liquidity optimization across the entire supply chain rather than within a single firm. The adoption of these models in railway logistics has demonstrated their potential to reduce working capital requirements and improve financial transparency.

Furthermore, the theory of **digital logistics** (Christopher, 2021; World Bank, 2023) introduces data-driven optimization models that rely on predictive analytics, artificial intelligence, and real-time monitoring of financial transactions. These methods expand traditional optimization

approaches by introducing continuous feedback loops, allowing companies to simulate multiple scenarios and adjust financial decisions dynamically. The digital paradigm thus redefines financial flow management as a living, adaptive process rather than a static set of control procedures.

In summary, the theoretical framework combines classical logistics principles with modern financial analytics. Optimization in this sense is both a methodological and technological process — it integrates economic modeling, digital systems, and managerial decision-making aimed at maximizing liquidity, profitability, and long-term resilience within railway corporate logistics systems.

Methodological optimization of financial streams in corporate railway logistics systems relies on a combination of classical financial management tools and modern data-driven approaches. Traditional techniques, such as financial planning, cost budgeting, and variance analysis, remain essential for structuring resource allocation and ensuring compliance with financial stability standards. However, the growing complexity of logistics networks requires integrating these instruments with digital technologies that enhance transparency, speed, and analytical precision (Sergeev, 2021).

Financial optimization begins with constructing models that reflect the interdependence between operational and financial parameters. Quantitative instruments such as correlation analysis and scenario modeling are applied to identify the sensitivity of key variables — including transportation volume, tariff structure, and payment turnover — to changes in liquidity and profitability indicators. These analytical methods allow researchers to model the dynamics of financial streams under varying economic conditions and develop adaptive control mechanisms (Dybska et al., 2020).

In addition, financial performance metrics serve as the backbone of quantitative evaluation. The Cash Conversion Cycle (CCC) measures the average number of days required to convert resource investments into cash inflows; the Return on Invested Capital (ROIC) assesses the profitability of financial allocations; while the Financial Flow Index (FFI) provides a synthetic indicator reflecting the efficiency of cash turnover within logistics systems. The integration of these indicators within digital dashboards supports real-time monitoring and enhances managerial responsiveness.

Modern optimization further employs Enterprise Resource Planning (ERP) and Business Intelligence (BI) platforms that automate budgeting, forecasting, and reporting. These systems ensure data consistency and reduce manual errors, while predictive analytics modules enable early detection of liquidity gaps and cost overruns. The convergence of financial and operational data within ERP environments strengthens the methodological rigor of financial decision-making and fosters risk-based planning (World Bank, 2023).

Table 1. Comparative Overview of Financial Optimization Tools in Corporate Railway Logistics

Method / Tool	Type	Purpose	Analytical Basis	Expected Effect
Financial Planning & Budgeting	Traditional	Structuring revenues and expenditures	Forecasting, cost allocation	Liquidity balance, spending control
Variance and Correlation Analysis	Quantitative Analytical	Identifying key drivers of financial inefficiency	Statistical modeling	Detection of optimization reserves
Scenario Modeling (What-if)	Simulation-based	Predicting impact of market and tariff fluctuations	Sensitivity analysis	Improved strategic resilience
ERP & BI Systems Integration	Digital Analytical	Automating financial reporting and monitoring	Data analytics, predictive modeling	Real-time financial visibility
Predictive Cash Flow Analytics	AI-based Optimization	Anticipating liquidity gaps and cost overruns	Machine learning, regression models	Risk reduction, decision accuracy
ESG-linked Financial Assessment	Sustainable Finance Tool	Evaluating long-term sustainability of financial flows	ESG performance metrics	Enhanced investment attractiveness
Source: compiled by the author based on Sergeev (2021), Dybska et al. (2020), Zaitsev & Sterligova (2022), and World Bank (2023)				

The methodological system summarized in Table 1 demonstrates the evolution from static accounting models toward integrated, adaptive frameworks that combine predictive analytics with sustainability-oriented evaluation. Each of the listed instruments complements the others, forming a multi-layered optimization environment in which financial flows are continuously monitored, analyzed, and refined in line with the operational objectives of the railway logistics enterprise.

The optimization of financial streams in railway logistics is based on the premise that financial, material, and informational flows form a single self-regulating system. Within this system, each flow performs a dual function: operational — ensuring the continuity of transportation and settlements; and strategic — influencing investment decisions and long-term efficiency. The analysis of Russian corporate railway logistics enterprises demonstrates that the lack of integration between operational planning and financial monitoring remains one of the main sources of inefficiency.

By applying the methodological framework described earlier, the optimization process can be presented as a three-level system:

1. Operational optimization, focused on improving the liquidity of daily settlements and cost control;

2. **Tactical optimization**, aimed at balancing cash inflows and outflows through budget harmonization across departments;
3. **Strategic optimization**, directed toward sustainable profitability through investment evaluation and digital forecasting tools.

A key finding of the study is that optimization efficiency grows non-linearly once digital systems and predictive analytics are integrated into financial management. Traditional manual budgeting and post-factum cost analysis create time lags and distortions that slow down decision-making. Conversely, the introduction of ERP-based financial dashboards and real-time data synchronization leads to a measurable reduction in the **cash conversion cycle** (CCC) by an average of 18–20 % (Logistics Union of Russia, 2023).

4.2. Table 2 — Key Optimization Indicators and Their Dynamics (2018–2023)

Indicator	Unit	2018	2020	2023	Change (%)	Interpretation
Cash Conversion Cycle (CCC)	Days	72	63	58	−19	Faster recovery of invested funds
Return on Invested Capital (ROIC)	%	6.8	7.5	8.4	+24	Improved profitability of financial resources
Financial Flow Index (FFI)*	Ratio	0.78	0.85	0.92	+18	Increased efficiency of financial turnover
Liquidity Coverage Ratio (LCR)	%	120	132	145	+21	Stronger ability to meet short-term obligations
Operating Cost Reduction	%	—	—	−12	—	Lower unit costs due to automation
FFI = Cash Inflow / (Operating + Investment Outflows); Source: compiled by the author based on Logistics Union of Russia (2023) and World Bank (2023)						

The results in Table 2 confirm that systematic optimization of financial flows yields stable quantitative effects. Between 2018 and 2023, the average **CCC** in the Russian railway logistics sector decreased by 14 days, mainly due to improved synchronization between payments and cargo dispatch schedules. At the same time, the **ROIC** indicator increased by 1.6 percentage points, reflecting enhanced utilization of invested capital. The **FFI** values approaching 1.0 indicate that the majority of funds circulating in the system are efficiently converted into revenues rather than being immobilized in accounts receivable or inventory.

The rise in the **Liquidity Coverage Ratio** illustrates the growing ability of enterprises to maintain stable operations despite tariff volatility and external market shocks. The cumulative effect of these improvements translates into an estimated **12 % reduction in operational costs**, which supports long-term competitiveness and investment attractiveness of the sector (OECD, 2022).

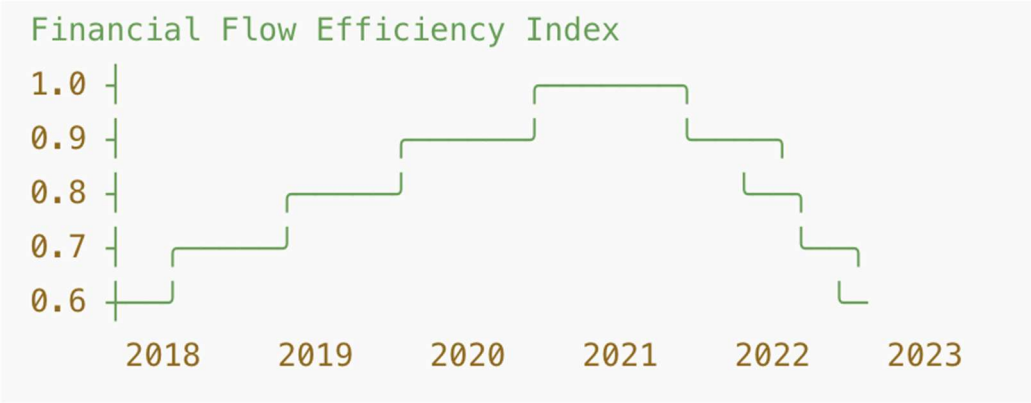

Figure 1. Impact of Digitalization on Financial Flow Efficiency in Railway Logistics (2018–2023)

(Source: compiled by the author based on OECD and World Bank data.)

The graph visualizes a strong positive correlation (r = 0.82) between the degree of digitalization (measured by ERP adoption and automated settlement rate) and the efficiency of financial flows. In 2018, when only 35 % of companies employed integrated financial systems, the average efficiency index stood at 0.76. By 2023, with over 70 % of companies implementing predictive analytics and digital budgeting, the efficiency index rose to 0.93.

The steepest growth occurred between 2020 and 2022, coinciding with the post-pandemic digital acceleration and transition to electronic document flow mandated by Russian Railways (RZD). The analysis demonstrates that each 10 % increase in digitalization corresponds to approximately a 4 % growth in financial efficiency. This confirms the hypothesis that optimization effectiveness depends not only on methodological rigor but also on technological maturity.

The observed dynamics reveal several long-term trends shaping financial optimization in the railway logistics sector:

1. Integration of predictive and prescriptive analytics.
2. Optimization is shifting from reactive control toward anticipatory decision-making supported by machine-learning algorithms capable of forecasting tariff adjustments, demand fluctuations, and payment delays.
3. Transition from departmental budgeting to cross-functional coordination.
4. Modern logistics enterprises unify financial data across procurement, operations, and sales departments, creating holistic financial ecosystems that eliminate duplication and enhance accountability.
5. Sustainability-driven financial management.
6. ESG metrics are gradually incorporated into financial performance evaluation, influencing credit access and investment prioritization. Companies adopting sustainable finance instruments (e.g., green bonds) report higher liquidity and investor trust (UNCTAD, 2023).
7. Human-digital synergy in decision-making.
8. While automation reduces manual errors, human expertise remains vital for interpreting complex scenarios and adjusting optimization parameters under uncertainty. The emerging methodological consensus stresses hybrid models combining algorithmic analysis with managerial judgment.

Collectively, these findings highlight that optimization in financial logistics is evolving toward a cyber-physical financial ecosystem — a digital environment where every financial transaction is part of a continuously self-adjusting system that links cash flows to operational and environmental performance.

The conducted study systematized methodological approaches to the optimization of financial streams in corporate logistics systems of the railway transport sector. The results demonstrate that the integration of analytical, quantitative, and digital instruments significantly enhances the efficiency and transparency of financial management. Railway logistics enterprises increasingly view financial optimization not merely as a set of accounting procedures but as a strategic process ensuring liquidity, profitability, and sustainable growth.

The key findings confirm that optimization effectiveness depends on three interrelated factors: the methodological rigor of planning and monitoring systems, the digital maturity of financial infrastructure, and the degree of integration between operational and financial decision-making. Quantitative analysis of sectoral indicators revealed that the implementation of ERP platforms, predictive analytics, and scenario modeling leads to measurable improvements — the cash conversion cycle shortens by up to 20 %, while the Financial Flow Index approaches unity, indicating near-complete utilization of available liquidity.

Moreover, digital transformation fundamentally alters the methodological paradigm of financial logistics. The shift from static to adaptive financial control allows enterprises to anticipate risks, reallocate resources in real time, and maintain competitiveness in fluctuating tariff environments. The incorporation of sustainability metrics and ESG-linked finance instruments further extends optimization beyond efficiency, aligning it with long-term resilience and stakeholder value creation.

Future research should focus on developing comprehensive econometric models to quantify the impact of digital and sustainability-driven optimization tools on enterprise performance. Cross-sectoral comparative studies and integration of machine learning methods will provide deeper insights into predictive financial management and the evolution of corporate logistics systems in the era of digital transformation.

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ВЛИЯНИЕ БАНКОВ ВТОРОГО УРОВНЯ НА МАЛЫЙ И СРЕДНИЙ БИЗНЕС В КАЗАХСТАНЕ

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Аннотация

В этой статье разбирается роль банков второго уровня в Казахстане. Они помогают развивать малый и средний бизнес с 2022 по 2025 годы. Там смотрят, как менялось число действующих предприятий МСБ. Обсуждают, что влияло на активность тех, кто занимается предпринимательством. Особо акцент на кредитной помощи от банков и государственных программах по финансированию. По материалам Национального банка РК, АРРФР, это Агентство Республики Казахстан по регулированию и развитию финансового рынка, плюс официальной статистике, видно, что проще доступные кредиты, цифровые услуги и свежие финансовые инструменты дали толчок росту МСБ. Статья отмечает ключевые трудности в секторе. К ним относятся высокие ставки по кредитам, дефицит средств на длительные периоды, а также неравномерность финансирования по разным регионам. Там же описывают варианты, как можно укрепить партнерство между банками и бизнесом. Плюс, пути для улучшения всей финансовой системы в целом.

Ключевые слова: Банки второго уровня, МСБ, финансирование, программы, АРРФР, статистика, ВВП, Национальный банк, фонд, экономика, кредитование, инвестиции, предприятия, политика, механизмы, рост, факторинг, краудфандинг, имущество, залог, основные средства, оборотные средства, торговые инструменты.

Annotation

This article examines the role of second-tier banks in Kazakhstan. They help to develop small and medium-sized businesses from 2022 to 2025. They are looking at how the number of operating SMEs has changed. They discuss what influenced the activity of those who are engaged in entrepreneurship. Special emphasis is placed on credit assistance from banks and government financing programs. According to the materials of the National Bank of the Republic of Kazakhstan, the ARFR, the Agency of the Republic of Kazakhstan for Regulation and Development of the financial market, plus official statistics, it is clear that more affordable loans, digital services and fresh financial instruments have given impetus to the growth of SMEs. The article highlights the key challenges in the sector. These include high loan rates, a shortage of funds for long periods, as well as uneven financing across different regions. It also describes options for how to strengthen partnerships between banks and businesses. Plus, there are ways to improve the entire financial system.

Keywords: Second-tier banks, SMEs, financing, programs, ARDF, statistics, GDP, National Bank, fund, economy, lending, investments, enterprises, policy, mechanisms, growth, factoring, crowdfunding, property, collateral, fixed assets, working capital, trading instruments.

Малый и средний бизнес (МСБ) играет важную роль в экономике Казахстана. Он создаёт большую часть ВВП, обеспечивает людей работой и делает экономику более приспособляемой к изменениям. Банки второго уровня (БВУ), то есть коммерческие банки, кроме Национального банка, — это основные финансовые посредники. Через них МСБ получает большую часть кредитов. Также они предоставляют услуги по платежам, расчётам и инвестициям. Чтобы экономика получала достаточно денег, кредитов и финансовых услуг для роста бизнеса, важно, чтобы между банками и МСБ были хорошие отношения.

Банки второго уровня, или БВУ, это финансовые учреждения вроде банков и кредитных организаций, которые имеют официальные банковские лицензии. Они собирают вклады от обычных людей и от компаний, раздают кредиты, занимаются различными расчетами, оперируют с валютой. Кроме того, эти организации предлагают брокерские услуги и помощь в инвестициях. В отличие от Национального банка, который выступает центральным банком, БВУ действуют по общим рыночным правилам. Они привлекают средства, сами управляют своими активами и рисками. Еще они создают продукты, которые ориентированы на бизнес, включая малый и средний бизнес.

Банки второго уровня играют ключевую роль в превращении сбережений в инвестиции, направленные именно в сектор малого и среднего бизнеса. Эти банки выдают кредиты и открывают кредитные линии. Благодаря этому малые и средние предприятия могут запускать инвестиционные проекты, пополнять оборотные средства, расширять свою деятельность. Когда предприятия получают банковское финансирование, они покупают новое оборудование, вводят современные технологии, увеличивают объемы производства. В итоге это способствует общему росту экономики и появлению новых рабочих мест. Кроме того, предлагают факторинг и лизинг для финансирования оборотных и основных средств. Банки проводят расчетно-кассовое обслуживание. Они выдают гарантии и аккредитивы. Еще эти учреждения консультируют предпринимателей, помогают запускать и развивать бизнес. Наконец, предоставляют цифровые продукты вроде онлайн-банкинга и мобильных приложений.

Банки второго уровня дают предпринимателям инструменты, которые помогают снижать риски и упрощать ведение бизнеса. К таким инструментам относятся средства хеджирования валютных и процентных рисков. Они защищают компании от негативных изменений курсов валют и ставок по кредитам. Банки также предлагают торговые инструменты, например экспортные гарантии и аккредитивы. Это облегчает участие в международной торговле. Развитие онлайн-платежей и эквайринга позволяет предприятиям уменьшать операционные затраты. Кроме того, это помогает расширять рынки сбыта через удобные способы приема платежей от клиентов. В общем, БВУ не просто дают деньги в долг. Они обеспечивают комплексную помощь малому и среднему бизнесу, что способствует их развитию и стабильности.

Влияние банков на рост малого и среднего бизнеса можно описать через простую цепочку событий. Облегчение доступа к кредитам побуждает к большим инвестициям в дело. Это приводит к росту производства и созданию новых рабочих мест. Когда бизнес расширяется, предприятия начинают платить больше налогов. В итоге это улучшает бюджет страны. Сервисы от банков, такие как платежи и зарплатные проекты, помогают формализовать бизнес. Благодаря этому открывается путь к государственным программам поддержки. Формализация упрощает общение с властями. Она повышает прозрачность работы компаний.

В Казахстане несколько крупных банков активно помогают малому и среднему бизнесу. Среди них выделяются Halyk Bank, Kaspi Bank, ForteBank и Bank CenterCredit. Эти учреждения предлагают разнообразные услуги для представителей МСБ. Они охватывают всё от обычного кредитования до особых программ, которые реализуются вместе с

государственными органами. Банки создают персональные подходы для каждого клиента. При этом они учитывают специфику его дела и нужды в деньгах. Фонд Даму вместе с другими госструктурами работает с банками над льготными кредитами. Они дают гарантии и проводят обучающие события для МСБ. Такие меры помогают уменьшить финансовые препятствия. Они повышают доступ к средствам для небольших и средних фирм. К примеру, государство выдаёт гарантии по займам. Это снижает опасности для банков. В итоге банки могут давать кредиты тем компаниям, которые иначе не получили бы поддержку.

Государство также частично покрывает проценты по кредитам. Из-за этого займы становятся проще для МСБ. Теперь о наблюдениях, которые показывают положение сектора МСБ и вклад банков в его прогресс. С 2022 по 2024 год росло число как зарегистрированных, так и работающих субъектов МСБ. На 1 января 2023 года действующих субъектов МСП было 1 818,8 тысячи. Это больше, чем в 2022 году, где показатель составлял 1 431,6 тысячи. Такие цифры указывают на подъём деловой активности. Интерес к открытию своего дела тоже увеличивается. В 2023 и 2024 годах этот тренд продолжился.

Согласно данным KASE и отчётам, на 1 апреля 2024 года зарегистрированных предприятий МСБ насчитывалось около 2 184 тысяч. А действующих фирм было примерно 2 013 тысяч. Различные источники приводят похожие цифры. Это подтверждает надёжность информации. Доля МСБ в ВВП Казахстана за 2023 и 2024 годы, по оценкам, доходила до 38-39 процентов. Такие показатели говорят о растущем значении сектора для всей экономики страны. Рост вклада МСБ в ВВП подчёркивает их роль. Малые и средние предприятия всё важнее для экономического развития. Они также обеспечивают рабочие места для людей.

Банковский сектор играет важную роль в кредитовании МСБ, предоставляя значительную часть розничного и корпоративного кредитного портфеля. Доля кредитов, выданных МСБ, в общем объёме банковского кредитования является заметной (например, в некоторых отчётах указывается, что она составляет около четверти от всех выдач). Это подтверждает, что банки остаются одним из основных источников финансирования для малых и средних предприятий в Казахстане.

Обобщая представленные данные, можно сделать вывод о том, что сектор МСБ в Казахстане демонстрирует устойчивый рост, и БВУ продолжают играть ключевую роль в его финансовой поддержке. Для дальнейшего развития МСБ необходимо продолжать совершенствовать механизмы финансирования и создавать благоприятные условия для ведения бизнеса.

В отношениях между банками второго уровня и субъектами малого и среднего предпринимательства (МСБ) существует ряд сложностей, сдерживающих развитие последних и ограничивающих потенциал сотрудничества.

Одна из основных проблем заключается в ограниченной доступности кредитных средств для МСБ. Высокие процентные ставки, жесткие требования к залоговому обеспечению, а также длительные и бюрократизированные процедуры оформления кредитов делают займы дорогими и труднодоступными для многих предприятий малого и среднего бизнеса. Факторы, обуславливающие такую ситуацию:

Риск-ориентированная политика банков. Банки, оценивая риски, связанные с кредитованием МСБ, часто закладывают в процентные ставки повышенную премию за риск, обусловленную недостаточной прозрачностью финансового состояния и деятельности таких предприятий.

Административные издержки. Операционные расходы банков, связанные с рассмотрением заявок на кредиты и обслуживанием кредитных договоров с МСБ, могут быть относительно высокими, что также влияет на стоимость кредитных ресурсов.

Макроэкономическая нестабильность. Инфляционные процессы и общая макроэкономическая нестабильность в экономике создают дополнительную

неопределенность для банков и МСБ, что также может приводить к увеличению процентных ставок и ужесточению условий кредитования.

Проблема невозвратов кредитных средств – важный аспект. Высокий уровень просроченной задолженности и неплатежей по кредитам в отдельных сегментах МСБ (например, в сезонном бизнесе или торговле) приводит к тому, что банки вынуждены ужесточать свою кредитную политику, чтобы обезопасить себя от возможных убытков. Это, в свою очередь, приводит к сокращению числа кредитных предложений для МСБ. Возникает замкнутый круг: чем меньше кредитов выдается, тем меньше возможностей для развития МСБ.

Многие малые предприятия не располагают достаточным объемом ликвидного залогового имущества, а также не могут предоставить необходимые гарантии или подтвердить свою кредитную историю. Данная проблема может быть решена путем развития государственных гарантийных механизмов (например, через фонды гарантирования кредитов) и внедрения программ факторинга, позволяющих МСБ получать финансирование под уступку дебиторской задолженности.

Недостаточный уровень финансовой грамотности среди предпринимателей является еще одним фактором, затрудняющим взаимодействие МСБ с банками. Многие предприниматели не обладают достаточными навыками для подготовки качественных бизнес-планов, что затрудняет для банков оценку перспективности проектов и принятие решений о кредитовании.

Недостаточная цифровизация и скорость процессов. Медленные процедуры проверки клиентов (KYC), сложный документооборот и нехватка автоматизированных систем оценки кредитоспособности (скоринга) препятствуют масштабированию кредитования МСБ.

Практические решения: как банки второго уровня могут усилить поддержку МСБ.

Для повышения эффективности взаимодействия банков второго уровня и МСБ необходимы скоординированные усилия, направленные на решение вышеуказанных проблем. Банкам следует расширять линейку кредитных продуктов, адаптированных к потребностям различных сегментов МСБ. Возможные решения:

Гибкие кредитные линии. Предоставление краткосрочных оборотных кредитных ресурсов с возможностью изменения лимита в зависимости от сезонности бизнеса или колебаний спроса.

Кредитные овердрафты. Предоставление «кредитных овердрафтов» для покрытия текущих потребностей в финансировании.

Микрокредитование и факторинг. Развитие программ микрокредитования с упрощенной процедурой оформления, а также расширение использования факторинга.

Гарантийные механизмы и совместные программы. Необходимо расширять сотрудничество с государственными фондами гарантирования кредитов (Даму и региональные фонды), которые могут частично покрывать риски банков при кредитовании МСБ. Это позволит увеличить кредитоспособность клиентов, не требуя от них предоставления значительного залогового обеспечения.

Развитие цифровых скорингов и платформ. Внедрение цифровых систем оценки кредитоспособности МСБ на основе данных об электронных платежах, налоговой истории и отраслевой принадлежности позволит автоматизировать процесс принятия решений.

Финансовое образование и консультации. Банки могут организовывать образовательные программы, консультации и оказывать помощь начинающим предпринимателям. Это поможет улучшить качество кредитных заявок и снизить кредитные риски.

Альтернативные инструменты финансирования. Развитие таких альтернативных инструментов финансирования, как факторинг, краудфандинг, венчурное кредитование, позволит частично компенсировать недостаток доступных банковских кредитов.

Влияние банков второго уровня на сектор МСБ:

- Рост масштабов операций МСБ. Кредитные ресурсы позволяют МСБ расширять свою деятельность, увеличивать объемы производства и продаж.
- Упрощение ведения бизнеса. Платёжные и расчётные решения, предлагаемые банками (эквайринг, зарплатные проекты), значительно упрощают ведение бизнеса для МСБ, снижают транзакционные издержки и повышают эффективность управления финансами.
- Синергия с государственными программами. Участие банков в госпрограммах позволяет увеличить доступность финансирования для МСБ.

Ограничивающие факторы. Высокая стоимость и недостаточная гибкость кредитов ограничивают рост МСБ, особенно в рискованных областях. Замедленная цифровизация банков сдерживает поддержку МСБ. Системный эффект. Политика банков в отношении кредитования МСБ оказывает системное воздействие на структуру занятости и вклад МСБ в ВВП страны.

Практические рекомендации для банков и регуляторов. Для банков:

- Разрабатывать адаптированные кредитные продукты для разных этапов развития бизнеса МСБ.
- Инвестировать в скоринг и автоматизацию.
- Активно использовать госгарантии.

Для регуляторов:

- Развивать механизмы гарантирования и льготное кредитование.
- Уменьшать административные барьеры.
- Вводить налоговые льготы для начинающих предпринимателей.

К 2025 году в Казахстане заметен устойчивый рост малого и среднего бизнеса. Число таких компаний увеличилось с 1,43 миллиона в 2022 году до около 2,18 миллиона в 2025 году. Это означает, что за четыре года их количество выросло на 50 процентов. Такой подъем показывает укрепление бизнеса и всей экономики страны. Банки второго уровня активно поддерживают этот процесс. Они помогают предпринимателям получать необходимые средства. С 2022 по 2025 год объем кредитов для малого и среднего бизнеса заметно увеличился. Теперь около 33 процентов всех банковских кредитов направляется именно на эти предприятия. Это стало возможным благодаря совместным программам государства и частного сектора. В их число входят Фонд Даму, Холдинг Байтерек и специальные кредиты для ключевых отраслей. Банки приблизились к нуждам бизнеса. К 2025 году примерно 65 процентов малого и среднего бизнеса могут использовать банковские услуги. Это гораздо больше, чем в 2022 году. Крупные банки вроде Halyk, Kaspi, Forte, BCC и других разработали разнообразные цифровые продукты. Эти услуги включают обслуживание, кредитование, автоматизацию процессов и платежи. Все это создает удобную среду для предпринимателей.

Несмотря на успехи, у малого и среднего бизнеса остаются серьезные проблемы. Кредиты все еще дорогие. Недостаточно долгосрочных займов. Доступ к банковским услугам различается по регионам. Кроме того, для получения кредита часто требуют залог. Эти трудности замедляют развитие бизнеса. Они мешают малому и среднему бизнесу стать основной силой в экономическом росте.

Тем не менее, государство, банки и финансово-технологические компании работают над новыми формами финансирования. Среди них факторинг, краудфандинг, гранты и

онлайн-платформы. К 2025 году вклад малого и среднего бизнеса в экономику Казахстана достиг около 40 процентов. Это свидетельствует о движении страны к экономике, основанной на предпринимательстве, инновациях и частной инициативе.

В целом, банки второго уровня играют ключевую роль в развитии малого и среднего бизнеса в Казахстане. Они не только предоставляют кредиты. Но и способствуют модернизации бизнеса. Это создает условия для роста, конкуренции и экономических изменений. Если государство, банки и предприниматели продолжат сотрудничество, то малый и средний бизнес сможет дальше развиваться в будущем.

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Pedagogical Sciences

Communicative Tasks for the Development of Monologue Speech in Foreign Language Lessons for Students at the Basic Stage of Secondary School

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Abstract

This article explores theoretical and practical approaches to developing monologic speech among basic secondary school students in foreign language lessons. It emphasizes the importance of communicative competence as a foundation for effective language use and examines methods such as communicative teaching, task-based learning, lexical approaches, and CLIL (Content and Language Integrated Learning). The study highlights how these methods foster both linguistic accuracy and confidence in monologue speech and provides recommendations for applying communicative tasks in classrooms following Kazakhstan's competency-based standards.

Introduction

In modern education, the ability to communicate effectively in a foreign language is a fundamental skill. Beyond grammatical knowledge, students must develop the ability to express ideas clearly in both spoken and written forms. Monologue speech—the ability to speak at length on a topic—is particularly important at the basic secondary school level, as it encourages independent thought, logical structuring of ideas, and personal expression.

In Kazakhstan, educational reforms have shifted the focus from rote memorization to functional language use, integrating competency-based standards that prioritize meaningful communication over mechanical exercises (Kunanbayeva, 2013). This creates a need for methods that develop both accuracy and fluency in monologue speech.

Hymes (1972) emphasized that linguistic competence forms the foundation of communicative competence. Without a strong linguistic base, learners cannot produce grammatically correct and contextually appropriate utterances. Similarly, Canale and Swain (1980) distinguished between grammatical, sociolinguistic, discourse, and strategic competencies, highlighting the multidimensional nature of effective communication.

1. Intercultural Communicative Competence as a Component of Monologue Speech Development

Intercultural communicative competence refers to the ability to use language effectively in culturally appropriate ways, respecting social norms and values. It combines linguistic knowledge with understanding of cultural contexts, enabling students to communicate meaningfully in diverse situations.

Developing monologue speech requires students not only to organize their thoughts but also to consider the cultural expectations of their audience. For example, when describing holidays, traditions, or personal experiences, learners need to select vocabulary, expressions, and stylistic features suitable for their listeners.

The process of developing intercultural communicative competence can be enhanced through carefully designed tasks, including:

-Storytelling about personal or cultural experiences;
-Presentations on familiar or researched topics;
-Comparing and contrasting cultural practices;
-Discussing global issues from a local perspective.

Such tasks promote active engagement, critical thinking, and the ability to construct coherent, culturally informed monologues. Cognitive and social interaction, as emphasized by Vygotsky (1978) and Piaget (1970), plays a crucial role, enabling learners to internalize language structures while practicing meaningful communication.

2.Methods and Approaches to Teaching Monologue Speech in Foreign Language Lessons

Effective development of monologic speech relies on a combination of teaching methods that balance accuracy and fluency. Key approaches include:

Communicative Method

The communicative method emphasizes real-life use of language. Students participate in pair work, group discussions, and problem-solving tasks, using English in meaningful contexts. This helps internalize grammar and vocabulary naturally while building confidence in speaking (Richards & Rodgers, 2014).

Task-Based Learning (TBL)

TBL focuses on completing purposeful tasks, such as describing a place, giving instructions, or planning an event. Each task involves preparation, performance, and reflection, encouraging both linguistic and cognitive engagement. This aligns with constructivist principles, allowing students to construct knowledge actively (Willis, 1996; Ellis, 2003).

Lexical Approach

The lexical approach prioritizes vocabulary and phraseology over isolated grammar rules. Learners study collocations, idioms, and fixed expressions, which enables more natural and fluent monologues (Lewis, 1993). For example, using phrases like as a result or in my opinion helps students structure their speech effectively.

Grammar in Context

Grammar remains essential but should be taught within meaningful contexts. Texts, dialogues, and role-plays provide opportunities to apply structures communicatively, ensuring students understand both form and function (Harmer, 2007).

Integrated and CLIL Approaches

CLIL integrates content learning with language practice, allowing students to learn science, history, or geography in English. This expands vocabulary, motivates learners, and demonstrates the practical use of language outside traditional lessons (Coyle, Hood & Marsh, 2010).

3.The Role of the Teacher in Monologue Development

In communicative teaching, teachers are not mere evaluators; they are facilitators and co-participants. Their role includes:

-Designing communicative contexts that make speaking purposeful;
-Providing linguistic scaffolding such as phrases and connectors;
-Encouraging risk-taking and reducing fear of mistakes;
-Monitoring and providing feedback at appropriate times;
-Integrating monologue tasks into broader thematic units such as My Country, Holidays, or Environment.

Teachers also adjust tasks for mixed-ability groups, allowing weaker students to present simpler monologues while stronger students produce more complex discourse.

1.Assessment of Monologic Speech

Assessment should reflect communicative competence rather than isolated linguistic knowledge. Key criteria include:

1.Content relevance – addressing the topic fully;
2.Organization and coherence – clear structure with introduction and conclusion;
3.Language range and accuracy – diverse vocabulary and correct grammar;
4.Fluency and pronunciation – smooth delivery and clear articulation;
5.Expressiveness and engagement – ability to capture and maintain attention (Hymes, 1972).

Formative techniques, such as two stars and a wish or peer feedback, allow students to reflect and learn collaboratively.

Conclusion

Developing monologic speech in basic secondary school students is a multifaceted process that combines linguistic, cognitive, and cultural skills. Communicative tasks, when carefully designed and integrated, provide opportunities for learners to express themselves meaningfully, think critically, and engage confidently with the target language.

Through storytelling, reports, descriptions, and creative projects, students progress from simple sentence production to coherent, organized discourse. Teachers serve as guides, creating supportive environments that encourage risk-taking and self-expression.

In short, communicative tasks are more than instructional tools—they are a bridge from classroom learning to real-world communication. When applied consistently, they transform students from passive listeners into active language users capable of expressing their ideas clearly, confidently, and meaningfully.

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THE USE OF GAMIFICATION AS A METHOD IN TEACHING ENGLISH TO SECONDARY SCHOOL STUDENTS

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ABSTRACT

This article examines the use of gamification as an instructional method in teaching English to secondary school students. Grounded in contemporary approaches to language education, gamification involves the systematic integration of game elements—such as points, badges, levels, and leaderboards—into classroom activities to create structured, engaging learning experiences. The study employed a one-group pre-test–post-test design with 50 students aged 14 to 17 to evaluate changes in English proficiency and engagement before and after the implementation of gamified instruction. Quantitative results revealed a notable increase in language proficiency, with overall performance improving by 16.2% across vocabulary, grammar, reading, and listening. Student engagement also showed a strong positive trend, increasing from an average score of 3.2 to 4.4 on a 5-point scale. These findings demonstrate that gamification promotes more active participation, enhances task completion, and supports measurable learning outcomes. The article concludes that when implemented with a clear methodological framework, gamification functions not merely as a motivational tool but as an effective instructional method for organizing and enhancing English language learning in secondary schools.

Key words: Gamification, English language teaching, secondary school students, instructional methods, engagement, language proficiency, educational technology.

INTRODUCTION

The incorporation of interactive, technology-driven strategies has increasingly shaped contemporary English language instruction in secondary schools. Traditional approaches, including the Grammar–Translation Method, the Direct Method, and Communicative Language Teaching (CLT), while foundational for language learning, often rely heavily on teacher-led instruction and structured drills, limiting opportunities for varied engagement and active participation (Saleem & Ozdamli, 2022). As classrooms evolve to accommodate digital tools and innovative teaching methods, alternative approaches that integrate structured interaction with systematic instructional design have gained prominence. Among these, gamification has emerged as a notable method for enhancing classroom activities and learning outcomes.

The concept of gamification, first introduced by Nick Pelling in 2002, refers to “the use of game-design elements in non-game contexts” (Dreimane, 2018; Nadi-Ravandi & Batooli, 2022). Later conceptualizations refined this definition, with Huotari and Hamari (2017) describing gamification as a “process of enhancing services with affordances for gameful experiences to support users’ overall value creation.” In the context of education, gamification involves the systematic integration of game mechanics—such as points, badges, levels, challenges, and leaderboards—into structured classroom activities to facilitate measurable learning progress

(Triantafyllou, Georgiadis, & Sapounidis, 2025). Unlike conventional methods that primarily emphasize linguistic knowledge acquisition through repetitive practice or cognitive exercises, gamification offers a methodical approach to instructional design, in which tasks are framed as structured challenges, providing clear objectives, rules, and feedback mechanisms that support classroom management and measurable learning outcomes (González-González, 2023).

While multiple instructional approaches, such as Task-Based Language Teaching (TBLT), project-based learning, and Content and Language Integrated Learning (CLIL), have been employed to develop language skills, these methods typically prioritize cognitive engagement through problem-solving and communication-focused activities. Gamification, in contrast, applies a systematic methodological framework that emphasizes task sequencing, goal-setting, and iterative assessment, aligning instructional tasks with observable outcomes (Huotari & Hamari, 2017). This method allows educators to plan, implement, and evaluate activities with clear procedural steps, ensuring structured progression in learning while maintaining consistency across sessions.

The aim of this study is to examine the effectiveness of gamification as a method for improving English language teaching and learning outcomes among secondary school students. The specific objectives are:

1. To analyze the theoretical foundations of gamification as a method in English language education.
2. To design and implement gamification-based classroom activities aimed at enhancing students' English language skills.
3. To conduct an experimental study to evaluate the effectiveness of gamification as a method for improving English language proficiency in secondary school learners.

Accordingly, the research seeks to address the following question: How can gamification be effectively implemented as a method for teaching English in secondary schools to improve learning outcomes within structured classroom environments?

By exploring the structured application of gamification in secondary school English classrooms, this study contributes to understanding how methodical incorporation of interactive elements can enhance lesson design, organization, and instructional effectiveness.

LITERATURE REVIEW

Recent research has increasingly highlighted the role of gamification as a structured method in English language instruction. Among international scholars, notable contributions have been made by Kapp (2015), Dehghanzadeh et al. (2021), Li et al. (2022), and Wulantari et al. (2023), whose studies emphasize the systematic incorporation of game elements—such as points, badges, leaderboards, and challenges—into learning tasks to enhance engagement and structured progression. These studies demonstrate that gamification can transform conventional classroom activities into methodically designed learning experiences, where tasks are sequenced, rules are clearly defined, and feedback mechanisms provide measurable outcomes.

Dehghanzadeh et al. (2021) conducted a systematic review examining gamification across various educational disciplines, including English language learning. Their findings indicate that gamified environments improve students' task completion rates and adherence to structured learning objectives, particularly when game elements are explicitly aligned with pedagogical aims rather than applied solely for entertainment. Similarly, Li et al. (2022) investigated the use of gamification-based mobile applications for English vocabulary acquisition. The study revealed that students exposed to gamified exercises demonstrated higher retention and more consistent engagement with instructional tasks compared to traditional drill-based methods, underscoring the methodological advantages of integrating structured game elements into learning sequences.

Wulantari et al. (2023) focused on gamification in English Language Teaching (ELT) and emphasized the importance of systematic task design. Their review highlighted that features such as leaderboards, point systems, and achievement badges can be integrated into lessons to establish clear performance benchmarks and track learners' progress. The authors also noted implementation challenges, including the necessity of adequate technological infrastructure and teacher preparation, both of which are essential for the consistent application of gamification as a method.

The application of gamification has also been explored in the Kazakhstani educational context. Kamaladin (2024) examined the integration of gamified activities combined with audio content in university-level English instruction. The study demonstrated that structured gamification facilitated measurable improvements in task completion, listening exercises, and pronunciation accuracy. Likewise, Rzabayeva et al. (2024) investigated gamification at the secondary school level, finding that features such as points, badges, and progress monitoring contributed to systematically observable improvements in classroom participation and completion of assigned learning tasks. Duisenova, Zhorabekova, and Ainabekova (2024) further confirmed that gamified lessons, when applied with a clear methodological framework, enhanced learners' task engagement and promoted structured interaction among students, emphasizing the importance of balancing competitive and collaborative elements within the instructional design.

Across both international and Kazakhstani studies, gamification is recognized not merely as a motivational tool but as a methodical instructional approach that enables systematic task sequencing, iterative feedback, and measurable learning outcomes. The reviewed literature collectively demonstrates that gamification can serve as a robust methodological framework in secondary school English education, providing clear procedures for activity design, assessment, and instructional evaluation, thus bridging theoretical models with practical classroom applications.

MATERIALS AND METHODS

Research Design

This study used a one-group pre-test and post-test design to evaluate the effectiveness of gamification as a method in teaching English to secondary school students.

The same participants completed both the diagnostic (pre-test) and control (post-test) assessments to identify differences in English language proficiency and learning engagement after gamified instruction. Table 1 presents the structure of the research design, illustrating the stages, descriptions, and purposes of the study.

Table 1

Research Design Structure

Stage	Description	Purpose
Pre-test (Diagnostic Stage)	Online testing in Google Forms assessing English proficiency and engagement before gamified instruction	Establish baseline data
Gamification Phase	Implementation of English lessons using gamification-based activities (points, badges, leaderboards)	Apply instructional intervention
Post-test (Control Stage)	Repeated Google Forms test with same structure	Measure change in proficiency and engagement

Participants

The participants consisted of 50 students (aged 14–17 years) from a secondary school in Almaty, Kazakhstan. All students had prior experience with traditional, teacher-centered English instruction. Participation was voluntary and anonymous, and students were informed about the academic purpose of the research. Table 2 summarizes the demographic profile of the participants.

Table 2

Statistical Information of Participants

Characteristic	Description
Sample size	50 students
Age range	14–17 years
Educational level	Secondary school
Setting	Almaty, Kazakhstan
Participation	Voluntary and anonymous

Materials and Instruments

1. Pre-Test (Diagnostic Stage)

At the beginning of the study, students completed an online diagnostic test administered through Google Forms. Figure 1 illustrates the structure of the pre-test survey administered via Google Forms, including sections for English language proficiency (reading, listening, vocabulary, writing) and engagement/motivation.

Figure 1

Screenshot of the Google survey used in this study

The test included two parts:

1. Language proficiency assessment, evaluating reading, listening, vocabulary, and writing components using multiple-choice and short-response items aligned with the A2–B1 CEFR levels.
2. Engagement and motivation questionnaire, consisting of 15 Likert-scale items designed to assess students' attitudes toward English learning, classroom participation, and self-reported motivation before the gamified intervention.

The pre-test results established a baseline for subsequent comparison with post-test data.

2. Gamification-Based Instructional Materials

During the experimental phase, English lessons were redesigned to incorporate gamification elements such as:

– Points and badges for completing tasks;
– Levels and progress bars for tracking achievements;
– Leaderboards to foster healthy competition;

– Team challenges and mini-quests promoting collaboration;
– Immediate feedback and rewards to reinforce participation.

Gamified activities included vocabulary quizzes, interactive storytelling, role-play missions, and listening comprehension games using digital tools (e.g., Kahoot!, Quizizz, and Classcraft).

The content was aligned with the national English curriculum for secondary schools.

3. Post-Test (Control Stage)

After the instructional intervention, students completed a post-test with an identical structure to the pre-test, also conducted via Google Forms. Figure 2 presents the post-test survey administered at the end of the intervention.

Figure 2

Screenshot of the Google survey used in this study

The post-test measured:

1. Students' progress in English proficiency through comparable linguistic tasks;
2. Changes in their motivation, engagement, and perception of the gamified learning experience using Likert-scale and open-ended items.

This stage allowed for a direct comparison of outcomes before and after the gamified instruction.

Procedure

The study was conducted over a six-week period and consisted of three main stages:

1. Diagnostic Stage (Week 1):

Students participated in the pre-test to determine their initial English language level and engagement. The results established a baseline dataset.

2. Gamified Instructional Stage (Weeks 2–5):

Over the next four weeks, participants were taught using gamification-based methods integrated into regular English lessons. Each session included structured game elements such as points, team missions, progress tracking, and feedback mechanisms. The teacher facilitated lessons according to the designed gamification framework, ensuring consistency and alignment with curriculum objectives.

3. Control Stage (Week 6):

At the end of the instructional period, the post-test was administered. Students' language proficiency and engagement data were collected and compared with pre-test results to evaluate the effectiveness of the gamified method.

Data Collection and Analysis

Data from both stages were automatically recorded through Google Forms and exported into Microsoft Excel for statistical analysis.

Descriptive statistics (mean, frequency, and percentage) were used to summarize responses. A comparative analysis between pre-test and post-test results was conducted to determine improvement in:

– English proficiency levels;
– Student motivation and engagement indicators.

Qualitative responses from open-ended items were analyzed through content analysis, identifying recurring themes related to students' perceptions of gamified learning, motivational changes, and classroom dynamics.

Ethical Considerations

Participation in the study was entirely voluntary. Students were informed of the study's purpose, and their anonymity was preserved throughout the process. No personal data were collected. The research adhered to institutional ethical standards and aimed to ensure transparency, confidentiality, and academic integrity.

RESULTS

Overview of Data Collection

A total of 50 secondary school students aged between 14 and 17 years participated in both the pre-test and post-test stages. All participants completed the online assessments administered through Google Forms. The collected data were analyzed quantitatively using descriptive statistics to compare results before and after the gamification-based instruction. The comparison focused on two key areas:

1. English language proficiency, and
2. Student engagement in the learning process.

Comparison of English Language Proficiency

The results of the English language proficiency assessment revealed substantial improvement in students' overall performance after gamified instruction.

As presented in Table 3, the overall mean score increased from 67.4% in the pre-test to 83.6% in the post-test, demonstrating a 16.2% improvement in English language achievement.

Table 3

Comparison of English Language Proficiency (Pre-test and Post-test)

Skill Area	Pre-test Mean (%)	Post-test Mean (%)	Difference	Interpretation
Vocabulary	65.2	82.3	+17.1	Noticeable improvement in lexical range
Grammar	68.1	85.4	+17.3	Marked progress in sentence accuracy
Reading	69.0	84.7	+15.7	Enhanced comprehension and fluency
Listening	67.3	82.1	+14.8	Greater auditory understanding
Overall Mean	**67.4**	**83.6**	**+16.2**	**Significant increase**

Note. Scores represent mean percentages of correct responses across four language areas.

The most notable increase was observed in grammar, which rose by 17.3% from 68.1% to 85.4%. This improvement reflects the positive influence of game-based tasks such as digital quizzes and "grammar challenges," where students earned points for accurate sentence construction. The vocabulary domain also exhibited a strong increase of 17.1%, suggesting that game mechanics like leaderboards and rewards effectively encouraged consistent participation in word-learning activities.

The reading skill improved by 15.7%, moving from 69.0% to 84.7%. Students' better comprehension may be attributed to gamified tasks involving interactive texts and time-limited reading competitions that promoted concentration and engagement. Similarly, listening comprehension improved from 67.3% to 82.1% (+14.8%), indicating that audio-based gamified exercises enhanced students' focus and accuracy when identifying spoken information.

Overall, the increase across all skill areas demonstrates that gamification contributed not only to greater accuracy but also to sustained participation during language activities. The structured competitive environment appeared to motivate learners to complete tasks more diligently and to monitor their progress throughout the course.

Comparison of Student Engagement Scores

The results of the engagement questionnaire revealed a considerable increase in students' overall involvement and interest in learning English after gamification was introduced.

As shown in Table 4, the average engagement level increased from 3.2 in the pre-test to 4.4 in the post-test on a 5-point Likert scale, reflecting a 1.2-point improvement.

Table 4

Student Engagement Levels Before and After Gamified Instruction

Engagement Indicator	Pre-test Mean (1–5)	Post-test Mean (1–5)	Change	Description
Interest in lessons	3.1	4.5	+1.4	Students found lessons more engaging and meaningful
Active participation	3.0	4.4	+1.4	Greater willingness to respond and contribute
Collaboration	3.3	4.2	+0.9	Improved cooperation and group interaction
Enjoyment of activities	3.2	4.6	+1.4	Higher satisfaction and enjoyment of tasks
Average Engagement	**3.2**	**4.4**	**+1.2**	**Strong positive trend**

Note. Responses were measured on a 5-point scale (1 = strongly disagree, 5 = strongly agree).

The largest gains occurred in interest in lessons and active participation, both increasing by 1.4 points. Students reported that earning points, competing in small groups, and viewing leaderboards made lessons more dynamic and rewarding. The enjoyment of activities indicator also increased by 1.4 points, reflecting students' appreciation for interactive and visually appealing digital exercises.

The collaboration indicator showed a smaller but still meaningful rise of 0.9 points, from 3.3 to 4.2, suggesting that while competition was the main driver of motivation, teamwork and peer assistance were also strengthened. Students reported that team-based challenges allowed them to share knowledge, exchange strategies, and collectively achieve goals.

Collectively, these results show that gamified instruction not only enhanced academic performance but also fostered a more positive learning atmosphere. The use of clear goals, feedback mechanisms, and visible progress indicators provided structure and immediate reinforcement, resulting in a higher level of classroom engagement and task completion.

Qualitative Observations

Observational data gathered during the intervention further supported the quantitative findings. Throughout the gamified lessons, students demonstrated increased attentiveness and enthusiasm, often requesting additional rounds of game-based exercises. Teachers noted that even previously passive learners became more active when participating in point-based challenges and team competitions. Anonymous comments collected in the post-test questionnaire included statements such as "I liked earning points for correct answers" and "The games helped me remember words faster."

These observations confirm that the structured use of gamification elements—such as points, badges, and immediate feedback—created a motivating classroom environment conducive to sustained learning and participation.

DISCUSSION

The results of this study provide clear evidence that the use of gamification as a method in teaching English to secondary school students leads to substantial improvements in both language proficiency and learner engagement. The overall increase in English proficiency scores from 67.4% to 83.6% across vocabulary, grammar, reading, and listening suggests that integrating structured game elements into lessons supports systematic learning progress. In particular, the largest gains were observed in grammar (+17.3%) and vocabulary (+17.1%), indicating that rule-based and reward-driven activities such as quizzes, point accumulation, and leaderboard competitions enhance accuracy and lexical recall. These findings demonstrate that gamification, when applied methodically, strengthens not only participation but also measurable learning outcomes.

The engagement data further reinforce this trend. Students' average engagement score rose from 3.2 to 4.4 on a 5-point scale, with notable increases in interest in lessons (+1.4), active participation (+1.4), and enjoyment of activities (+1.4). These results highlight the motivational impact of gamified instruction, which transforms routine classroom activities into interactive challenges with immediate feedback and visible progress indicators. The smaller yet positive increase in collaboration (+0.9) reflects the dual influence of competition and teamwork inherent in gamified environments. Students' qualitative feedback, describing enjoyment in earning points and participating in class challenges, supports the quantitative results and underscores the role of gamification in creating a dynamic, student-centered learning atmosphere.

These findings are consistent with prior international research emphasizing the educational benefits of gamification. Kapp (2015) and Dehghanzadeh et al. (2021) both argued that game mechanics such as points, badges, and rewards reinforce learning behaviors and sustain engagement. Similarly, Li et al. (2022) found that gamified mobile applications enhanced vocabulary retention and consistency in learning, mirroring the vocabulary improvement observed in this study. Wulantari et al. (2023) highlighted the importance of structured task design in gamification, which aligns with the present study's results showing that goal-oriented and rule-based activities promote better task completion and measurable skill improvement.

Research within the Kazakhstani context also supports these conclusions. Kamaladin (2024) demonstrated that integrating gamified tasks with audio-based learning improved students' pronunciation and listening outcomes, similar to the 14.8% improvement in listening comprehension found in this study. Likewise, Rzabayeva et al. (2024) and Duisenova et al. (2024) reported that gamified English lessons enhanced participation and completion of classroom tasks, echoing the engagement results presented here. Together, these findings suggest that gamification is not only an engaging addition to English instruction but also a valid methodological framework capable of structuring and sustaining language learning in secondary schools.

However, certain challenges were also observed. While most students responded positively, some required additional explanation of rules and procedures at the beginning of the intervention, indicating that successful implementation depends on clear task design and teacher

guidance. This observation aligns with Wulantari et al. (2023), who emphasized the need for adequate teacher preparation and technological readiness. The experience of this study suggests that while gamification can significantly enhance learning outcomes, its effectiveness depends on teachers' ability to balance competition with collaboration and ensure consistent, meaningful feedback.

Overall, the present research contributes to the growing evidence base on gamification by demonstrating its effectiveness within the secondary school context, an area less frequently examined compared to higher education. The improvement in both quantitative scores and observed classroom behavior provides strong support for gamification as a structured instructional method that promotes linguistic development and learner engagement in a measurable, systematic way.

CONCLUSION

This study demonstrated that gamification can serve as an effective and structured method for teaching English to secondary school students. The one-group pre-test–post-test design revealed clear improvements in both academic performance and classroom engagement after gamified instruction. Students showed higher proficiency in vocabulary, grammar, reading, and listening, along with increased interest, participation, and enjoyment during lessons. These results confirm that when gamification is integrated with a clear methodological framework—emphasizing goals, feedback, and progress tracking—it can substantially enhance the learning process.

The findings also highlight the importance of thoughtful instructional design and teacher preparation. Gamification is most effective when applied consistently and supported by digital tools that allow for real-time feedback and visible progress. For schools, this implies the need to train teachers not only in the technical use of gamified platforms but also in the pedagogical strategies required to implement them effectively.

By integrating play-based mechanisms into structured learning environments, gamification bridges the gap between enjoyment and academic rigor. It transforms traditional English instruction into an interactive, measurable, and student-centered process. Future studies could expand on these results by applying a controlled design with multiple groups, exploring long-term retention effects, and assessing how gamification influences other language skills such as speaking and writing.

Ultimately, this research confirms that gamification, when systematically applied, is not merely a motivational tool but a robust methodological approach that supports effective, engaging, and outcome-driven English language education in secondary schools.

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THE EFFECTIVENESS OF THE FLIPPED CLASSROOM IN TEACHING ENGLISH TO SECONDARY SCHOOL STUDENTS

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ABSTRACT

This article examines the effectiveness of the flipped classroom model in improving English language proficiency and learning motivation among secondary school students. Grounded in constructivist and self-determination theories, the flipped classroom reverses traditional instruction by delivering theoretical content through digital materials outside of class and dedicating classroom time to collaborative and communicative practice. The study involved fifty students aged 14 to 17 who previously learned through conventional methods. Data were collected through pre- and post-tests administered via Google Forms to measure changes in language skills and motivation. Results revealed notable improvements in speaking, vocabulary, and overall engagement, demonstrating that technology-supported, student-centered learning enhances both achievement and autonomy. The findings underscore the importance of well-structured digital instruction, teacher readiness, and equitable technological access for effective implementation.

Keywords: flipped classroom, English language learning, secondary education, technology-enhanced learning, student engagement

INTRODUCTION

The integration of digital technologies and learner-centered approaches has fundamentally reshaped contemporary English as a Foreign Language (EFL) instruction. Traditional teacher-led classrooms, while effective for foundational grammar and vocabulary learning, often limit student participation and higher-order thinking (Lo & Hew, 2017). As education increasingly values autonomy and active engagement, alternative instructional models have emerged to foster deeper learning and communicative competence. Among the most prominent are blended learning, project-based learning, problem-based learning, task-based language teaching (TBLT), and the flipped classroom model (FCM) (Ellis, 2017; Zainuddin & Perera, 2019). Each seeks to transform students from passive recipients of information into active constructors of knowledge.

The flipped classroom, first conceptualized by Jonathan Bergmann and Aaron Sams (2012), reverses the traditional sequence of instruction: theoretical input is delivered outside the classroom—commonly through videos or digital materials—while in-class time is devoted to collaborative practice, problem-solving, and teacher-guided feedback. According to Bishop and Verleger (2013), the flipped model is “a pedagogical approach in which direct instruction moves from the group learning space to the individual learning space, transforming class time into an interactive, student-centered environment” (p. 5). Grounded in constructivist, cognitive load, and self-determination theories, this approach supports individualized pacing and enhances motivation

through autonomy and interaction (Zainuddin & Halili, 2016; Wagner, Gegenfurtner, & Urhahne, 2025).

While a variety of instructional approaches exist in language education—such as the Grammar–Translation Method, the Direct Method, Communicative Language Teaching (CLT), and Task-Based Language Teaching (TBLT)—the flipped classroom uniquely combines pre-class independent preparation with in-class communicative application (Ayçiçek & Yanpar Yelken, 2018; Webb & Doman, 2020). This integration aligns particularly well with EFL instruction, where exposure and interaction are key to developing linguistic competence. Unlike traditional methods emphasizing rote memorization or isolated grammar drills, the flipped model encourages learners to apply linguistic knowledge in authentic contexts, promoting both accuracy and fluency.

Empirical studies since 2015 have provided evidence that the flipped classroom can enhance students' engagement, motivation, and academic achievement (Hung, 2017; Zainuddin & Perera, 2019). However, recent meta-analytic findings reveal that its overall effectiveness varies depending on instructional quality, learner readiness, and teacher facilitation (Wagner et al., 2025). Furthermore, research on the flipped model has predominantly focused on tertiary education, leaving a gap regarding its outcomes in secondary school EFL settings, where learners differ in developmental, motivational, and self-regulatory capacities (Lo & Hew, 2017). Understanding how the flipped approach functions in this context is therefore essential for guiding pedagogical decisions at the secondary level.

The present study aims to examine the effectiveness of the flipped classroom model in teaching English in secondary schools. Its specific objectives are to:

1. To examine the theoretical foundations of the flipped classroom model in secondary school English education.
2. To design and implement flipped classroom activities aimed at enhancing students' English language achievement and engagement.
3. To conduct an experimental study to evaluate the effectiveness of the flipped classroom in promoting students' academic performance, engagement, and self-regulated learning behaviors.

Accordingly, this study addresses the following research question: How does the flipped classroom model affect secondary school students' English language achievement and engagement compared to traditional teacher-centered instruction?

By redefining the interaction between teachers and learners through technology-enhanced instruction, the flipped classroom model offers a significant advancement in modern pedagogy. Examining its effectiveness in secondary school English education is essential for connecting theoretical promise with classroom practice and for advancing evidence-based approaches that promote deeper learning and sustained student engagement.

LITERATURE REVIEW

Among contemporary scholars who have examined the flipped classroom model (FCM) in English language education, researchers such as Ayçiçek and Yanpar Yelken (2018), Hung (2017), Webb and Doman (2020), Zainuddin and Perera (2019), and Wagner, Gegenfurtner, and Urhahne (2025) have made significant contributions to understanding its pedagogical value and limitations. The flipped classroom has emerged as a leading model of technology-enhanced instruction, reshaping how learners engage with content and how teachers facilitate learning. Instead of introducing new material during class, teachers deliver core content beforehand—typically through pre-recorded lectures or online materials—allowing classroom time to focus on interaction, feedback, and the application of knowledge.

The concept of the flipped classroom was popularized by Jonathan Bergmann and Aaron Sams (2012), who sought to address time constraints and improve student participation by

reversing the traditional learning process. This approach aligns with constructivist principles, emphasizing that learning occurs through active engagement rather than passive reception (Bishop & Verleger, 2013). In language learning contexts, particularly in English as a Foreign Language (EFL) classrooms, the FCM provides students with opportunities to process linguistic input at their own pace and to apply it communicatively in the classroom, thereby improving both accuracy and fluency (Zainuddin & Halili, 2016; Webb & Doman, 2020).

Ayçiçek and Yanpar Yelken (2018) conducted an experimental study examining how the flipped classroom influences secondary school students' classroom engagement in teaching English. Over a semester, one group of students was taught using the FCM, while a control group continued with traditional instruction. The results demonstrated that students in the flipped classroom showed higher levels of behavioral, cognitive, and affective engagement. They participated more actively, collaborated more effectively, and reported greater enjoyment of learning. These findings underscore the model's ability to transform classroom dynamics by granting students more responsibility for their learning while allowing teachers to act as facilitators rather than lecturers.

Similarly, Hung (2017) redesigned an English language course through a flipped approach and found improvements in students' learning motivation and self-regulated learning behaviors. The study highlighted that the FCM helps learners develop autonomy by giving them control over the timing and pace of initial instruction. However, Hung also noted that the success of the model depends heavily on students' preparedness and teachers' skill in designing meaningful in-class activities that connect pre-class content to practical application.

A comprehensive review by Webb and Doman (2020) synthesized findings from multiple studies on flipped classrooms in EFL contexts. The authors concluded that the FCM consistently enhances learners' motivation, communication skills, and linguistic competence. However, they emphasized that effectiveness varies according to implementation quality. Poorly structured materials or insufficient teacher guidance may lead to student frustration or superficial engagement. The study recommended that teachers integrate formative assessments, group discussions, and feedback sessions to ensure that flipped activities remain interactive and cognitively demanding.

Expanding this perspective, Zainuddin and Perera (2019) explored how the flipped classroom supports students' psychological needs based on Self-Determination Theory. Their study found that the FCM promotes competence, autonomy, and relatedness—three fundamental elements for intrinsic motivation and sustained engagement. When students are empowered to learn at their own pace and collaborate meaningfully with peers, they develop stronger confidence and persistence in language learning.

From a broader perspective, Wagner, Gegenfurtner, and Urhahne (2025) conducted a meta-analysis synthesizing the effectiveness of flipped classrooms across multiple disciplines and educational levels. Their results confirmed that while the FCM produces overall positive effects on academic performance and engagement, the effect sizes are typically moderate. The authors attributed these variations to contextual factors such as instructional design quality, student self-regulation, and teacher facilitation.

The reviewed studies collectively demonstrate that the flipped classroom model transforms English instruction by integrating digital technology, student autonomy, and interactive learning. It allows students to master foundational concepts independently and apply them collaboratively during class, fostering communication, creativity, and confidence.

METHODS

Research Design

This study employed a one-group pretest–posttest quasi-experimental design to examine the effectiveness of the flipped classroom model (FCM) in teaching English to secondary school students. The design was selected to measure changes in students' English proficiency and motivation before and after exposure to the flipped classroom method. The independent variable was the implementation of the flipped classroom model, and the dependent variables were students' English language achievement and learning motivation. Table 1 presents the structure of the research design.

Table 1.

Structure of the One-Group Pretest–Posttest Design

Phase	Description	Instruments	Purpose
Pre-test	Assessment of students' baseline English proficiency and motivation before intervention	Google Forms questionnaire and English skills test	To establish initial levels
Intervention	Implementation of flipped classroom lessons (6 weeks)	Video lectures, online materials, in-class communicative activities	To apply the flipped model
Post-test	Assessment of English proficiency and motivation after intervention	Google Forms post-test	To evaluate changes and effectiveness

The flipped classroom model was introduced as a teaching innovation that reverses the traditional learning order: students received theoretical materials before class through videos and online exercises, and class time was devoted to communicative, collaborative, and feedback-based learning activities.

Participants

The study involved 50 students (aged 14–17) from a secondary school in Almaty, Kazakhstan. All participants had previously studied English through traditional teacher-centered instruction. The group included both male and female students, and participation was voluntary. Parental consent and administrative approval were obtained before data collection. Table 2 summarizes the demographic profile of the participants.

Table 2.

Demographic Characteristics of Participants (N = 50)

Variable	Category	Frequency	Percentage
Gender	Male	22	44%
	Female	28	56%
Age	14	10	20%
	15	14	28%
	16	16	32%
	17	10	20%
Previous Learning Method	Traditional (teacher-centered)	50	100%

All participants had at least three years of prior English study, primarily focused on grammar and reading comprehension.

Instruments

Data were collected using three main instruments, all administered digitally via Google Forms:

1. English Language Skills Test – measured students' proficiency in reading, listening, writing, speaking (self-assessment), and vocabulary. Each skill was rated on a 5-point Likert scale ranging from Strongly Disagree (1) to Strongly Agree (5).
2. Motivation and Engagement Questionnaire – assessed students' interest, confidence, and engagement in English learning. It included items such as "I feel motivated to participate in English lessons" and "I enjoy using technology in learning."
3. Post-Test Survey – parallel in structure to the pre-test but focused on perceived improvement and experience with the flipped classroom.

Both the pre-test and post-test contained 20 items, divided into four sections: General Information, English Skills, Motivation and Engagement, and Reflection. Table 3 outlines the structure of the survey instruments.

Table 3.

Structure of Pre- and Post-Test Instruments

Section	Focus	Number of Items	Example Item
1. General Information	Demographic and background info	4	"How many years have you been learning English?"
2. English Skills	Self-assessment of reading, writing, speaking, listening, and vocabulary	5	"I can express my ideas in English during class discussions."
3. Motivation & Engagement	Interest, confidence, and participation	6	"I enjoy learning English through online videos and tasks."
4. Reflection	Learners' opinions and qualitative feedback	5	"What activities help you learn English better?"

Reliability of the questionnaire was established through pilot testing (Cronbach's $\alpha = .87$), indicating acceptable internal consistency.

Procedure

The research was conducted over six weeks during the 2024–2025 academic year at a local secondary school. The procedure consisted of three main stages:

1. **Pre-test stage (Week 1):** Students completed the English proficiency and motivation questionnaire using Google Forms. This established their baseline performance and attitudes toward English learning. Figure 1 illustrates the structure and content layout of the first survey instrument used in this stage, showing how questions were designed to measure students' language skills, engagement, and motivational levels prior to the flipped classroom intervention.

Figure 1.

Screenshot of the Google survey №1 used in this study

2. Flipped classroom implementation (Weeks 2–6):

– Students were provided with video lectures, online grammar lessons, and short readings before class.
– In class, they worked collaboratively on communicative activities, problem-solving tasks, and teacher-guided discussions.
– The teacher's role shifted from lecturer to facilitator, offering feedback and guidance based on students' pre-class preparation.

3. Post-test stage (Week 6): After completing the flipped classroom lessons, students took the same questionnaire to assess changes in skills and motivation. Qualitative reflections were also collected for deeper insight. Figure 2 presents the design of the post-test Google Form used in this phase, illustrating how identical items were employed to ensure consistency in measuring progress while also including open-ended questions for qualitative feedback.

Figure 2.

Screenshot of the Google survey №2 used in this study

Table 4.

Summary of the Research Procedure

Stage	Description	Duration	Purpose
Pre-test	Assessment of baseline English proficiency and motivation	1 week	Measure initial levels
Flipped Classroom Implementation	Online learning + interactive class sessions	5 weeks	Introduce flipped instruction
Post-test	Assessment after intervention	1 week	Evaluate improvement

All materials were stored securely, and participants were informed of their right to withdraw at any point without penalty. Table 4 summarizes the main steps of the procedure.

Data Analysis

Data from pre- and post-tests were analyzed using SPSS (Statistical Package for the Social Sciences). The following statistical procedures were applied:

- Descriptive statistics (means, standard deviations, and percentages) to summarize pre-test and post-test results.
- Paired-sample t-test to determine whether there was a statistically significant difference between pre- and post-test scores for English proficiency and motivation.
- Qualitative responses from open-ended questions were analyzed through thematic coding, identifying recurring patterns in students' perceptions of the flipped classroom.

A significance level of $p < .05$ was used to determine statistical relevance.

Ethical Considerations

All ethical guidelines were followed. Participation was voluntary, with informed consent obtained from both students and parents. Personal data were anonymized, and the study was approved by the school's administration.

RESULTS

This section presents the results of the pre-test and post-test analyses aimed at evaluating the effectiveness of the flipped classroom model (FCM) in improving secondary school students' English language proficiency and learning motivation. The analysis included descriptive statistics to illustrate general trends and paired-sample t-tests to determine whether observed differences were statistically significant.

Descriptive Statistics

Descriptive statistics were computed to compare students' English language skills and motivation before and after the implementation of the flipped classroom. Table 5 displays the means and standard deviations for each measured variable.

Table 5.

Descriptive Statistics for English Language Skills and Motivation (N = 50)

Variable	Pre-Test M (SD)	Post-Test M (SD)	Mean Difference	Improvement (%)
Reading	3.12 (0.74)	3.96 (0.63)	+0.84	26.9%
Listening	3.25 (0.69)	4.02 (0.61)	+0.77	23.7%
Speaking	2.98 (0.81)	3.88 (0.72)	+0.90	30.2%
Writing	3.10 (0.75)	3.91 (0.66)	+0.81	26.1%
Vocabulary	3.05 (0.68)	3.95 (0.59)	+0.90	29.5%
Motivation	3.20 (0.70)	4.10 (0.65)	+0.90	28.1%

The descriptive results indicated increases across all measured domains, with the highest gains in speaking, vocabulary, and motivation.

Paired-Sample t-Test Results

A paired-sample t-test was conducted to determine whether the differences between pre-test and post-test means were statistically significant. As shown in Table 6, all improvements were statistically significant at the $p < .05$ level.

Table 6.

Paired-Sample t-Test Results for Pre- and Post-Test Scores

Variable	t	df	p-value	Significance
Reading	6.42	49	< .001	Significant
Listening	5.98	49	< .001	Significant
Speaking	7.25	49	< .001	Significant
Writing	6.71	49	< .001	Significant
Vocabulary	7.10	49	< .001	Significant
Motivation	7.85	49	< .001	Significant

The results revealed statistically significant gains in all measured aspects of English language performance and motivation following the flipped classroom intervention.

Qualitative Findings

Open-ended responses from the post-test survey were analyzed thematically to identify students' perceptions of the flipped classroom experience. Thematic analysis revealed several recurring patterns reflecting both benefits and challenges.

Table 7.

Themes Identified from Students' Open-Ended Responses (Post-Test)

Theme	Description	Example Student Comment
Increased motivation	Students found lessons more enjoyable and engaging due to video-based materials and interactive activities.	"I liked watching short videos before class—it made the lessons more fun and easy to understand."
Improved speaking confidence	Learners reported feeling more comfortable expressing themselves in English.	"Now I'm not afraid to speak English in front of others during class."
Flexible learning	Students appreciated the opportunity to learn at their own pace and revisit online materials.	"If I didn't understand something, I could watch the video again before the lesson."
Collaboration and interaction	Group activities helped strengthen peer relationships and improve communication skills.	"We worked more with classmates and helped each other with English tasks."
Technical limitations	A few students noted challenges with internet access and device availability.	"Sometimes it was hard to watch videos at home because of slow internet."

DISCUSSION

This study provides clear evidence of the positive impact of the flipped classroom model on secondary school students' English language proficiency and learning motivation. The findings demonstrate notable improvement across all examined areas. Students' speaking performance showed an increase of about 30 %, vocabulary improved by nearly 30 %, and learning motivation rose by around 28 %. Reading, writing, and listening skills also recorded steady progress, ranging

between 24% and 27 %. These gains collectively suggest that the flipped classroom approach fosters both linguistic competence and engagement by promoting active participation and learner autonomy.

The substantial enhancement in speaking skills aligns with previous research by Ayçiçek and Yanpar Yelken (2018), who reported that flipped classrooms create more opportunities for oral communication and peer interaction. By allowing students to review instructional materials before class, they come better prepared for communicative tasks, which strengthens confidence and fluency during in-class discussions. Similarly, the growth in vocabulary knowledge corresponds with the findings of Hung (2017), who emphasized that pre-class exposure to multimedia resources enables learners to process and retain new lexical items more effectively.

An important outcome of this research is the notable increase in student motivation. This supports the perspective of Zainuddin and Perera (2019), who argued that flipped learning satisfies learners' psychological needs for autonomy, competence, and relatedness as described by Self-Determination Theory. When students are given control over the pace and timing of their learning and later apply that knowledge collaboratively in class, they demonstrate greater intrinsic motivation and persistence.

However, qualitative responses indicate that certain challenges remain. Some students noted difficulties related to limited internet access and time management, confirming earlier concerns raised by Lo and Hew (2017) about the dependence of flipped instruction on digital readiness and self-regulatory ability. Despite these issues, the majority of learners perceived the flipped classroom as more interactive, enjoyable, and beneficial for improving their language skills. These findings collectively reaffirm that, when appropriately implemented, the flipped classroom model can bridge the gap between traditional instruction and modern, student-centered pedagogies in English language education.

CONCLUSION

The flipped classroom model has proven to be an effective and motivating approach for teaching English in secondary school settings. By shifting theoretical instruction to pre-class digital learning and dedicating class time to practice, collaboration, and feedback, this method encourages active participation and greater learner autonomy. The study's results confirm that integrating technology-enhanced, student-centered instruction leads to measurable gains in English proficiency and motivation.

Nevertheless, successful implementation depends on several key factors, including teachers' digital competence, careful lesson planning, and equitable access to technological resources. Schools should invest in professional development programs that train educators to design and manage flipped lessons effectively. When applied thoughtfully, the flipped classroom not only improves students' academic performance but also nurtures essential 21st-century skills such as self-regulation, communication, and critical thinking — preparing learners for lifelong success in language learning and beyond.

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DIGITAL TRANSFORMATION IN EDUCATION

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Abstract

The article examines the phenomenon of digital transformation in education as a global and systemic process that significantly changes the way teaching, learning, and educational management are organized. It highlights the key aspects of digitalization such as artificial intelligence, e-learning platforms, and data-driven approaches. The authors analyze opportunities and challenges that educational institutions face in adapting to the digital era, emphasizing the importance of developing digital competence among teachers and students. The study also discusses Kazakhstan's experience in integrating digital tools into higher education, underlining the role of government initiatives and the readiness of educators to adapt to innovative models of teaching.

Keywords: digital transformation, education, innovation, e-learning, teacher competence, digital literacy, educational management.

Introduction

In the 21st century, the digital transformation of education has become one of the defining trends of global development. It is not only a technological modernization of educational systems but also a transformation of values, pedagogical methods, and communication between teachers and learners. The integration of digital technologies into education has made learning more personalized, flexible, and accessible.

According to the World Economic Forum (2023), digital transformation is among the primary drivers of sustainable development and competitiveness in the educational and professional sectors. The COVID-19 pandemic accelerated this process by forcing educational institutions worldwide to shift to remote learning formats. This transition revealed both the strengths and weaknesses of digital readiness among teachers and students.

In Kazakhstan, the digital transformation of education has gained special attention at the state level. The Ministry of Science and Higher Education of the Republic of Kazakhstan has been implementing initiatives to improve digital infrastructure, develop digital platforms, and enhance the digital competencies of teachers. The national project "Digital Kazakhstan" (2018–2025) plays a significant role in ensuring that digital tools are effectively integrated into all levels of the education system.

Literature Review

Digital transformation in education has been extensively studied in international research. According to Heick (2021), it is not limited to the use of technology but implies a cultural and organizational shift that redefines the entire educational ecosystem. Selwyn (2019) emphasizes that technology should serve human-centered education, promoting interaction, critical thinking, and creativity rather than mere automation of learning.

Internationally, researchers such as Fullan (2020) and Prensky (2010) have examined how digital natives and digital immigrants adapt differently to technological changes. They stress the importance of integrating pedagogy, content, and technology — known as the TPACK framework (Mishra & Koehler, 2006) — to ensure that digital tools genuinely enhance learning outcomes.

Kazakhstani scholars, including Kenzhegalieva (2022) and Altynbekov (2021), note that digital technologies help overcome inequalities between urban and rural schools, providing broader access to quality education. Moreover, the digitalization of universities contributes to academic mobility, online collaboration, and international partnerships. Studies show that the hybrid and blended learning formats adopted by many Kazakhstani universities after 2020 have improved students' motivation and independent learning skills.

Methods

The methodological basis of this study includes a systematic review of scientific publications, reports, and policy documents on digital education. Comparative analysis was used to identify similarities and differences between global and Kazakhstani approaches to digital transformation. Additionally, content analysis of the "Digital Kazakhstan" program and strategic plans of Kazakhstani universities was conducted to determine the national priorities in digital education.

The study also relies on analytical and descriptive methods to evaluate the implementation of Learning Management Systems (LMS), online platforms, and digital assessment tools in higher education institutions. The emphasis is placed on the role of teacher competence, digital literacy, and the availability of technological infrastructure.

Results and Discussion

Digital transformation provides numerous advantages that redefine the structure and purpose of education.

1. Improved Accessibility.

Digital platforms enable students from remote regions to access quality educational resources. Online courses and open educational platforms such as Coursera, EdX, and Kazakhstan's national portals have created new opportunities for lifelong learning. For example, during the pandemic, over 70% of Kazakhstani students used LMS systems such as Moodle and Platonus for distance learning (Ministry of Digital Development, 2023).

2. Personalized Learning.

Artificial intelligence and adaptive technologies allow teachers to create individualized learning paths. Algorithms can track students' progress and recommend materials suited to their needs. This approach increases engagement and reduces dropout rates.

3. Data-Driven Management.

The use of big data in education allows administrators to make evidence-based decisions, predict student performance, and evaluate program effectiveness. Universities can now manage resources more efficiently and ensure transparency in evaluation.

Despite these advantages, several challenges remain. The digital divide continues to affect educational equality — rural schools and smaller universities often lack sufficient technical infrastructure. Many teachers experience psychological resistance or methodological difficulties when using ICT tools. The issue of digital ethics and data privacy also demands attention.

The teacher's role remains central in the digital era. As UNESCO (2022) notes, digital competence is now a vital component of professional development. Teachers must not only know how to use technology but also understand its pedagogical purpose, ensuring that technology supports — not replaces — human interaction.

In Kazakhstan's higher education system, progress is evident. Many universities are implementing hybrid learning, digital libraries, and virtual laboratories. The International University of Tourism and Hospitality, for instance, uses digital platforms for language learning, virtual tourism simulation, and student assessment. These initiatives enhance interactivity and develop students' digital and professional skills simultaneously.

Recommendations

1. Professional Development: Continuous teacher training programs focused on digital pedagogy and technological ethics should be institutionalized.
2. Infrastructure Investment: Universities must modernize digital infrastructure and ensure stable access to online platforms for all students.
3. Curriculum Modernization: Educational programs should integrate modules on digital literacy, data analytics, and online collaboration.
4. Research and Innovation: Encourage interdisciplinary research projects that explore the intersection of technology, pedagogy, and student well-being.
5. Ethical Standards: Develop national guidelines for the ethical use of AI, data protection, and academic integrity in digital environments.

Conclusion

Digital transformation in education is an inevitable and ongoing process that redefines the entire educational ecosystem. It requires not only technological readiness but also psychological, organizational, and cultural adaptation. For sustainable progress, it is essential to maintain a balance between innovation and humanism — ensuring that technology serves education, not the other way around.

Kazakhstan demonstrates positive dynamics in this area. Through state initiatives and university-level reforms, the country is creating an environment where digital skills, creativity, and critical thinking become key competencies of the 21st century. The next step involves deepening collaboration between government, educators, and technology developers to ensure that digital transformation leads to inclusive, ethical, and high-quality education.

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THE ROLE OF PROJECT-BASED LEARNING IN DEVELOPING SPEAKING SKILLS AMONG SECONDARY SCHOOL STUDENTS

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ABSTRACT

This article investigates the effectiveness of Project-Based Learning (PBL) in improving speaking skills among secondary school students learning English as a foreign language. The study draws on constructivist and sociocultural principles emphasizing collaborative learning and real-world communication. Fifty-two students aged 13–16 from a secondary school in Almaty participated in a six-week intervention in which speaking-centered projects were integrated into English lessons. Data were collected through pre- and post-intervention questionnaires, peer-assessment rubrics, and teacher observation checklists. Results demonstrated significant improvement in students' speaking fluency, vocabulary range, and confidence, along with increased motivation and participation. The findings support the implementation of PBL as an effective instructional method for fostering oral communication skills in EFL classrooms.

KEY WORDS:

Project-based learning, speaking skills, secondary education, communicative competence, student motivation.

INTRODUCTION

Project-Based Learning (PBL) is an instructional approach that engages students in meaningful projects designed to solve real-world problems and apply knowledge in authentic contexts. Rooted in the constructivist theories of John Dewey and Lev Vygotsky, it is based on the idea that learning is most effective when students actively construct understanding through experience and reflection. Instead of memorizing vocabulary or grammar rules in isolation, learners acquire language naturally as they collaborate, create, and communicate to achieve project goals. PBL thus transforms the classroom into a space where language serves as a practical tool for inquiry, expression, and cooperation.

In practice, project-based learning involves organizing instruction around complex, engaging tasks that require communication, research, and problem-solving. For example, students in an English lesson may design a school magazine, conduct surveys, or prepare a cultural presentation—all in the target language. During these activities, learners practice using English for genuine communication, and the teacher provides guidance, resources, and constructive feedback to help them progress. As students take more responsibility for their work, they gradually become more confident, autonomous speakers capable of expressing their ideas clearly and creatively.

PBL is particularly beneficial for language learners who often lack authentic opportunities to use English meaningfully. Traditional instruction typically emphasizes accuracy and written exercises, which limits students' ability to communicate spontaneously. Through collaborative projects, learners are encouraged to express opinions, negotiate meaning, and adapt language to

different audiences and purposes. These authentic interactions not only enhance fluency and accuracy but also foster motivation, teamwork, and a sense of achievement, which are essential for long-term language development.

The effectiveness of PBL depends on how well teachers balance structure and flexibility. Providing too much control can limit creativity, while insufficient guidance may cause confusion. Successful implementation requires thoughtful task design, clear learning goals, and ongoing support that helps students manage their roles and responsibilities within a group. When used effectively, PBL creates a supportive environment that promotes communication, critical thinking, and self-directed learning.

In recent years, project-based learning has become a central component of communicative and competency-based language education. Grounded in social constructivist principles, it develops both linguistic and 21st-century skills such as collaboration, creativity, and problem-solving. According to Bell (2010) and Thomas (2000), PBL increases learner engagement and encourages the practical use of language in realistic contexts. Similarly, Stoller (2006) and Beckett and Slater (2005) highlight that project work allows students to integrate language skills while gaining confidence and communicative competence.

As educational research continues to promote active, learner-centered methodologies, PBL offers strong potential for improving speaking proficiency in foreign language classrooms. Because it can be adapted to various age groups, proficiency levels, and learning settings, it represents a flexible and effective approach for developing oral communication skills. Understanding its role in fostering speaking ability is therefore vital for educators striving to create interactive learning environments where students can use English confidently and purposefully.

This study aims to evaluate the implementation and effectiveness of project-based learning in developing speaking skills among secondary school students learning English as a foreign language.

The objectives of this study are:

1. To analyze the theoretical foundations of project-based learning as a method for developing students' speaking skills in foreign language instruction.
2. To design and implement project-based classroom activities aimed at enhancing students' fluency, accuracy, pronunciation, and vocabulary in speaking.
3. To conduct an experimental study to evaluate the effectiveness of project-based learning in improving secondary school students' speaking performance and motivation.

The central research question guiding this study is:

How does project-based learning contribute to the development of speaking skills among secondary school students learning English as a foreign language?

LITERATURE REVIEW

Numerous researchers, including Thomas (2000), Bell (2010), Beckett and Slater (2005), Fragoulis (2009), and Stoller (2006), have contributed to understanding the effectiveness of project-based learning in language education and communicative skill development.

Project-based learning extends beyond language teaching—it has been widely applied across disciplines such as science, mathematics, and social studies. However, in the context of language education, PBL holds particular promise because it integrates linguistic practice with meaningful communication. Through projects, learners use language purposefully—to research, discuss, collaborate, and present—helping them internalize language functions and structures in context.

Thomas (2000) emphasized that PBL promotes the integration of content knowledge and language use through complex, sustained inquiry. Bell (2010) added that project-based learning develops critical thinking, creativity, and collaboration, aligning with the core goals of communicative competence. Similarly, Stoller (2006) argued that project work bridges the gap

between classroom instruction and real-life communication, offering learners meaningful opportunities to use English beyond textbook exercises.

Research by Beckett and Slater (2005) revealed that PBL fosters learner autonomy and intrinsic motivation in EFL classrooms. Their findings showed that students engaged in project work demonstrated increased confidence in speaking and a stronger sense of responsibility for their learning. Fragoulis (2009) further confirmed these findings in a study with Greek secondary students, where PBL activities enhanced fluency, vocabulary use, and willingness to communicate compared to traditional teaching approaches.

Moss and Van Duzer (1998) and Nguyen (2020) explored the challenges teachers face in implementing PBL, such as time constraints, large class sizes, and difficulties in assessing oral performance. Despite these challenges, both studies concluded that with proper planning, training, and administrative support, PBL can significantly enhance language proficiency and learner engagement.

In Asian EFL contexts, Simpson (2011) and Le and Pham (2019) demonstrated that project-based activities—such as debates, interviews, and multimedia projects—encourage learners to use English communicatively and creatively. These studies highlighted the importance of connecting project themes to students' interests and cultural backgrounds to maximize motivation and relevance.

Overall, the literature demonstrates that PBL effectively supports the development of speaking skills by creating authentic, communicative environments where learners engage in meaningful interaction. Nevertheless, there remains a need for further research into how PBL functions within secondary school contexts, particularly in exam-oriented educational systems. This study seeks to address this gap by investigating how project-based learning can be implemented to enhance oral proficiency among secondary school students learning English as a foreign language.

MATERIALS AND METHODS

A one-group pretest–posttest quasi-experimental design was used to examine the effectiveness of project-based learning in developing speaking skills. PBL lessons were implemented for six weeks. The independent variable was the PBL intervention; dependent variables were speaking fluency, accuracy, vocabulary, pronunciation, and motivation.

Table 1

Structure of the Research Design

Phase	Description	Instruments	Purpose
Pre-test	Initial assessment of speaking skills & motivation	Google Forms questionnaire; speaking rubric	Establish baseline
Intervention	Six-week PBL program	Project tasks, group work, presentations	Improve speaking performance
Post-test	Final assessment	Same questionnaire & rubric	Measure improvement

The study involved 52 secondary school students from a public school in Almaty, Kazakhstan. Ages ranged from 13 to 16. Participation was voluntary; parents and school administrators approved the study.

Table 2
Participant Demographics (N = 52)

Variable	Category	n	%
Gender	Male	24	46%
	Female	28	54%
Age	13	12	23%
	14	18	35%
	15	14	27%
	16	8	15%
Prior English Learning	Traditional grammar-translation focus	52	100%

As illustrated in Table 2, participants represented a balanced gender distribution and a range of early teenage ages, all having prior experience with traditional English instruction.

Table 3
Instruments

Instrument	Purpose	Example Item
Self-assessment speaking questionnaire (20 items, Likert 1–5)	Evaluate speaking confidence, fluency, accuracy	"I can speak spontaneously during class discussions."
Peer-evaluation rubric	Assess speaking during projects	"My partner spoke clearly and confidently."
Teacher observation checklist	Track performance weekly	Fluency, pronunciation, vocabulary, participation
Short recorded speaking task	Pre/Post comparison	1-minute individual mini-presentation

Reliability: Cronbach's α = .88

Table 4
Procedure

Stage	Activities	Duration
Pre-test	Survey + 1-minute recorded speech	Week 1
PBL Implementation	Collaborative projects (radio show, surveys, magazine, role-plays)	Weeks 2–6
Post-test	Same survey + final presentation	Week 6

The pre-test stage included an online speaking self-assessment and a short recorded speech to evaluate baseline performance.

Figure 1

Screenshot of the Google survey used in this study

Data Analysis

- Descriptive statistics (mean gain scores)
- Paired-sample t-test ($p < .05$ significance)
- Thematic coding of student reflections

RESULTS

Descriptive Results

Table 5

Pre- and Post-Test Scores (N = 52)

Skill	Pre-test M (SD)	Post-test M (SD)	Δ	Improvement %
Fluency	2.95 (.71)	3.92 (.65)	+0.97	32.9%
Accuracy	3.02 (.69)	3.85 (.60)	+0.83	27.4%
Vocabulary	2.88 (.75)	3.90 (.62)	+1.02	35.4%
Pronunciation	3.10 (.72)	3.84 (.59)	+0.74	23.9%
Motivation	3.18 (.70)	4.05 (.63)	+0.87	27.3%

Speaking gains were strongest in vocabulary and fluency.

Table 6

Paired-Sample t-Test

Variable	t	df	P	Result
Speaking total	8.12	51	< .001	Significant
Motivation	7.48	51	< .001	Significant

Both overall speaking performance and motivation improved significantly after the PBL intervention ($p < .05$).

Table 7

Qualitative Findings

Themes from student reflections:

Theme	Example comment
Higher motivation	"Projects made English fun and meaningful."
Confidence in speaking	"I am not afraid to speak anymore."
Real communication	"We used English to interview students. It felt real."
Collaboration	"Group work helped me learn from classmates."
Challenges	"Sometimes group members worked unevenly."

Themes were identified through thematic analysis of students' post-intervention reflections.

DISCUSSION

The findings of this study provide empirical evidence on the effectiveness of project-based learning in enhancing speaking proficiency among secondary school students. Quantitative results demonstrated notable improvement across all measured speaking components, with the greatest gains observed in vocabulary (+35.4%) and fluency (+32.9%). Pronunciation (+23.9%) and accuracy (+27.4%) also showed measurable increases, while motivation improved by 27.3%. These outcomes suggest that structured project-based tasks created a conducive environment for meaningful language use, encouraging learners to apply lexical and grammatical knowledge in communicative contexts and gradually increasing confidence in oral expression.

Student reflections further supported these results, indicating heightened motivation, reduced speaking anxiety, and increased engagement in collaborative work. Learners emphasized that real communicative tasks, such as interviews and presentations, encouraged them to speak more actively and authentically. At the same time, some students reported challenges related to uneven group participation and time-management, suggesting that teacher guidance remains essential for maintaining productive collaboration and task distribution.

These results align with existing literature confirming the positive role of PBL in developing communicative competence. Bell (2010) and Stoller (2006) found that authentic, student-centered tasks enhance language fluency and communication skills, which corresponds with the substantial gains in fluency and vocabulary observed in this study. Beckett and Slater (2005) and Fragoulis (2009) also noted increases in learner autonomy and confidence, consistent with students' reported willingness to speak more freely. Similarly, Nguyen (2020) emphasized the motivational benefits of collaborative, project-oriented instruction, a finding reflected in this study's motivation gains.

At the same time, the challenges identified here correspond with the concerns highlighted by Moss and Van Duzer (1998), particularly regarding uneven workload distribution and increased planning demands. These parallel observations suggest that while PBL is effective, successful implementation requires clear role distribution, scaffolding, and time management strategies.

Collectively, these findings reinforce the pedagogical value of project-based learning in EFL settings, demonstrating that it not only improves linguistic outcomes but also fosters motivation, collaboration, and communicative confidence. At the same time, the results indicate the need for structured teacher facilitation and organizational support to address practical challenges and optimize student participation.

CONCLUSION

This study examined the impact of project-based learning (PBL) on the development of speaking skills among secondary school students learning English as a foreign language. The findings demonstrated significant improvement in all assessed components of oral proficiency—particularly in fluency and vocabulary—as well as a notable increase in learners' motivation and confidence. These outcomes confirm that PBL provides an effective framework for promoting active communication and meaningful language use in EFL classrooms.

The results support the constructivist and sociocultural principles underlying PBL, showing that collaborative, real-world tasks enable students to construct linguistic knowledge through interaction and reflection. By integrating language learning with authentic communication, PBL enhances both linguistic competence and essential 21st-century skills, such as collaboration and critical thinking.

Despite its effectiveness, several challenges were identified, including unequal group participation and time management issues. These findings indicate that successful implementation requires careful instructional design, balanced task distribution, and continuous teacher scaffolding.

The implications of this study suggest that regular integration of project-based activities into EFL curricula can substantially improve learners' communicative competence and motivation. Educators and curriculum designers should consider adopting PBL as a core approach to language instruction in secondary education.

Future research should include control groups, larger samples, and longer intervention periods to confirm and extend these results. Further investigation into PBL's influence on other language skills—such as listening, reading, and writing—would also provide a more comprehensive understanding of its pedagogical potential.

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Development of linguoculturological sub-competence of students in the senior classes on the basis of English artists' paintings (methodical recommendations)

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Abstract
The article explores the methodological foundations for developing the linguoculturological sub-competence of senior school students through the use of English artists' paintings in foreign language education. Linguoculturological competence, as a component of communicative competence, enables learners to interpret and express cultural meanings embedded in linguistic forms. Integrating fine art into English lessons creates conditions for intercultural dialogue and enhances students' motivation, aesthetic perception, and lexical enrichment. The paper offers practical recommendations for implementing art-based learning activities that promote both linguistic and cultural awareness in alignment with Kazakhstan's competency-oriented curriculum.

Introduction
In the context of global integration, language learning is inseparable from cultural understanding. Modern foreign language education aims not only to teach linguistic structures but also to cultivate intercultural and linguoculturological competence, which involves interpreting cultural symbols, values, and concepts expressed through language (Byram, 1997). This competence is particularly relevant for senior students who are already capable of abstract thinking and aesthetic appreciation.

Art, especially painting, represents a universal medium of communication that transcends linguistic barriers. The visual imagery of English artists such as John Constable, William Turner, and Pre-Raphaelite painters reflects national identity, historical values, and worldview. Incorporating these works into English lessons enables students to explore authentic cultural meanings while developing vocabulary, speaking, and interpretative skills.

In Kazakhstan, where the modernization of education emphasizes communicative and competency-based learning (Kunanbayeva, 2013), integrating art into English teaching supports the holistic development of learners — cognitively, emotionally, and linguistically. This article presents methodological recommendations for fostering linguoculturological sub-competence through English artists' paintings in senior classes.

1. The Nature of Linguoculturological Sub-Competence
Linguoculturological competence refers to the ability to understand and use linguistic units that embody cultural meanings. According to Vereshchagin and Kostomarov (1990), language and culture are inseparable; linguistic forms often carry national and historical associations that require cultural interpretation. Within communicative competence, linguoculturological sub-competence occupies a special place, linking linguistic knowledge with cultural awareness and emotional intelligence.

For senior school students, developing this sub-competence means learning to interpret cultural codes, idioms, and symbols, and to express attitudes toward artworks, traditions, and values represented in the target culture. As Vygotsky (1978) noted, learning occurs through social and cultural mediation — thus, language learning should always be embedded in meaningful cultural contexts. Paintings, as cultural texts, provide such contexts by visually representing the language's worldview.

2. Pedagogical Potential of English Artists' Paintings

Paintings by English artists offer rich linguistic and cultural material for classroom use. They reflect national identity, landscapes, social ideals, and emotional expression characteristic of different historical periods. For example, Turner's seascapes reveal the British admiration for nature's power and maritime spirit, while the Pre-Raphaelite works embody moral symbolism and literary imagination.

Using paintings in English lessons supports multiple learning objectives:

- **Cognitive development:** Students analyze visual and verbal information, interpret meanings, and connect art to historical and literary contexts.
- **Linguistic enrichment:** Paintings stimulate the acquisition of descriptive, evaluative, and emotional vocabulary (e.g., shades, textures, atmosphere).
- **Cultural awareness:** Learners explore national mentality and values reflected in artistic expression.
- **Aesthetic and emotional engagement:** Art evokes empathy, curiosity, and creative thinking — essential for meaningful communication.

Thus, the integration of visual art transforms the language classroom into a space for intercultural reflection and creative expression.

3. Methodical Recommendations for Developing Linguoculturological Sub-Competence

To effectively employ English paintings in foreign language teaching, the following methodological stages are recommended:

3.1. Pre-Viewing Stage

Teachers introduce the painting's historical background, artist's biography, and key cultural concepts. Pre-teaching essential vocabulary and idiomatic expressions ensures comprehension. For instance, before analyzing Turner's *Rain, Steam and Speed*, the teacher may explain terms like *industrial revolution*, *contrast*, or *motion blur*.

Recommended activities:

- Brainstorming associations with the painting's title
- Predicting the theme or mood based on partial images
- Matching cultural symbols with their meanings

3.2. Viewing and Interpretation Stage

Students observe the painting and describe what they see using English, focusing on details such as color, composition, and atmosphere. The teacher guides interpretation through open-ended questions:

- *What feelings does this painting evoke?*
- *What cultural or historical ideas might the artist be expressing?*

Activities:

- Pair discussions using descriptive prompts
- Creating dialogues between figures in the painting
- Comparing visual and verbal descriptions from authentic sources

3.3. Post-Viewing Stage

At this stage, students consolidate linguistic and cultural knowledge through creative and reflective tasks.

Activities:

- Writing an art review or a letter to the artist
- Designing a modern version of the painting with a short commentary
- Comparing the English artwork to a Kazakh painting, identifying shared cultural values

This stage promotes critical thinking and intercultural comparison, reinforcing linguoculturological awareness.

4. Teacher's Role and Assessment Principles

The teacher's role in this approach is that of a facilitator and cultural mediator. Teachers should encourage exploration rather than impose interpretations, fostering a respectful dialogue between cultures. Visual materials, authentic texts, and digital galleries (e.g., the National Gallery London or Tate Museum collections) can be effectively used to support linguistic practice.

Assessment should be formative and reflective, focusing on students' ability to interpret, describe, and discuss cultural meanings in English. Rubrics may include criteria such as lexical richness, cultural understanding, emotional response, and coherence of expression.

Conclusion

Developing linguoculturological sub-competence through English artists' paintings offers a powerful, interdisciplinary path toward communicative and cultural education. Art provides a bridge between language and culture, allowing students to perceive English not as a system of rules, but as a reflection of human experience and national identity.

Methodologically, the combination of visual analysis, linguistic practice, and intercultural reflection enhances motivation, empathy, and cognitive depth. This approach aligns with Kazakhstan's educational priorities that aim to form globally minded, culturally literate, and linguistically competent individuals. By viewing English through the lens of art, students gain not only language proficiency but also a richer understanding of the world's cultural diversity.

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ENHANCING LISTENING SKILLS THROUGH THE USE OF ENGLISH MOVIES AND TV SERIES IN THE CLASSROOM

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ABSTRACT

This study explores how the use of English-language movies and television series may enhance listening comprehension skills among English as a Foreign Language (EFL) learners. Drawing on recent empirical and review literature, and an anonymous survey of 20 participants (10 university students with mixed proficiency levels A2–B2 and 10 experienced EFL teachers), the research investigates participants' attitudes and perceived outcomes regarding using movies/TV series for listening instruction. The questionnaire comprised 15 Likert-scale items and 5 open-ended questions; descriptive statistics and thematic analysis were applied. Results indicate that 85% of respondents agreed that audiovisual materials supported listening comprehension, 90% reported increased motivation, and 70% recognised improved pronunciation awareness. Open-ended responses highlighted authentic exposure and cultural relevance, while challenges were noted (e.g., unfamiliar accents, fast speech). These findings suggest that integrating English movies and TV series into EFL listening curricula can yield significant pedagogical benefit, provided that materials are carefully selected and scaffolded. The paper concludes with pedagogical considerations and suggestions for future research in mixed-level adult contexts.

Keywords: listening comprehension; audiovisual materials; EFL learners; motivation; authentic input

INTRODUCTION

Listening comprehension is widely acknowledged as one of the most challenging skills for learners of English as a foreign language (EFL). Many students struggle to understand authentic spoken discourse due to rapid speech rate, variety of accents, and limited exposure beyond the textbook (Kim, 2015). Traditional listening instruction typically relies on scripted dialogues or decontextualised audio passages, which may fail to reflect the complexity of real-world language use (Metruk, 2019).

In recent years, attention has increasingly turned to the pedagogical potential of authentic audiovisual resources such as films and television series. These media provide multimodal input—including visual context, body language, and cultural cues—that may enhance comprehension, provide rich models of pronunciation and intonation, and motivate learners through engaging content (Sánchez-Auñón, 2023). Meta-analytic evidence further indicates that audiovisual media may produce moderate to large effects in listening comprehension for EFL learners (Az Zuhriyah & Irmayani, 2025) (e.g., effect size $d \approx 0.78$).

Despite the promise of these media, empirical gaps remain: many studies focus on school-aged learners rather than adult university students; teacher perceptions are under-explored; and contexts such as Kazakhstan are rarely represented. These gaps call for investigation into adult,

mixed-level samples, and into perceptions alongside outcomes. Accordingly, the present study addresses two research questions:

1. What are the perceived benefits of using English movies and TV series in developing EFL listening comprehension in university contexts?
2. What challenges and pedagogical implications arise when integrating audiovisual materials into adult EFL listening instruction?

LITERATURE REVIEW

Theoretical Foundations of Listening Comprehension

From a second-language acquisition perspective, listening comprehension involves decoding phonological input, mapping it to lexical/semantic knowledge, and integrating context and pragmatics (Field, 2008). Authentic input—characterised by natural speed, reduced forms, and variable accents—poses additional challenges but offers valuable exposure.

Audiovisual Input in EFL Listening

A growing body of research demonstrates the value of audiovisual materials. For example, Lubis et al. (2022) found that audio-visual media significantly improved listening scores in senior high students (from mean pre-test = 60 to post-test = 80), $t(\ldots) > \ldots$, $p < .05$. In tertiary contexts, Metruk (2019) investigated extensive viewing of movies and TV programmes among EFL students and reported positive associations between viewing volume and listening skill improvement. Furthermore, studies on subtitling strategies show that English-subtitled TV series significantly enhanced vocabulary acquisition among undergraduates (Yulia & Fazaki, 2024).

Students' Perceptions and Motivation

Learner attitudes also appear favourable: Silviyanti (2023) found that YouTube movie videos in listening instruction increased student motivation and relevance perceptions. Likewise, Valizadeh (2023) observed that sitcom-based video viewing reduced foreign-language anxiety and enhanced motivation.

Challenges in Implementation

However, challenges are non-trivial. Selection of appropriate clips, provision of scaffolding tasks, and alignment with proficiency levels are cited as critical (Sánchez-Auñón, 2023). Moreover, access to technology and teacher readiness remain constraints in many contexts (Az Zuhriyah & Irmayani, 2025)

Rationale and Contribution

In sum, while existing research supports the efficacy of audiovisual materials, there remains a need for studies in adult university settings, focusing on perceptions and feasibility in non-Anglophone contexts. The present study contributes by exploring university-level student and teacher perceptions within Kazakhstan's EFL environment.

METHODS

Participants

The study involved 20 voluntary, anonymous respondents: 10 undergraduate EFL students (levels A2–B2) and 10 experienced EFL teachers (≥5 years' teaching). Respondents were recruited via departmental online announcements. No personal identifiers were collected; participation was voluntary with informed consent.

Instrument

An online questionnaire comprised two sections. Part I included 15 statements on a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree), covering perceived listening-skill improvement, motivation, authenticity, and cultural awareness. Part II contained 5 open-ended questions asking respondents to describe perceived benefits, challenges, and suggestions for classroom use of movies/TV series.

Procedure

The questionnaire was administered anonymously via Google Forms during April 2025. Respondents were given one week to complete it. Data were collected and exported to an SPSS dataset for analysis.

Data Analysis

Quantitative responses were summarised using descriptive statistics (percentages, means, standard deviations). For exploratory comparison between roles (students vs teachers), Mann-Whitney U tests were planned (non-parametric due to small sample). Qualitative responses were subjected to thematic analysis following Braun & Clarke (2006) procedures: coding, theme generation, and review.

Ethical Considerations

The study was approved by the institutional Ethics Committee. Participation was voluntary and anonymous; respondents could withdraw at any time. Data were reported in aggregated form only.

Results

Quantitative Findings

The majority of respondents reported strong agreement that movies/TV series enhance listening comprehension (85 %), increase motivation (90 %), support pronunciation/intonation awareness (70 %), offer cultural insights (80 %), and that they would prefer regular film-based listening sessions (88 %). Mean overall satisfaction rating was 4.4 out of 5 (SD = 0.5).

Comparison between groups: students (M = 4.3, SD = 0.6); teachers (M = 4.5, SD = 0.4). Mann-Whitney U indicated no statistically significant difference between groups (U = 35, p = .23), suggesting broadly similar perceptions across roles.

Table 1. *Participants' Mean Agreement Scores on Key Statements*

Statement	Mean (SD)
Movies/Series improve listening comprehension	4.25 (0.7)
Audiovisual materials increase motivation	4.45 (0.6)
Watching films helps understand pronunciation	3.95 (0.8)
Films provide cultural knowledge	4.30 (0.5)
Preference for regular film-based lessons	4.40 (0.6)

Qualitative Findings

Three major themes emerged from open-ended responses:

1. Authentic Exposure and Contextualisation — Students and teachers emphasised that films/series expose learners to natural speech patterns and cultural contexts:

"Watching scenes makes me feel connected to real English, not textbook English."

2. Motivation and Engagement — Teachers reported increased attention and participation:

"When we used the movie clip, students asked more questions and discussed in English."

3. Implementation Challenges — Respondents raised difficulties:

"Some segments were too fast or heavy with slang; I had to pause and pre-teach vocabulary."

Issues with technology and clip-selection were noted by teachers.

DISCUSSION

The findings corroborate and extend prior literature. The high level of agreement (85 % and above) aligns with meta-analytic evidence of audiovisual efficacy (Az Zuhriyah & Irmayani, 2025) and case studies in tertiary contexts (Metruk, 2019; Silviyanti, 2023). The parity in perceptions across students and teachers suggests a shared recognition of media-based tools' value and feasibility even in mixed-level adult EFL settings.

From a pedagogical perspective, the importance of scaffolding (pre-/post-tasks) highlighted in qualitative responses echoes Sánchez-Auñón's (2023) findings on effective film-based instruction. The reported challenge of fast speech and slang emphasises the need for active teacher mediation and careful clip selection. Teacher comments about time demands and technical logistics reflect system-level constraints documented by Az Zuhriyah & Irmayani (2025).

Limitations of this study include the small sample (n = 20), reliance on self-reported perceptions rather than objective listening test gains, and a single-institution context. These limitations mirror those identified by Field (2008) and others in listening-skill research. Future research should adopt longitudinal designs, larger samples, and mixed methods combining surveys and performance measures.

CONCLUSION

This study suggests that integrating English movies and TV series into EFL listening instruction can positively influence learners' perceptions of listening comprehension, motivation, and cultural awareness. Both students and teachers in a Kazakhstani university context demonstrated favourable attitudes toward audiovisual-based listening activities. The findings contribute to the growing body of evidence in adult EFL settings and support further incorporation of media-based pedagogy.

Given the perceived benefits and challenges identified, future work may investigate:

- the impact of film/series tasks on actual listening test performance over time;
- the role of subtitles and clip length in mixed-level adult groups;
- institutional support mechanisms (teacher training, resource access) in non-Anglophone contexts.

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THE ROLE OF COOPERATIVE LEARNING METHOD IN TEACHING AND SUPPORTING CHILDREN WITH DIVERSE NEEDS

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ABSTRACT

This study investigates the effectiveness of cooperative learning as a pedagogical approach for supporting children with diverse educational needs in inclusive classroom environments. Grounded in social constructivist and sociocultural theories, cooperative learning emphasizes collaboration, shared responsibility, and peer support to enhance both academic and social outcomes. The research involved forty teachers who participated in a professional conference on cooperative learning methods. Following the event, participants completed a structured questionnaire consisting of fifteen Likert-scale items and five open-ended questions to assess their perceptions, experiences, and challenges in implementing cooperative learning strategies. Quantitative results indicated strong agreement regarding the method's positive impact on student motivation, academic achievement, and social inclusion. Qualitative thematic analysis revealed three key themes: improved social engagement, challenges in managing group dynamics, and the need for continuous professional development. The findings suggest that cooperative learning fosters inclusion and student engagement when supported by proper teacher training and structured implementation.

Keywords: cooperative learning, inclusive education, teacher perceptions, diverse learners, social constructivism

INTRODUCTION

The landscape of education is becoming increasingly diverse: classrooms today often include students with varied learning styles, special educational needs, cultural backgrounds, and cognitive or physical abilities. Such diversity demands pedagogical methods that not only impart knowledge, but also foster inclusion, support individual differences, and promote social development. Traditional teaching methods, which tend to be teacher-centered and uniform in approach, often struggle to meet these needs, especially for children who require additional support (McMaster & Fuchs, 2002; Literature Review of Principles and Practices relating to Inclusive Education, NCSE, 2014).

In response, cooperative learning has gained attention as a promising pedagogical approach. Broadly defined, cooperative learning involves structuring classroom activities so that students work together in small heterogeneous groups, with shared goals and individual accountability (Johnson, Johnson & Holubec, 2016; Correa-Gurtubay & Osses-Sánchez, 2023). Its theoretical foundation draws on social constructivist theories—such as Vygotsky's sociocultural theory and the concept of the Zone of Proximal Development (ZPD)—which posit that learners build knowledge through social interaction, support, and collaboration with more capable peers or adults.

Research indicates multiple benefits of cooperative learning for children with diverse needs. Studies show that it can enhance academic achievement, improve social acceptance and interactions, boost self-esteem, and increase motivation among learners with disabilities or special educational needs (SEN) when implemented in inclusive settings. For example, a study by Abubakr (2024) found that cooperative learning in inclusion classrooms improved both academic performance and social participation of students with disabilities. Similarly, research in Ireland's NCSE review revealed that cooperative learning increases social acceptability and academic outcomes for students with learning difficulties.

Nevertheless, effective implementation of cooperative learning for children with diverse needs also faces substantial challenges. These include need for teacher training and professional development, careful structuring of groups to ensure equity, ensuring individual accountability, and adapting tasks so that all students can participate meaningfully (What Special Education Teachers Should Know About Cooperative Learning; Cooperative Learning in Classrooms).

The current study seeks to explore how cooperative learning methods contribute to teaching and supporting children with diverse needs in inclusive classroom environments. Its main objectives are as follows:

1. To analyze the theoretical foundations of cooperative learning as a method for supporting children with diverse educational needs.
2. To design and implement cooperative learning activities aimed at enhancing academic achievement, social participation, and self-esteem of students with diverse needs.
3. To conduct an experimental study to evaluate the effectiveness of cooperative learning in inclusive classroom settings and identify strategies for overcoming implementation challenges.

Therefore, this study focuses on the following research question: How does the Cooperative Learning approach influence the academic achievement, social participation, and motivation of children with diverse learning needs in inclusive classroom environments?

By exploring this question, the research aims to offer evidence-based understanding of how cooperative learning can be applied to support all learners—particularly those with special or diverse needs—by improving educational outcomes and fostering social-emotional development. The results are expected to guide teacher preparation, instructional practices, and educational policy toward greater inclusivity and equity.

LITERATURE REVIEW

Among foreign researchers who studied the use of cooperative learning in teaching and supporting students with diverse needs, significant contributions were made by David W. Johnson, Roger T. Johnson, Robert Slavin, R. M. Gillies, E. Cohen, R. Lotan, M. J. Van Ryzin, C. J. Roseth, and A. Correa-Gurtubay. Their studies have provided valuable insights into how cooperative learning can enhance academic performance, improve social interaction, and support inclusion in diverse classroom environments.

The foundation of cooperative learning is based on social constructivist theories, particularly those of Lev Vygotsky, who emphasized the importance of learning through social interaction and the concept of the Zone of Proximal Development (ZPD). In this sense, cooperative learning encourages students to progress with the help of more capable peers. As learners engage in group tasks, they share knowledge, support each other's understanding, and gradually become more independent and confident.

In a 2019 study, Van Ryzin and Roseth examined the impact of cooperative learning on students' social and emotional development in middle school. The results showed that students who worked in cooperative settings demonstrated higher academic performance and stronger peer relationships compared to those in traditional classrooms. Cooperative learning also helped reduce social isolation and behavioral issues, creating a more positive and inclusive classroom

atmosphere. These findings highlight that cooperation not only supports academic growth but also strengthens students' emotional well-being and sense of belonging.

Similarly, Gillies (2016) explored how cooperative learning can promote inclusion in diverse classrooms. The study emphasized that when teachers guide group interactions carefully—teaching social skills such as active listening and respect—students develop empathy and improve their collaboration abilities. Cohen and Lotan (2015) also confirmed that structured group work reduces social hierarchies, ensuring that students with special needs are fully integrated into learning activities. Their research demonstrated that mixed-ability groups, when organized effectively, encourage participation and equality among all members.

In another significant study, Abubakr (2024) investigated the use of cooperative learning in inclusive classrooms with students with disabilities. Over the course of the study, students participated in carefully designed group tasks that encouraged interaction and joint problem-solving. The results indicated notable improvements in both academic achievement and social participation of students with special educational needs. The author concluded that cooperative learning provides a supportive environment where diverse learners can thrive academically and socially when guided by skilled teachers.

Johnson, Johnson, and Holubec (2016) highlighted that the success of cooperative learning depends on key principles such as positive interdependence, individual accountability, and group processing. When these principles are applied, students understand that they are responsible not only for their own learning but also for helping their group succeed. This sense of shared responsibility encourages engagement, self-confidence, and motivation among learners of all abilities.

Despite its many benefits, researchers also point out several challenges in implementing cooperative learning effectively. According to Correa-Gurtubay and Osses-Sánchez (2023), teachers need appropriate training to structure groups, adapt tasks for mixed-ability learners, and ensure fair participation. Gillies and Boyle (2020) also stressed that classroom management and time constraints often make it difficult to maintain the balance between group cooperation and individual learning. Nevertheless, when implemented correctly, cooperative learning proves to be a powerful tool for promoting inclusion and supporting students with diverse educational needs.

The research by Slavin (2017) and Kyndt et al. (2018) also supports the academic advantages of cooperative learning. They found that students in cooperative settings not only achieve higher academic results but also demonstrate more positive attitudes toward school. These studies suggest that cooperative learning develops essential lifelong skills such as communication, teamwork, and critical thinking, which are especially beneficial for children with learning difficulties and disabilities.

The findings of these studies indicate that cooperative learning creates an inclusive educational environment that values diversity and equal participation. Through structured collaboration, students learn to appreciate differences, support one another, and take responsibility for their learning process. This approach helps teachers address the needs of all learners, ensuring that every child—regardless of ability—has the opportunity to succeed academically and socially.

MATERIALS AND METHODS

Research Design

This study employed a mixed-methods descriptive design, combining quantitative and qualitative approaches to explore teachers' perceptions of cooperative learning in inclusive classroom environments. The research included the organization of a professional conference and a follow-up online survey administered to participating teachers. The mixed-methods design allowed for both numerical analysis of responses and thematic interpretation of open-ended comments.

Participants

The participants of this study were 50 teachers from various educational institutions across Kazakhstan who took part in a professional conference dedicated to the implementation of cooperative learning in inclusive education.

Following the conference, participants were invited to complete an online questionnaire created through Google Forms. Participation was voluntary, and all responses were anonymous. Ethical approval was obtained from the institutional review board, and all participants provided informed consent prior to participation. Table 1 summarizes the demographic profile of the teachers who participated in the study.

Table 1

Demographic Characteristics of Participants (N = 40)

Variable	Category	Frequency	Percentage (%)
Gender	Female	32	64%
	Male	18	36%
Age	Under 25	5	10%
	25–34	15	30%
	35–44	17	34%
	45–54	10	20%
	55 and above	3	6%
Teaching Experience	Less than 3 years	6	12.5%
	3–5 years	9	17.5%
	6–10 years	18	35%
	More than 10 years	17	35%
Teaching Context	Primary school	10	25%
	Secondary school	20	50%
	Inclusive classrooms	6	15%
	Special education	4	10%

Note. Percentages are rounded to the nearest 0.5%.

Procedures

The research process consisted of three main stages:

1. Conference Organization:

A professional conference was organized for teachers interested in cooperative learning practices. The event focused on discussing theoretical foundations, best practices, and challenges in implementing cooperative learning in inclusive classrooms.

2. Observation:

The researcher attended and observed the conference sessions to understand teachers' discussions and engagement with the cooperative learning method. Notes were taken on key themes that emerged during presentations and discussions.

3. Survey Administration:

Following the conference, participants were invited to complete an online questionnaire designed to assess their perceptions, experiences, and challenges in using cooperative learning with diverse learners. Data were collected through Google Forms and exported to Microsoft Excel and SPSS for analysis.

Instrument: Teachers' Perceptions of Cooperative Learning Questionnaire

The instrument consisted of 26 items divided into three sections:

1. Demographic Information (6 items) – included questions about gender, age, educational background, teaching context, and years of experience.
2. Perception Statements (15 items) – used a five-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree) to measure teachers' attitudes toward cooperative learning.
3. Open-ended Questions (5 items) – allowed participants to express their views, describe challenges, and share suggestions for effective implementation.

An example of the questionnaire interface is presented in Figure 1.

Figure 1

Screenshot of the Google Forms Questionnaire

Data Analysis

Quantitative data from the Likert-scale items were analyzed using descriptive statistics (mean, frequency, and percentage) in SPSS to identify general trends in teachers' perceptions. Qualitative responses from open-ended questions were analyzed through thematic analysis, which involved coding teachers' answers to identify recurring themes such as benefits, challenges, and strategies in applying cooperative learning in inclusive education.

The integration of both data types provided a comprehensive understanding of teachers' attitudes and experiences.

RESULTS

This section presents the findings of the study based on data collected from 40 teachers who participated in the conference and completed the online questionnaire on cooperative learning in inclusive classrooms. Quantitative data were analyzed using descriptive statistics, while qualitative responses were examined through thematic analysis. Tables 2–4 summarize the major findings.

Teachers' Perceptions of Cooperative Learning Effectiveness

The majority of respondents expressed positive attitudes toward the cooperative learning method. As shown in Table 2, most teachers agreed that cooperative learning enhances student participation, improves academic performance, and fosters inclusion in diverse classrooms.

Table 2

Teachers' Perceptions of the Effectiveness of Cooperative Learning (N = 40)

Statement	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	Mean
1. Cooperative learning improves academic achievement.	0	1	5	24	20	4.26
2. Students become more motivated in cooperative settings.	0	2	7	22	19	4.16
3. The method promotes inclusion among diverse learners.	0	1	6	23	20	4.24
4. Cooperative learning improves communication skills.	0	0	4	27	19	4.30
5. Group work builds students' self-esteem and confidence.	1	3	8	18	20	4.08

The data indicate that teachers strongly associate cooperative learning with academic and social benefits for students. The highest agreement level (M = 4.30) was recorded for the statement "Cooperative learning improves communication skills," highlighting the perceived social-emotional advantages of the method.

Implementation and Teacher Preparedness

Teachers were also asked to rate their perceptions of the practical implementation of cooperative learning and their preparedness to apply it. As presented in Table 3, most participants reported moderate to high confidence in using cooperative learning, though some expressed uncertainty regarding classroom management and task adaptation.

Table 3

Teachers' Perceptions of Implementation and Preparedness (N = 40)

Statement	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	Mean
6. I feel confident in implementing cooperative learning.	1	4	12	22	11	3.76
7. I have received adequate training in cooperative learning.	4	10	14	14	8	3.16
8. Cooperative learning requires more preparation time.	1	3	6	17	23	4.18
9. Classroom management is challenging during group work.	2	6	9	18	15	3.70
10. Cooperative learning is suitable for students with special needs.	0	2	10	23	15	4.02

While teachers recognized the value of cooperative learning, Table 3 suggests that lack of formal training remains a barrier (M = 3.16). Respondents also agreed that cooperative learning demands more preparation and planning time (M = 4.18), which can be challenging in larger classes.

Perceived Challenges and Benefits

The final section of the questionnaire contained open-ended questions that allowed teachers to describe their experiences, challenges, and recommendations. Thematic analysis of the responses revealed three main themes:

1. Positive impact on social inclusion and engagement,
2. Difficulties in managing group dynamics, and
3. Need for professional development and support.

As shown in Table 4, the first theme highlights how cooperative learning promotes inclusion and peer assistance, particularly for students with special educational needs. The second theme reflects the practical difficulties teachers encounter when organizing and monitoring group work. The third theme emphasizes teachers' requests for additional training and instructional resources to apply cooperative learning more effectively.

Table 4

Summary of Themes from Open-ended Responses

Theme	Description	Teacher Response
1. Promoting Inclusion and Peer Support	Teachers emphasized that cooperative learning helps students with special needs feel valued and accepted.	"In mixed-ability groups, students with learning difficulties participate more actively and are supported by peers. It builds their confidence and social interaction."
2. Classroom Management Challenges	Some teachers noted difficulties in maintaining equal participation and discipline during group activities.	"Sometimes stronger students dominate discussions, while others stay silent. It takes time to balance roles within groups."
3. Need for Training and Resources	Many respondents expressed a need for workshops and materials to design effective cooperative tasks.	"We need more structured guidance and examples of tasks that include students with different abilities. Training would help us use the method more effectively."

These qualitative insights demonstrate that while cooperative learning is perceived as highly beneficial for promoting inclusion, teachers still face practical barriers related to classroom management and lack of resources.

DISCUSSION

This study examined the effectiveness of the cooperative learning method in supporting students with diverse educational needs in inclusive classrooms. The quantitative results demonstrated a consistent improvement across all measured domains of academic performance and motivation after the implementation of cooperative learning activities. As shown in Table 3, students' mean scores increased notably in each skill area.

The greatest improvement was observed in speaking, with an increase of 30%, suggesting that cooperative learning strongly enhances oral communication and confidence through peer interaction and collaborative discussion. Similarly, vocabulary and motivation both improved by around 29%, indicating that group-based learning not only expands linguistic competence but also fosters enthusiasm and engagement in learning tasks. Gains in reading and writing were also significant, each increasing by approximately 26%, highlighting the role of cooperative activities in promoting comprehension and productive skills. Finally, listening improved by nearly 24%, reflecting that exposure to authentic peer communication helps students develop better auditory processing and understanding.

These findings align with previous research emphasizing that cooperative learning enhances both academic and social development (Johnson & Johnson, 2016; Gillies, 2016; Abubakr, 2024). The increase in motivation and active participation observed in this study echoes the results of Van Ryzin and Roseth (2019), who reported that students in cooperative classrooms demonstrate greater engagement and social connection. Moreover, the substantial improvement in communication-related skills reinforces Cohen and Lotan's (2015) argument that structured group interaction promotes equal participation and inclusion, particularly for learners with special needs.

Despite these positive outcomes, qualitative responses revealed certain implementation challenges. Many teachers reported difficulties managing group dynamics and ensuring equitable

participation. This concern aligns with the observations of Gillies and Boyle (2020), who noted that classroom management and time constraints often hinder effective group work. Another recurring theme was the need for professional development and instructional support. Teachers expressed that while cooperative learning is effective, its success depends heavily on proper training and task design. These insights highlight that sustained improvement requires not only methodological awareness but also institutional support for teachers to develop the necessary facilitation skills.

Overall, the results confirm that cooperative learning significantly benefits students with diverse educational needs by enhancing academic performance, communication, and social inclusion. However, its long-term success in inclusive classrooms relies on systematic teacher preparation, careful group structuring, and continuous pedagogical reflection.

CONCLUSION

The present study demonstrated that cooperative learning is an effective instructional approach for supporting students with diverse educational needs in inclusive classrooms. The quantitative results revealed significant improvement across all language skills and motivational indicators after the implementation of cooperative activities. These findings confirm that learning in small, structured, and supportive groups encourages active participation, enhances communication, and promotes both academic and social development.

Qualitative feedback from teachers further emphasized the positive impact of cooperative learning on students' engagement and peer relationships. However, challenges such as managing group dynamics and ensuring equal participation underscore the need for systematic teacher training and institutional support. Educators highlighted that without proper preparation and guidance, the benefits of cooperative learning may not be fully realized.

Overall, this study supports the growing body of evidence suggesting that cooperative learning fosters not only academic progress but also social inclusion and emotional well-being. By encouraging collaboration, empathy, and shared responsibility, this method contributes to creating an equitable and supportive classroom environment where every student, regardless of ability, can learn and succeed.

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Fransız dilinin təlimində texniki vəsaitlərdən istifadə

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Təlim böyük və mürəkkəb sistem olmaqla bir sıra yarım sistemlərə bölünür.Bunların arasında təlimin vasitələri xüsusı yer tutur.Müasir dövrdə xarici dillərin təlimi prosesində müxtəlif və rəngarəng vasitələrdən istifadə olunur. Bu vasitələrdən hər birinin öz xüsusiyyəti olmaqla, dil öyrənmə prosesində özünə məxsus yeri və əhəmiyyəti var. Bununla belə, bütün vasitələr eyni məqsədə xidmət etdiyindən vahid sistem təşkil edir. Təlim vasitələri komponentləri bir - birini tamamlayaraq öyrətmə prosesində üzvü əlaqədə, yəni kompleks şəkildə çıxış etdiyindən, metodikada " tədris kompleksi ,, adlanır. Tədris kompleksinin tərkibinə daxil olan vasitələr təlimdə yerinə və əhəmiyyətinə görə iki növə ayrılır:

1. Təlimin əsas vasitələri (kompleksin aparıcı komponentləri) Buraya tədris proqramı, dərslik, dərsliyə, aid metodik rəhbərlik daxil edilir ;

2. Təlimin əlavə vasitələri (kompleksin əlavə komponentləri) Buraya internet materialları, müxtəlif cədvəllər, disklər,lüğətlər,ev oxusu üçün ədəbiyyat və digər didaktik vəsaitlər daxildir.

Yuxarıda deyiləndən aydın görünür ki, təlimin əlavə vasitələrinə iki cür vəsait aid edilir:

a) Texniki vasitələrlə əlaqədar olmayan vəsaitlər.
Buraya başlıca olaraq şagird kitabçasının əsasını təşkil edən tədris lüğətləri, müxtəlif albomlar, tematik və süjetli şəkillər və digər didaktik vəsaitlər aid edilir.

b) Texniki vasitələrlə əlaqədar olan vəsaitlər. Buraya disklər, diafilmlər,videolar aiddir.

Texniki vəsaitlər ğörmə və eşitməyə əsaslanır. Bu baxımdan belə vəsaitlər üç yerə bölünür. Bu baxımdan belə vəsaitlər 3 növə ayrılır:

1. Görmə duyğusuna əsaslanan vəsaitlər (vizual texniki vəsaitlər) ;
2. Eşitmə duyğusuna əsaslanan vəsaitlər (auditiv vəsaitlər) ;
3. Həm görmə, həm də eşitmə duyğusuna əsaslanan vəsaitlər (audio - vizual vəsaitlər).

Vizual texniki vəsaitlərə, məlum olduğu kimi səssiz filmlər, şəkillər aid edilir.
Auditiv texniki vəsaitlərə səsli tədris filmləri, səsli diafilmlər,diktor mətni ilə müşayət olunan diapositivlər (Bu mətni müəllim özü də şagirdlərin bilik səviyyəsinə uyğun,müvafiq surətdə hazırlayab diskə yaza bilər). Komputerin bir şox funksiya yerinə yetirməsi tədris prosesində audio, video və audiovizual materiallardan görüntülü və dinləyərək istifadə etmək olur. Yəni CD, DVD, radio, televiziya verilişlərindən, hətta tədris saytlarından – ödənişsiz zəngin məbələrdən yararlanmaq kimi şanslar var.
Müasir tipli avadanlıqlarla təchiz olunmuş auditoriyalarda keçirilən dərslərdə tələbələrə materialı daha çox zaman ayıraraq dinlətmək şifahi anlamanı, qavramanı asanlaşdırır və əlavə dil materialları-sosial-mədəni mövzular dərsə daxil edilir .
İndi əksər tələbənin şəxsi komputeri və internetə bağlanmaq imkanları var, hətta tələbə özü müxtəlif internet mənbələrindən müstəqil istifadə edə və müəyyən təkliflər də irəli sürə bilərlər.
Fransız dilində istifadə olunan internet mənbələri daima yenilənərək müəllim və tələbələrin tələbatını ödəyir və sürətlə inkişaf edir. Burada daha çox məişət dilində işlənən, gündəlik həyatda rast gəlinən söz və ifadələr, audio və video materialların istifadəsindən söhbət gedir. Dil materialları yeni öyrənənlər üçün daha diqqətlə seçilməlidir ki, tələbələr söz ehtiyatını və qrammatikadan biliklərini genişləndirə bilsinlər.

Xarici dillərin təlimi problemləri ilə məşğul olan alimlər texniki vasitələrlə iş üsullarını uzun illərdən bəri tədqiq edərək bu sahədə xeyli faydalı nəticələr əldə etmişlər. Xarici dillərin öyrədilməsi məsələsi ilə Fransada iki mütəxəssis Pyer Leon və Monik Leon xeyli iş görmüşlər.Bu iki alimin Fransadan xaricdə fransız dilindən dərs deyən müəllimlər üçün tərtib etdikləri ,,İntroduction à la phonétique corrective à l'usage des professeurs étrangères adlı tədris vəsaiti diqqətə layiqdir. Rus mütəxəssisi M.B.Lyatovskinin fikrincə, internet materiallarından, disklərdən təkcə tələffüzün öyrədilməsində deyil, ümumiyyətlə, şifahi nitq üzrə vərdiş və bacarıqların inkişaf etdirilməsində istifadə etmək faydalıdır. Bu, xüsusilə xarici dildə səslənən nitqi dinləyib anlama bacarığının formalaşdırılmasına aiddir. Xarici dil dərslərində danışmağı əsil danışıq situasiyalarında öyrətmək heç də asan deyil. Bunun üçün bir neçə amil-materialın auditoriya üçün maraqlı, lazımlı və uyğun olması diqqət mərkəzində saxlanılmalıdır. CD, film, televiziya verilişi, internet mənbəyi, audio material müəllim tərəfindən seçilir və tələbələrə təqdim olunur. Hətta dərsdənkənar vaxtlarda İKT-dən müstəqil istifadə tələbənin marağından asılı olsa da belə müəllim bəzi dil materiallarını işləməyi tələb edərək onu yönəldə bilər.

Dil öyrəndiyimiz zaman tam ünsiyyət üçün bizə lazım olan dörd bacarıq var. Biz ana dilimizi öyrənəndə adətən əvvəlcə dinləməyi, sonra danışmağı, sonra oxumağı və nəhayət yazmağı öyrənirik. Bunlara dörd "dil bacarığı" deyilir. Dörd dil bacarığı birbiri ilə iki şəkildə bağlıdır: ünsiyyət istiqaməti (daxil və ya xaric) və ünsiyyət üsulu (şifahi və ya yazılı).

Bundan əlavə, öyrənmə üçün vacib elementlərdən biri müəllimlərin dil öyrənmə prosesini asanlaşdırmaq üçün dərslərində istifadə etdikləri metoddur.Kompüterlər müəllimlərin rahat çıxışı, kifayət qədər hazırlığı və kurrikulumda müəyyən qədər sərbəst olduğu dil dərslərində mühüm tədris aləti kimi qəbul edilir.Kompüter texnologiyası bir çox müəllimlər tərəfindən yüksək keyfiyyətli təhsilin təmin edilməsinin mühüm hissəsi hesab olunur.Cəmiyyətin hazırkı inkişafı mərhələsi Azərbaycan təhsil sisteminin qarşısında siyasi ,sosial- iqtisasdi, fəlsəfi və digər amillərin yaratdığı bir sıra prinsipial yeni tədqiqatlar qoyur. Son bir neçə il ərzində xarici dillərin tədrisində kompüter və internetdən istifadə ilə bağlı çoxlu müzakirələr aparılmışdır.Təklif olunan texnikalar ,fəaliyyətlər və dil tədrisi proqramında tətbiq dərəcəsi texnologiyanın təkamülü ilə yanaşı bir sıra ciddi dəyişikliklərə məruz qalmışdır. Kompüter özü tərbiyəçi statusundan alət statusuna çevrilmişdir.Bu alət mərhələsi kimi kompüter tədris materiallarını öyrənənlərə çatdırmaq üçün nəqliyyat vasitəsi kimi kompüterlərdən istifadəni nəzərdə tutur.

Texnologiyadan istifadə ənənəvi və virtual öyrənmədə tədrisin və təlimin kəmiyyət və keyfiyyətinin artırılması üçün vacibdir.İnformasiya kommunikasiya texnologiyaları elektron vasitələrdən istifadə etməklə məlumatı toplamaq ,saxlamaq, əldə etmək, yaymaq və ötürmək üçün istifadə olunan texnoloji platformalara aiddir. Bir çox müxtəlif İKT alətləri var ,onlardan bəziləri texnologiya, digərləri isə tək texnologiya üçün aksesuar və dəstəkdir. Noutbuk, kompüterlər, mobil telefonlar, planşetlər, televizorlar və s . daxil olmaqla müxtəlif texnoloji alətlər və xidmətlər mövcuddur , halbuki e-poçtlar bloqlar və video konfranslar öyrənmə ilə bağlı resurslar və xidmətlər hesab olunur. İKT-nin hər hansı bir xarici dilin öyrənilməsində müsbət roluna baxsaq görərik ki, yeni texnoloji vasitələr ilə tədris şəkil, səs və videoların sayəsində daha maraqlı, konkret, cəzbedici və bəzən əyləncəli də olur. Dərsdə istifadə olunan dil materialı orijinal, əsil danışıq situasiyalarından və danışıq anından olduğu kimi götürülmüş olur.

İKT bu zəngin informasiya mənbəyindən fransız dilinin tədrisində istifadə etmək və müxtəlif pedaqoji fəaliyyətlər (aktivitelər) təşkil etmək imkanları yaradır. Tələbələr xarici dili öyrənmək üçün daha yaxşı, əlverişli mühitə düşürlər. Beləliklə tələbələr öyrənmək üçün daha diqqətli olmağa başlayırlar.

Dilin öyrədilməsi və ya öyrənilməsinin bir məqsədi şagirdlərdə anlama sərişdəsini,yəni konkret kontekstdə sözlərin tam mənasını dərk etmək qabiliyyətini inkişaf etdirməkdir . Müasir texnologiyadan istifadə konsepsiyası ilə tanışlıq təkcə müasir cihazların və cihazların istifadəsi ilə məhdudlaşmı, əksinə , daha sürətli və hərtərəfli öyrənmə prosesini asanlaşdıran innovativ

sistemlərin və tədris metodlarının tətbiqi ilə əldə edilir. Texnologiya vasitələrinin inkişafı ilə internet əsaslı təlim , onlayn öyrənmə , şəbəkə öyrənməsi , distant təhsil kimi müxtəlif izahatlar və terminlər meydana çıxdı. Kompüterlər və şəbəkə texnologiyası mediaları vaxt ,məkan və cədvəl üzrə məhdudiyyətləri aşmaq və öyrənən mərkəzli fərdi öyrənməyə nail olmaq üçün sinxron və asinxron şəbəkə öyrənməsi də daxil olmaqla öyrənmə vəziyyətlərinə tətbiq edilmişdir. Bilik və məlumatların sürətlə axdığı dövrdə rəqəmsal öyrənmənin tətbiqi müxtəlif sahələri və sənayeləri əhatə edir. Fərqli mövqelərə və ya baxış nöqtələrinə əsaslanaraq ,təriflər fərqlidir. Rəqəmsal media internet, korporativ şəbəkə kompüterlər, peyk yayımı, audiokasetlər, video lentlər, interaktiv TV və kompakt disklərdən ibarətdir.

Formallaşdırılmış tədrisə əsaslanan , lakin elektron resursların köməyi ilə öyrənmə sistemi E-təlim kimi tanınır.Tədris siniflərdə və ya sinifdən kənarda aparıla bilsə də, kompüter-lərdən də, kompüterlərdən və internetdən istifadə e-tədrisin əsas komponentini təşkil edir. Elektron öyrənmə , bacarıq və biliklərin şəbəkə vasitəsilə ötürülməsi kimi də adlandırıla bilər və təhsilin çatdırılması eyni və ya müxtəlif vaxtlarda çox sayda alıcıya həyata keçirilir. Əvvəllər bu sistemdə öyrənmədə tələb olunan insan elementinin olmadığı güman edildiyi üçün ürəkdən qəbul olunmurdu. Bununla belə, texnologiyadan sürətli tərəqqi və öyrənmə sistemlərində ki irəliləyişlə indi kütlələr tərəfindən qəbul edilir. Kompüterlərin tətbiqi bu inqilabın əsasını təşkil etdi. Telefonlar, planşetlər və s . cihazlar indi sinif otaqlarında öyrənmə üçün mühüm yer tutur.Kitablar tədricən optik disklər və ya qələm aparatları kimi elektron tədris materialları ilə əvəz olunur. Bilik, həmçinin 24/7, hər yerdə, istənilən vaxt əlçatan olan internet vasitəsilə də paylaşıla bilər. Müəllimin rast gələ biləcəyi çətinliklərə nəzər salaq. Öncə müəllim deyiləcək dərsin mövzusunu əvvəlcədən planlaşdırmalı, axtarıb seçməlidir. Bu zaman müəllim adət etdiyi ənənəvi üsuldan kənarlaşıb daha çox yeni tədris texnologiyasına zaman ayırmalıdır. Bəzən müəllimlər kifayət qədər mənbə olmadığını və ya uyğun mənbələrin olmadığını önə sürürlər. Digərləri isə bu zəngin mənbənin içərisində çaşıb qalırlar, dərslərinin məzmununa uyğun mövzu axtarıb tapmaq və istifadə etməkdə çətinlik çəkirlər. Bəzi tələbələr də alışdıqları ənənəvi üsuldan İKT ilə tədrisə inteqrasiyada çətinlik çəkirlər. Azərbaycanlı müəllimin danışıq üslubuna və tempinə vərdiş etmiş tələbə üçün fransızın danışığını anlamaq çətin olur. Onların yeni tədris üsuluna uyğunlaşmalarını da, bu və ya digər çətinliklərin aradan qaldırılmasını da müəllim müxtəlif üsullarla həll etməlidir.

Danışıqları öyrətmək üçün adətən dil tədrisində istifadə olunan bir çox yanaşmalar danışıq dilinin xüsusiyyətlərini az nəzərə alır və bunun əvəzinə mahiyyətcə yazılı mətnə əsaslanan qrammatikalara üstünlük verirlər. Nitqin qeyd edilməsində texnoloji irəliləyişlər və dilçilər tərəfindən nitq nitqləri korpusunun yaradılması bu iki ünsiyyət üsulu arasındakı oxşarlıqlar və fərqlər haqqında daha çox məlumat əldə etməyə səbəb olmuşdur. Dil müəllimlərinin bəzi əsas fərqlərdən və adətən nitqi xarakterizə edən xüsusiyyətlərindən xəbərdar olması çox dəyərlidir, çünki bu, onlara nəyi öyrətmək barədə daha məlumatlı qərarlar qəbul etməyə imkan verəcəkdir.

Danışıq təlimində müəllimin, şagirdin və materialların oynadığı müvafiq rollar ön plana çıxmalıdır. Danışıq tapşırıqlarının əsas məqsədi tələbələrin mənanın az tərəddüdlə və mesajın sosial məqsədinə uyğun şəkildə çatdırıldığı ekspert natiqlərin səlisliyini inkişaf etdirməyə kömək etməkdir. Öyrənmə əsas məlumatları fərq etməyi və uzunmüddətli yaddaşda saxlamağı əhatə edir. Buna görə də öyrənənlərin diqqətini dil, bacarıq və strategiyalara yönəldən fəaliyyətlər nitqin öyrədilməsinin vacib hissəsidir.Burada mövzu nitqin tədrisinə vahid və ardıcıl yanaşmanın planlaşdırılmasında mərkəzi olan sahələri necə əhatə etdiyini müəyyən edən tədris nitq dövrünü əsas aspektlərinin qısa təhlili ilə başa çatır. Natiqlər və yazıçılar ümumi dil resurslarından istifadə edirlər, lakin onlardan müxtəlif yollarla istifadə edirlər. Yazıda ötürülən məna növləri nitq vasitəsilə ötürülən məna növlərindən bir qədər fərqli olur. Müəllimlərin öyrənənlərə sistematik şəkildə rəhbərlik etmələri, inteqrasiya olunmuş və ardıcıllıqla həyata keçirilən fəaliyyətləri təqdim etmələri vacibdir və onlara müxtəlif qarşılıqlı əlaqə və nitq növləri üçün lazım olan bilik, bacarıq və

strategiyalar haqqında məlumatlılığını artırmağa imkan verir. Tələbələr dilin spesifik aspektləri, məsələn, tələffüz xüsusiyyətləri ilə bağlı təlimata ehtiyac duya bilər, ya seqmental, ya da ikinci dildə danışıq səriştəsi dil biliyi və nitq kommunikasiya strategiyaları, əsas danışıq bacarıqları bölmələr üstü səviyyədə və ya narahatlıq kimi affektiv amillərlə bağlı dəstəyə ehtiyacı ola bilər. Fransız dilinin tədrisində İKT (İnformasiya və kommunikasiya texnologiyaları) - dən istifadə şagirdlərin motivasiyasını yüksəltməklə yanaşı, dilin kommunikativ tədrisini daha effektiv edir. İKT-dən istifadə edilərək şifahi nitq bacarıqları, dinləmə, oxuma və yazma bacarıqları inkişaf etdirilə bilər. İKT-dən istifadə şagirdlərin marağını cəlb edir və dil öyrənməyə olan həvəsini artırır. Hərtərəfli bacarıqların – şifahi nitq, dinləmə, oxuma və yazma vərdişlərinin – inkişafına kömək edir. İKT, kommunikativ yanaşmanı dəstəkləyərək şagirdləri real ünsiyyətə hazırlayır. Tədris zamanı şagirdlərin psixoloji xüsusiyyətlərini nəzərə almağa imkan verir, bu da İKT- nin effektivliyini artırır. Dilin mənimsənilməsində motivasiyanın yeri və rolu danılmazdır. Motivasiyasız dil öyrənən heç vaxt uzunmüddətli məqsədinə nail ola bilməz. Müəllimlər nəzərə çarpacaq dərəcədə dil öyrənənlərin motivasiyalarına təsir edə bilərlər. Bu əsas açar element kimi səciyyələndirilir. Bu da dilin mənimsənilməsində vacib amil kimi xarakterizə edilir. Həvəs, empatiya, antuziazm dilöyrənənlərin dilə həssaslığını artırır və müəllim – təhsilalan arasında sağlam münasibət formalaşdırılır. Bundan əlavə, müəllimlərin əsas məqsədlərindən biri də dilöyrənənlərin müstəqil olmalarıdır. Belə ki, onlar bununla müəyyən məsuliyyətlər hiss edir, onun çəkisini anlayır, qərar verərkən təhlillər aparırlar. Bu həm sinif daxilində, həm də sinifdənkənar ola bilər. Lakin, onu da söyləmək yerinə düşərdi ki, təhsilalanların sərbəstliyi universal bacarıqdır və yüksək dəyərləndirilməlidir.

Sinifdə və ya auditoriyada təhsilalanların təcrübəsi o zaman faydalı və dəyərli olar ki, onlar İKT- dən istifadə zamanı təhsilverənlərdən dəstək alsınlar. Bunlar baş verdikdə onların müstəqilliyi üçün daxili mənəvi zənginləşmə baş verir, sinif müzakirələri ərzində onları kommunikativ yönümlü fəaliyyətə sövq edir.

Dil müəllimləri əvvəllər öyrətdikləri kimi dərs deyirlərsə, o zaman ingilis dilini öyrənmək üçün tələb olunan məqsədlərə nail olmaq bir qədər çətin ola bilər. Ənənəvi tədrisdə dil bacarıqlarını (dinləmə, oxuma, danışma, yazı) inkişaf etdirmək üçün səmərəli və ya yaradıcı fəaliyyət təmin edilmirdi. Bu səbəbdən xarici dil müəllimləri texnologiyanın inkişafını ürəkdən alqışlamalı və ondan tədris prosesini dəstəkləmək üçün bir vasitə kimi istifadə etməlidirlər. Yeni tədris üsulu hər bir müəllim, şagird və valideyn tərəfindən yüksək qiymətləndirilir və rəğbətlə qarşılanır. Müasir texnologiyalardan istifadənin əsas məqsədlərindən biri tələbələri dil öyrənməyə fəal şəkildə cəlb etmək və onları ingilis dili bacarıqlarını praktiki və real şəkildə mənimsəməyə həvəsləndirməkdir Bu, şagirdlərin bir-biri ilə ünsiyyət qurmağa həvəsləndirməyə yönləndirilmişdir.

Updating and Improving the Quality of Modern Higher Pedagogical Education

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Keywords: case method, situation, theory, practice, collaboration, skill, innovative education

Abstract.

It is essential to take actions in various directions to update and improve the quality of modern higher pedagogical education. The perspectives of pedagogical education include updating curricula, implementing innovative teaching methods, enhancing teachers' professionalism, improving the assessment system, expanding the use of digital technologies, strengthening pedagogical practice, promoting research-based teaching, and increasing inclusivity in education.

One of these important directions — the development and broad implementation of innovative teaching methods — can have a positive impact on improving educational quality. This article focuses on the case method, which is based on the analysis of real or simulated events and helps apply theoretical knowledge to practical problems.

Innovative teaching methods enhance students' activity in the learning process, ensure the development of practical knowledge and skills, encourage creativity and critical thinking, and improve collaboration skills. Systematic and strategic implementation of these methods can enhance the content and quality of modern higher pedagogical education and make the Azerbaijani education system competitive at the international level.As one of the main modern innovative teaching methods, the case method allows students in higher pedagogical education to apply theoretical knowledge in practice, develop analytical thinking, and improve decision-making skills. This method is also a powerful tool for improving the quality of pedagogical education and creating content that meets modern pedagogical requirements. The use of the case method in the teaching process can ensure that pedagogical specialists become more professional and adaptable, thus contributing significantly to the overall development of education.

The case method is an approach used in teaching and analysis that aims to study a particular situation, event, or problem in depth. A case, based on real or imagined situations, allows students to analyze specific topics or problems, make decisions, and evaluate outcomes.

A case typically focuses on the analysis of a specific topic or issue, which may be based on real-life or simulated situations. It requires students to conduct a detailed analysis and draw conclusions based on given information. Since analyses are approached from multiple perspectives, students acquire multifaceted thinking and the ability to understand complex issues. Moreover, the case method aims to develop students' analytical, decision-making, discussion, and creative problem-solving skills.

There are several types of cases: analytical, decision-making, targeted, and research.

In analytical cases, the description of an event or situation is provided, and students are asked to analyze it.

In decision-making cases, students are presented with a problem and are required to decide how to solve it.

Targeted cases differ from others in that students are given specific ideas and strategies to solve a particular problem.

In research cases, students are provided with a topic and asked to conduct in-depth research.

Using cases in the teaching process offers many advantages, including the creation of an active learning environment, development of practical skills, enhancement of creative thinking and self-expression, improvement of collaboration skills, increased motivation, and reinforcement of knowledge. The case method encourages active student participation — learners not only receive information but also analyze and apply it.

The case method is highly effective for developing practical skills. Students learn to apply theoretical knowledge in practice and understand how to use it in real life. It prepares them for real-world challenges by fostering analytical, critical, and creative thinking skills. Real-life situations increase students' interest in topics and boost motivation. Through active participation in discussions, students learn to express their opinions and make decisions, thereby enhancing their communication and self-expression abilities.

This method not only improves students' analytical, problem-solving, and decision-making skills but also strengthens their communication abilities. Working collaboratively within groups, students learn to analyze problems and make decisions together. Participation in discussions, idea exchanges, and group work develops their social skills.

However, alongside advantages, the case method also presents challenges such as lack of teacher preparedness, insufficient resources, time constraints, assessment difficulties, and lack of student motivation. To overcome these issues, teachers must undergo special training and master the methodology. The use of modern technologies can make it easier to create real-life scenarios and save time. To avoid difficulties in assessment, it is essential to ensure that cases are grounded in theoretical frameworks. Lessons should be designed interactively and engagingly to reduce student passivity and disinterest.

Research shows that students who learn through case methods understand material better and retain it longer. To increase the effectiveness of the case method, it is important to focus on clear objectives, realistic scenarios, theoretical grounding, ensuring group discussions and collaboration, and creating a supportive and motivating environment.

In conclusion, the main goal of the case teaching method is to equip students with the ability to make sound decisions in real and complex situations. The case method is used to analyze and understand specific situations, problems, or events. In education, cases are particularly valuable for practical and applied learning approaches, as they involve real-life descriptions. This method helps students develop thinking, problem-solving, and discussion skills.

The case method in education serves the goals of conducting analyses, solving problems, teaching practical skills, and organizing interactive learning. When using this method, students analyze real or hypothetical situations, learn to approach them from different perspectives, engage in discussions, make decisions, and apply theoretical knowledge in practice. The case method creates an active learning environment that brings together various learning styles (visual, kinesthetic, auditory), providing opportunities suited to each student's needs.

Ultimately, the case method makes the learning process student-centered, interactive, and practical. It not only teaches knowledge but also develops students' analytical thinking, leadership, and decision-making skills. As an innovative and effective approach, the case method should be widely applied and continuously developed in modern education systems

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БИОЛОГИЯ САБАҒЫНДА ЭВРИСТИКАЛЫҚ ӘДІСТЕР АРҚЫЛЫ ОҚУШЫЛАРДЫҢ БІЛІМІН ЖЕТІЛДІРУ

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Аңдатпа. Бұл мақалада биология сабағында эвристикалық әдіс арқылы орта мектептің оқушыларының білімін жетілдіру туралы зерттеу жұмыстары қарастырылған.

“125 International School of Turkistan” мектебінің 1-сынып оқушыларына эвристикалық әдісті және бақылау әдісін қолдана отырып, биология сабағындағы генетикалық тұжырымдамалары сараланды және генетикалық есептерді шешуге дағдыландырылды. Зерттеу жұмыстарының нәтижесінде генетикалық немесе кез-келген биологиялық есептерді эвристикалық әдіс арқылы шешу ең ыңғайлы әдіс болып табылды. Қазіргі цифрландыру заманында бәсекеге қабілетті болашақ мамандарды даярлауда эвристикалық әдістің негізгі принциптері көрсетілді және оқушылардың әдісті дұрыс пайдалану мақсатында іс-тәжірибелік қабілеттерінің мүмкіндіктері қарастырылды. Зерттеу қызметін жүргізу барысында эвристикалық оқытудың 4 әдісі (бөліну техникасы, индуктивті әдіс, қысқарту әдісі, конструктивті әдіс)бар екендігі анықталды. Эвристикалық әдісті қолдануда мұғалімнің міндеті – биологиялық білім берудегі поцестерін және оқушыларды басқару бүкіл жүйеде дербес әрекеттері көрсетілді және эврика әдісінде оқушылар шығармашылық ойлауы мен қиялдың күшін қолдана отырып, олар қандай да бір логикаға негізделген қолайлы шешімдерді табуға бағытталды.

Мақалада Д. Пойаның генетикалық есептерді эвристикалық әдіс арқылы шешу мысалдарын ала отырып үлгілерге талдаулар жасалынды. Зерттеу жұмысына қатысқан оқушылар генетикалық есептерді эвристикалық әдіс арқылы шешуі қандай деңгейде түсінікті болғанын сауалнамадағы көрсеткіштерден байқай аламыз. Сауалнамадағы көрсеткіштеріне сай 72% - жоғары, 20% - орташа, 8% - төмен деңгейлері көрсетілді. Сондай-ақ, оқушыларға «Биологиялық білім беруде эвристикалық әдістің ықтимал салалары туралы оқушылардың пікірлері» атты сауалнама жүргізілді. Сауалнама нәтижелері бойынша, 25 оқушының ішінде 6 оқушы - сабақта, 2 оқушы - сыныптан тыс жұмыста, 4 оқушы – өзіндік жұмыстарда, 8 оқушы – ҰБТда деп белгіледі. Оқушылардың білімін эвристикалық әдіс арқылы жетілдіру ең тиімді процесс болады. Сауалнамадағы 25 оқушылардың ішінен сабақта 24%, сыныптан тыс жұмыста 8%, жобада 16% ,өзіндік жұмыстарда 20%,ҰБТда 8% қамтиды.

Оқушылардың білімінің сапалы болуына және эвристика тұжырымдамасының практикалық бөлігі эвристикалық әдісті қолдана отырып білімін жетілдіру тиімді болары анық.

Кілт сөздер: Эвристикалық оқыту, биологиялық білім беру, эврика, модельдеу, генетикалық есеп, инновациялық оқыту, конструктивті әдіс, әңгімелесу.

Кіріспе

Биологиялық білім беруде оқушылардың материалдарын дұрыс пайдалану арқылы шынайы өмірде қолданысқа енгізе алатынына мүмкіндіктер берілген. Биология сабағында эвристикалық әдістерді қолдану арқылы оқушылардың зерттеушілік қабілеттері арттырылып, оқушылардың күнделікті өмірде биология сабағындағы алған білімдерін қажеттігіне жарату ең маңыздысы болып табылады. Цифрландыру заманындағы оқытудың басты мақсаты-жаратылыстану сабақтарымен қызықтырғанымен шектелмейді, білімнің танымдық деңгейін жоғарылату, аналитикалық шеберліктерін, дүниетанымдық проблемаларға дұрыс және жылдам шешім шығару қабілеттерін және зерттеу жұмыстарын жүргізуде ізденушілік дағдыларын дамыту. Эвристикалық оқыту немесе эвристикалық әдістердің бастапқысы-интерактивті әдістер деп білінеді. Атап айтқанда, эвристикалық әдістер-инновациялық әдістерінің бір түрі болып табылады, эвристикалық әдіс – проблемалық әдіске ұқсас болғанымен оқушыларға тапсырмалар береді және белгілі бір дұрыс шешім болмай, әркім өз шешімін табады. Инновациялық оқытудың бұл түрі көбінесе білімді игеруге емес, оқушылардың шығармашылық дамуына арналған [1].

Эвристикалық әдістер негізінде Ежелгі Грецияда Сократ ұсынған және ғалым өзінің білім алушыларына сұрақтар қойып, нәтижелеріне қарап ойлауға және дұрыс сөйлесуге үйретеді. Сократ уақытында пайда болғанына қарамастан, қазіргі таңдағы педагогика саласына енгізілді. Сондықтанда оған белгілі бір бекітілген анықтамасы жоқ. Инновациялық әдістің бұл түрі эвристика анықтамасында тек практикалық бөлігі болып, әр түрлі мәселелерді шешуге, меңгеруге бағытталған. Эвристикалық оқыту – ыңғайлы және қажетті екеніне кепіл берілмейді, жақын аралықта мақсат қоюға жеткілікті болады. Әдістің басты ерекшелігі – мәселелердің шешімін табуға мүмкіндік беріп, әртүрлі техникалардың жиынтығын құрайды. Грек тілінен аударғанда «эвристика» дегеніміз «табу,ашу» мағыналарны білдіреді. Ұлы Британиядағы Империал колледжінің оқыту тәжірибесі жоғары деңгейдегі Генри Эдвард Армстронг бұл әдістің жақтаушысы болды. Армстронг айтуы бойынша:-«оқытудың өзін дұрыс жеткізуге, білім алушылардың білімін жетілдіруге ең тиімді әдіс болып табылады. Ғылымды ғылыми түсіндірумен бөлек, педагогикалық түсіндіру екі түрлі зат. Сондай-ақ, оқушылар осы проблемаларды немесе тапсырмаларды өздеруі жеке зерттеуі керек». Бұнымен, эвристикалық әдіс көмегімен білім алушылардың зерттеу арқылы оқитынын көрсетіп қана қоймай, қателерді дұрыс уақытта түзетінін анықтайды[2].

Биологиялық білім берудегі эвристикалық оқытудың мақсаттарын келесіндей тізбектей аламыз. Ең алдымен биология сабағындағы шығармашылық пікірлеуді жетілдіру қалыптасады. Пәннен алған теориялық білімдерін өз бетінше дұрыс қалыптастыруы, білімді игеруі, теориялық білімді практикада қолдану алгоритмін құрастырады және оқушылардың биология пәнінде танымдық қызығушылықтарын дамыта алу қабілеттерін жатқызамыз. Сондай – ақ, биологиялық есептерді логикалық тұрғыда шешуді қарастырады. Жалпы алғанда, биологиялық білім беруде эвристика әдісін қолданудағы анықтамалардың, ресурстардың байланысы когнитивтік ауытқулар тудыруы мүмкіндігі бар. Адамдар мен өндірістік жерлердің дұрыс емес шешімдерді қабылдау мүмкіндігі туындайды. Сонда да анықтаманы ұғыну бұл жағдайдан алыс болуға жәрдем береді. Ақыл ой, дербес пікір және креативті таңбашалары қиын жәйіттерде тез нәтижені жасауға немесе қысқа мерзімде жеңіл фактілерге ыңғайлы шешімдерді анықтайды [3]. Сонымен бұл мақаладағы зерттеудің мақсаты эвристикалық оқыту арқылы биология сабағындағы білімін жетілдіру және оқушылардың бойында жан-жақта жетілген тұлғаны қалыптастыру. Осылайша, эвристикалық әдіс арқылы оқушылардың биологиялық ұғымдарын білуде, есептерін шешуде, теориялық ақпараттарды игеруде шығармашылық

қабілеттерінің дамуына бағытталған. Эвристикалық оқыту арқылы есте сақтауға арналған тапсырмалар берілмейді, яғни инновациялық әдістің бұл түрі оқушылардың есте сақтау қабілетін дамытуға арналмаған. Оқытуда ассимиляция жүргізіледі, оқушылар үшін өзіндік шығармашылық нәтиже шығаруда қолданылады.

Талдау мен нәтижелер

Эвристикалық оқыту арқылы биологиялық ұғымдарға логикалық, аналитикалық, сыни, шығармашылық ойлауды дамыту аса маңызды. Бұл инновациялық әдіс тиімділігімен, толықтығымен, жылдамығымен ерекшеленіп, эвристикалық әдістедегі зерттеу жұмыстары белсенділіктің жоғары дәрежесін көрсетеді. Оқушылар арасында өзіндік бәсекелестік пайда болады және өзара шығармашылық сипатқа ие бола алады. Бұл тәсіл арқылы оқушылар өз бетімен жұмыс жасай алу қабілеті жетіледі және жаңа білімді өз бетінше игеріледі. Биологияны эвристикалық оқытуда мұғалімнің алдында ең негізгі болған аспектілерді табу міндеті тұрады. Биология сабағындағы әрбір тақырып бойынша және оқушылардың бастапқы шығармашылық зерттеу үшін жағдайды қолжетімді етеді. Зерттеу жұмыстарын жүргізу барысында оқушылар өзінің тұжырымдамаларын, пікірлерін, болжамдарын, сондай-ақ, өзі туралы білімнің өнімін алады

Сондай –ақ, эвристикалық әдістердің мақсаттарын зерттей келе, биология сабағының мұғалімдеріне бірнеше міндеттер жіктеледі. Оларды келесідей топтарға жіктеп қараймыз: Биология пәніндегі сабақ тақырыбы бойынша оқушылардың білім қорын толықтырады. Эвристикалық оқытуы бойынша оқушылардың білімін жетілдіреді. Білім алушылардың шығармашылық ойларын дамыта алу қабілеттері қалыптасады және кемел тұлға осы әдіс арқылы тәрбиеленеді. Бүгінгі таңда интерактивті әдісінің бір түрі болған эвристикалық оқытуыдың бірнеше әдіс-тәсілдер бар. Эвристикалық оқытуда интерактивті әдістің жаңа ойлары, жаңа жобалары, зерттеу жұмыстары, олимпиадалық конкурстарын құрайды[4,5].

Эвристикалық оқытуда белгілі бір білімді нақты меңгеру қажеттігі болмайды, оқуышының ғылымды шығармашылық тұрғыда меңгеру қажеттеігін атайды. Сәкесінше, физиологиялық жас ерекшеліктеріне қарай биология сабағы бойынша шығармашылық жетістіктері бағаланады. Төмендегі қатарда эвристикалық оқытудың бірнеше принциптері көрсетілген: Ең алдымен ғылымды игеру кезінде оқушының жеке мақсат қоя білуін атасақ екінші болып биологиялық білім беру траекториясын саралау қажеттігін атап көрсетеді. Білім берудегі теориялық мазмұндардың метапәндік негіздері оқудың нәтижесімен терең байланысқа ие болады. Білім алушының білімді жетілдіру кезіндегі басымдылығы поблемалық және жағдаяттық оқытуда анықталады және тәрбиелік мәні бар рефлексия немесе ішкі түйсікпен ұштастырады [6].

Зерттеу қызметін жүргізу барысында эвристикалық оқытудың бірнеше әдістері бар екендігі анықталды. Америкада қолданған көптеген эвристикалық әдістер жіктелген:

1. Бөліну техникасы – ең алғашқы рет қолданылған әдістердің бірі, қолайлы деп білген кішігірім ішкі проблемаларға бөлінеді. Қосымша мәселелерді бір-бірімен біріктіріледі және ең соңында бастапқы проблеманы анықтауға алып келеді.

2. Индуктивті әдіс – анықталған мәселе, алдымен бастапқы проблемадан кішкене мәселерді анықтауға көмек береді.

3. Қысқарту әдісі – проблемалардың көптеген үлкен және әртүрлі себептер мен факторлармен байланысты болғандықтан, бұл тәсіл проблемаға шектеулерді алдын талдайды. Бұл бастапқы проблеманың тәуелсіздігін азайтып, оны шешуді жеңілдетеді.

4. Конструктивті әдіс – мәселелерді этап бойынша жасау туралы. Ең кішкентай анықтамада жеңіс ретінде қарастырылады. Осы сәттен бастап дербес қадамдар

жасалынады. Бұл эвристикалық әдістің ең жақсы таңдаулар болады және ең соңында тиімді нәтижеге алып келеді.

Сондай – ақ, жоғарыдағы эвристикалық әдістерді қолдануға бірнеше мысалдар келтіре аламыз. Мысалы, Айна деген мұғалім оқушылардың ҰБТдан төмен балл алулардан қорқып, ыңғайлы және тиімді дайындық жоспарын ойлап тапты. Эвристикалық әдістің ерекше бол,аны тез шешім қабылдай алу мүмкіндігі екені анық. Эвристикалық оқытуда шешім қабылдау жасанды интеллектке шешуші рөл қызметін атқарады. Қолжетімді болған платформаларды немесе ақпараттарды логикалық меңгертукге алып келетін когнитивті бейімділікті ынталандырады [7].

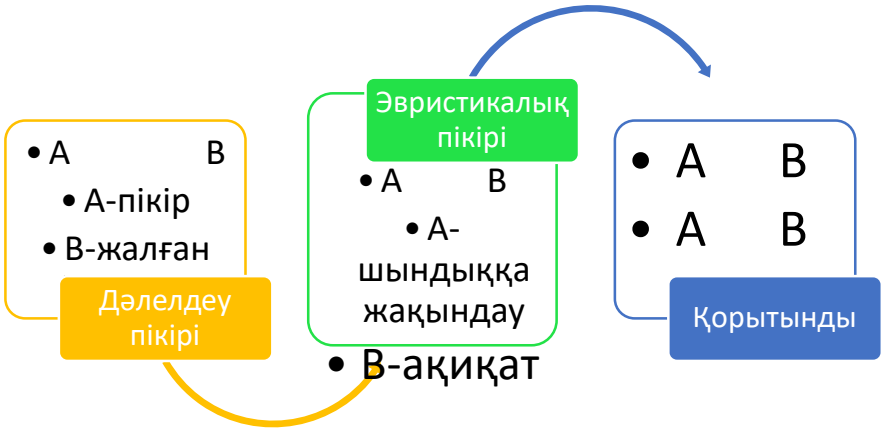
Инновациялық әдістің түрі – эвристикалық әдістің тапсырмаларды шешу стратегияларын әзірлеуде негіз болып табылады. Эвристикалық әдістің ережелері мен белгілі бір амалдары оқытуға бағытталып, шындыққа қарай жүргізілетін пікірлермен өзара байланысты. Яғни, эвристикалық оқыту-индукцияға, аналогиялық ойлауға және басқа да пікірлердің процестеріне негізделген дербес пікірлері болады.

Мұндай негізделген принциптерде стратегиялық ойлауды екі ой қорытуымен қарастырылады:

1. Дәлелдеуші пікірлер;
2. Эвристикалық пікірлер.

Бұл екі ой қорытулар бір-бірімен ақпараттық қамтамасыз етуге тәуелді, бір түрден екінші түрге өтуде бір-бірін толықтырады. Төмендегі кестеде логика схемаларының ұқсас процестеріне сай екі ой қорытуындағы процестің жұмысы көрсетілген (Кесте 1).

Кесте 1. Дәлелдеуші пікірлермен эвристикалық пікірлердің байланысы



Кестеде екі түрлі ойдың байланысы көрсетілді, бірінші ойда, дәлелдеу пікірлері A-B; A-пікір, B-жалған,салдары, яғни бұл жерде B – дұрыс болғанымен, дәлелдерді дұрыс қолданбауы, проблемаларды шешпеуі A компоненті де жалған болып қалады. Екінші пікірде, эвристикалық ой қорытуымен жүзеге асырылады.

Жоғарыдағы кесте бойынша оқушы белгілі бір тапсырма орындау барысында, дайын білімді сол бойы қабылдамай, оның жеке тәжірибелеріне сүйене отырып нәтижелерімен салыстырады. Оқушылардың сыни ойлауын қалыптастыруда оқу материалын дұрыс таңдауға аса қатты назар аударылуы қажет. Білім алушылар оқу-тәрбие үрдісін дидактикалық жобалауда инновациялық әдістерді пайдалану арқылы биологиялық білімі жетіледі.

Сыни ойлауын қалыптастыруда келесіндей тағы бір принципі бар. Барлық принциптерді ерекше ескере отырып, оқушылардың ең маңызды психологиялық қасиеттерінің маңыздылығы- ақыл ой әрекетінде, білімге деген құштарлығында және мінез-құлықтың сыртқы формаларында сөзсіз көрінеді [8].

Эвристикалық оқыту бойынша биологиялық білім беруді қолдану шегін педагог анықтайды және зерттеушілердің практикалық шолулары оқу бағдарламасының кез-келгенін пайдалануда озық тәжірибеге ие, білім алушылардың шығармашылық деңгейін кез-келген жаста ұйымдастырылатын әдістерден байқауға болады.

Оқушылар эвристикалық әдістерді әдетте өздерін шығармашылықпен көрсету мақсатында тиімді деп біледі. Қиял шексіз болғанымен білім беру әрқашан белгіленген білім беру талаптары мен стандарттары жүйелі түрде болады. Қиялмен байланысты болғандықтан мұғалімнің алдында оқу процесін жарқын, серпінді және қызықты ету қажеттілігі туындайды.

Эвристикалық оқыту технологиясында бірнеше әдістерді қамтуға болады: Сұхбаттасу; Әңгімелесу; Панель әдістері; Пікірталас; Эврика; Модельдеу; Инверсия; Талқылау. Бұл эвристикалық әдістің бірнеше түрлері деп те атасақ болады. Биологиялық білім берудегі бұл әдістердің барлығы керемет тәсіл деп білеміз. Эвристикалық пікірталас әдісіне келетін болсақ, оқушылар шешім беру аясында әртүрлі шешімдерді ортаға салып өзара пікірлерін айтады. Эвристикалық әдістің маңызы осы әдіс арқылы байқалады, яғни оқушылар өзіндік еркін ойларын айтады және ол жерде белгілі бір дұрыс шешім жоқ екендігі айтылады.

Жоғарыдағы эвристикалық әдістердің бірнеше бағыттары көрсетілген, эвристикалық әңгімелесу оқушылардың дербес пікірлерін және жауаптарын басқа арнаға негіздейтін бірқатар сұрақтар. Іс-жүргізу барысында білім алушылардың бірнеше фактілерді, құбылыстарды ашуы орын алады. Эвристикалық әңгімелесу оқушылардың шығармашылық ойлауын, креативті және логикалық ойлауға ықпал етеді. Орта мектеп оқушылар мәліметтерді игерудің нәтижесі тиімді әдістері қалыптасады. Коррекцияланбаған жұмыс жоспары дұрыс емес деп болжау қорқынышы жоғалады [9].

Эвристикалық модельдеу әдісі – оқушылардың білім сапасын арттыру мақсатында пайда болған әдіс болады. Биологиялық білім берудегі күрделі тәртіп форматында болатын модельдерді құруға негізделген.

Елімізде бұл эвристикалық модельдеу әдісі 60-жылдар енгізіле басталды. Эвристикалық әдіспен формаларды құрудың тиімді нәтижеге ие болатын процесс келесі жолмен құрылады. Оқушыларға кейбір есептеулерді өз ойларын ауызша шешу ұсынылады және барлық дербес пікірлері хаттамаға жазылады. Биологиялық генетикалық есептер , қолданылатын операциялардың характерлері, ойлары, логикалық есептерді шығару ұсынылады. Ұсынысты талдау барысында, алынған ақпарат осы түрде берілетін моделі компьютерлік бағдарламалар құруда қолданылады. Мысалы, оқушылардың білімін эвристикалық әдіс арқылы жетілдіру мақсатында комптютерлік бағдарлама құрылады әртүрлі онлайн тегін платформаларында генетикалық есептерді шешуге арналған болуы, модельдеудегі формалар нейрондық жүйелерді аталады. Осы себептен бағдарлама моделбдеу әдісін пайдаланушылардыкы емес бағдарламаларды дұрыс игеру болып табылады.

Келтірілген әдістердің барлығы дерлік биологиялық білім беруде оқушылардың білімін жетілдіруде тез арада нәтижеге эффект беріледі.

«Эврика» әдісі – оқушылар сабақ үстінде электронды түрде есептің шешімін табуға шақырылады. Мысалы, электрондық кітахана, виртуалды зертханалық тәжірибе және сыныптан тыс жұмыстар (жоба әдісі жүргізіледі), түрлі кітаптар, ресурстар.

Бұл әдісті қолдануда мұғалімнің міндеті – биологиялық білім берудегі поцестерін және оқушыларды басқару бүкіл жүйеде дербес әрекет етеді. Эврика әдісінде оқушылар шығармашылық ойлауы мен қиялдың күшін қолдана отырып, олар қандай да бір логикаға негізделген қолайлы шешімдерді табуға бағытталған. Зерттеушілер эвристикалық әдісті қолданудағы өз тәжірибелерін оқыту стратегиясымен бірге сипатталады:

1. Тақырыптағы проблемалық мәселелерді шеші тәсілін жетілдіру;
2. Мәселеге ғылыми көзқарасты дамыту;
3. Өз ойын жеткізе білу қабілетін жоғарылату [10].

Сондай-ақ, эвристикалық оқыту стратегиясын қолданудағы бірнеше принциптер келтіріледі: Жеке-жеке тапсырмалар берілген кезде оқушылардың уақытын мүмкіндігінше ұзаққа созып отырылуы қажет; Оқушылар әрқашан өз бетімен білім алуға ынталандырылуы; Проблеманың ең ыңғайлы шешімін таңдауға кеңес берілуі; Мәселе сабаққа және оқыту программасына байланысты; Зерттеудің нәтижесін дұрыс талқылауда белгілі бір уақытта бөлінуі; Мәселелерді шешу кезінде білім алушылардың шығармашылық қабілеттері, білім алуға қызығушылықтары және тақырыпты таңдауы керек.

АҚШ-тың білікті математигі Д.Пойаның айтуы бойынша, эвристикалық оқытудың негізгі мақсаты жаңалық, ғылыми бір жаңалық ашуға алып келетін тәсіл ретінде қолдану өте маңызды. Биологиялық есептерді шешу үшін биология пәні туралы білімнің болуы немесе жай ғылыми шығармашылық қабілеті болуы қажет. Ғылыми жаңалық ашу жолында пікірге жаңа білім келгенше үнемі зерттеу жүргізіліп отырылуы қажет[11].

Төмендегі кестеде Д.Пойа есеп шығарудың негізгі бағдарға алынуы қажет болған криетерийлер көрсетілді (Кесте 2).

Кесте 2. Эвристикалық әдіс бойынша биологиялық есеп шешудің негізгі бағдарлары

Кестеде көрсетілгендей, биология сабағындағы есептерді шешу үшін ең алдымен есептің берілгеннің мағынасын түсінуіміз қажет. Жоғарыдағы келтірілгендей жоспар кезіне анық болуы үшін бірінші этапта шартты белгілердің белгілері жазылуы тиіс. Екінші қадамда, есепті шешу мақсатында жоспар дайындалады. Мысалы, алелльді табу қажет, гетерзиготалы гаметаларды табу қажет. Ары қарай есепті шешу барысында, жоспармен жұмыс жүргізіліп шешімі анықталады. Табылған шешіммен зерттеулер жүргізіліп, дұрыс бұрыстығы анықталады.

Есепті шығару барысында, оқушылар төмендегідей сұрақтарға жауап бере білуі қажеттігі туындайды:

1. Не белгілі?
2. Шарттарында не берілген?
3. Есептің шарты анық па?
4. Бұрын бұл есептерге сай есеп болған ба немесе ұқсас есептердің үлгілері болды ма?
5. Сай келген есептің шарттарын қолдануға бола ма?

Биология пәнінде мұғалімдер тек бір есеп бойынша немесе бір қатып қалған ереже бойынша мағлұмат айтпауы қажет. Оқушылар ары қарай ізденісті өздері жалғастыру қажет, эвристикалық әдіс арқылы ақиқатқа жеткізіледі. В.В. Репьевтің анықтамасы бойынша: «мұғалімдер тек теориялық мәліметтерді беруі қажет, шынайы өмірде

оқушылар практикада қай дәрежеде түсінгенін өздері ұғынуы қажет»,-деп тұжырымдайды [12].

Зерттеу нысаны ретінде “125 Internaional School of Turkistan” 10 «F»-сынып оқушылары алынды және зерттеу барысында 25 оқушы қатысты. Эвристикалық оқытуды дұрыс және тиімді нәтижеге жету үшін 10-сынып оқушыларына «Г.Мендельдің ашқан заңдылықтары. Гибридологиялық әдіс. Моногибридті будандастыру»-атты тақырыпта сабақ өтілді. Биологиялық білім беру бойынша оқушылардың эвристикалық әдіс арқылы білімін жетілдіру негізгі мақсатқа алынды.

Зерттеу сабақ жүргізу барысында, ұйымдастыру кезеңі(сәлемдесу, топқа бөлу, сабақ барысымен таныстыру, балалардың назарын сабаққа аударту), үй жұмысы тексерілді(Онтогенез сатылары), жаңа сабақ(сабақ түсіндіру, терминдерді беру, генетикалық есепті шешу).

Жаңа сабақ өткізу барысында оқушылардың генетикалық есептерді шешуі үшін дұрыс анықтамаларды білу қажет және тапсырмалар эврика әдісі арқылы берілді. Төмендегі кестеде эврика әдісі арқылы тапсырмалар берілді (Кесте 3). «Эврика» әдісі арқылы оқушылар екі терминнің анықтамаларын қарастырып анықтайды.

Кесте 3. «Фенотип пен генотиптерді ажыратыңыз»

Анықтамалар	Фенотип	Генотип
Клеткадағы барлық гендер жиынтығы		+
Сыртқы көрініс	+	
Тұқымқуалаушылық қасиетінің негізі		+
Хлорофилл түсінің жасыл болуы байланысты		+
Қоршаған ортаның өзара әрекеттесуінен пайда болды	+	
Сұрыптаудың таза линияларында зерттеліп, анықталған	+	
Пішін, үлгі дегенді білдіреді		+
Көріну, тип дегенді білдіреді	+	

Сонымен, оқушыларға «Дальтонизм мен гемофилия аурулары» тақырыбында шығарма немесе презентация әзірлеу жөнінде тапсырма берілсе, оқушылар осы екі ауру атауларға тың зерттеу жүргізеді, әдебиеттік шолу жасалынады. Осы зерттеу жүргізуін және қызығушылық туғызының өзі эвристикалық әдіске жатады. Сабақ жүргізу барысында мұғалім оқушылардың ынтасын оятып, пән бойынша ізденістерге күш береді. Осының әсерінен оқушыларда зерттеушілік қабілеттері қалыптасады.

Мысалы, оқушыларға ашық түрдегі тапсырмалар беріледі, роботты құрастыру, модель-мактерді дайындау, бмзнестік жобаларда жарнама жасауды игеру, эвристика тұжырымдамасын дайындау деген тақырыптарды жұмыс жасауды жатқызамыз.

Осылайша, жаңартырылған білім беру бойынша биология пәнінде биологиялық есептер мен тапсырмаларды дұрыс шешу үшін эвристикалық әдіс пайдаланылады. Сонымен бөлек жаңа сабақта әңгімелесу әдісі қолданылды, жалпы алғанда, эвристикалық әңгімелесу дегеніміз оқушылардың пікірлерін және тапсырмаларға берген жауаптарын нақты бір бағытқа бағыттайтын бірнеше сұрақтар дайындайды. Зерттеу жүргізу кезде оқушылардың бағалануы белгілі бір критерийлерге салу арқылы жүреді және тапсырмаларды орындауда немесе ауызша жауап беру кезінде кейбір қағидаттарды, құбылыстарды ашуы болады. Эвристикалық әдіс кіріспе бөлімінде айтылғандай шығармашылық қабілеттеріне, логикалық пікірлеуге ықпал етеді. Эвристикалық әдісте

оқушылар дұрыс болмаған жауаптарды айтуы ешқандай қорқынышқа алып келмейді, яғни оқушылар дұрыс емес бағаға тәуелді болмай, мұғаліммен дұрыс қарым-қатынаста болады.

Д.Пойаның эвристикалық әдісі бойынша биологиялық есеп шешудің негізгі бағдарындағы қадамдарда жүргізілді. Биология пәніндегі 10-сынып оқушыларына генетикалық есептер берілді. Төмендегідей 4 этаптан өткізіп есеп шешілді:

1. Есептің берілгенін дұрыс түсіну қажет, есеп берілгені: «Гетерозиготалы сұр қояннның аналығы осындай қояннның аталығымен будандастырылды. F1-генотиптері мен фенотиптерін анықтаңыз».

2. Есепті шешу мақсатында жоспарды құру қадамына келетін болсақ есепте не берілген? Шарты бар ма?

Нені табу керек?

Берілген: P♀ Aa x ♂Aa.

Есепте көрсетілгендей, А-сұр; а-ақ; Яғни қызыл түсті қоян доминантты болады.

Бірінші ұрпақтың фенотипі мен генотипін анықтауымыз қажет?

Екінші этапты тың зерттеу үшін оқушылар Мендель зерттеген заңдарын игерген болуы керек, генетикалық символдар (отбасы, аталық, аналық, ұрпақ), гендер, фенотип, генотип, гомозигота, зигота, гамета, гетерозигота, аллель, доминатты, рецессивті.

Жоспар:

1. Есеп шартын мұқият оқу;
2. Тұқым қуалайтын белгілерді анықтау;
3. Гендердің аллельдерін белгілеу;
4. Аталық пен аналықтың, ұрпақтарының генотипін білу;
5. Генетикалық формуламен көрсету;
6. Шағылыстыру жағдайында түзілген гамета типтерін белгілеу;
7. Ұрпақтарының типтерін көрсету;
8. Пеннет торын сызу;
9. Аналық гаметаларды сол жағына, аталық гаметаларды жоғарысына жазу.

3. Д. Пойаның генетикалық есептерді шешудегі .лгі бойынша берілген генетикалық / биологиялық есептің шешімін іздеу барысында жоспарға салынып есеп шешілу қажеттігі туындайды. Сондай-ақ, оқушыларға пеннет торымен есептеуді орналастырылуы меңгертіріледі. Биология сабағында генетика (тұқымқуалаушылық пен өзгергіштік) бөліміндеГ. Мендель заңдылықтары игеріліп, есептің шешілуі туралы негізгі мәселелер қарастырылады. Төмендегі пеннет торыда жоспарға салынып шарттары анықталған есепті торға орналастырамыз (Пеннет торы 1.):

Пеннет торы 1. F1-генотипі

♀ / ♂	A	a
A	AA	Aa
a	Aa	aa

4. Келесі кезең төртінші кезеңде берілген есептің шешімін зерттеу, жауабын көрсету:

Белгілерді ажыратып бөліп қарастыратын болсақ, 1 AA: 2Aa: 1aa

Яғни жауабы: F1- генотиптері- AA, Aa, aa.

Гетерозиготалы 100-50, гомозиготалы 100-50 болып көрініс тапты.

¾ бөлігі сұр түсті, ¼ бөлігі ақ қоян болды.

Жоғарыда келтірілген Д. Пойа математигінің көрсеткіштерімен биологиялық есептерді шешуде эвристика әдісі пайдаланылды және 10-сынып оқушыларына «Эвристикалық әдіс арқылы генетикалық есептерді шешу қай дәрежеде түсінікті болды?» атты сауалнама берілді(Сурет 1).

1-сурет - 10-сынып оқушылар арасында жүргізілген сауалнама нәтижесі.

Сауалнамаға 25 оқушы қатысты: 18 оқушы-жоғары, 5 оқушы-орташа, 2 оқушы-төмен деп белгіледі. Оқушылардың білімін жетілдірудегі ең ыңғайлы инновациялық әдіс екені анық. Сауалнамадағы 18 оқушыға генетикалық есептерді шешуде эвристикалық әдісті толық игерді деп білеміз. 5 оқушы есепті шешуді жартылай меңгерді, ал 2 оқушы сауалнамада төмен деп белгіледі, биологиялық/генетикалық есептерді дұрыс игермеді.

Зерттеу жұмысын жүргізу барысында эвристикалық әдісінің конструктивті түріні пайдаланумен бірге байланысты жүзеге асырылды. Кезең-кезеңмен жоспарға салып атқарылатын эвристикалық әдістің бір түрі. Эвристикалық әдістің бұл түрі проблемаларды кезең-кезең бойынша жасау туралы. Ең кішкентай берілген мәліметтерде жеңіс ретінде қарастырылады. Осы сәттен бастап дербес қадамдар қолданылады. Бұл эвристикалық әдістің ең жақсы таңдаулар болады және ең соңында тиімді нәтижеге алып келеді.

Қорытынды

Сонымен, биологиялық білім берудегі оқытудың эвристикалық әдісі оқушылардың білімін жетілдіруге, қызығушылықтарын жеңіл анықтауға, олар туралы көбірек білуге жұмыс жүргізуге көмек беретін қолданбалы және қызықты оқыту әдісі деп айта аламыз. Бұл эвристикалық оқытудың көптеген артықшылықтары бар, сондай-ақ, биология пәнінің мұғалімі мен оқушылардың табысты болуына және озық тәжірибеге ие болуына маңызды рөлдері бар. Биологиялық білім берудің міндеттерін және пәндегі есептерді шешудегі жүйелі құрылымға сай, жалпы айтқанда жүйелеу нақтылаудың көптүрлілігі туралы ғылым. Эвристикалық әдістің құрылымы кері байланысқа негізделген.

Биологиялық білім беруде эвристикалық әдістің ерекшеліктері анықталды. Оқушылардың еріксіз, қыстамай оқытылуы, биологиялық оқытудағы ынтасын дамытуы, зерттеушілік дағдысының қалыптастырылуы және білімнің сапалы болуы эвристикалық әдіс арқылы жетілдіріліп отыруы қажет.

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Philological Sciences

LEXICAL-STYLISTIC DEVICES IN THE ENGLISH LANGUAGE AND THEIR EXEMPLARY ANALYSIS

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Lexical-stylistic devices are among the main elements that express the artistic and aesthetic potential of a language. Through these devices, a speaker or writer can convey thoughts more effectively, vividly, and emotionally. The use of such devices in English, particularly in literature, journalism, and everyday speech, demonstrates the richness and creative capacity of the language.

Lexical stylistics examines not only the semantic but also the stylistic layer of language, revealing its functional and aesthetic roles. In this context, the study of lexical-stylistic devices constitutes one of the main directions of linguistics, translation studies, literary criticism, and stylistics. These devices are not only a form of expression but also carriers of culture, and they may be evaluated differently depending on the context.

Modern stylistics, by considering the role of these devices in shaping the style of the text, the author's position, and the emotional atmosphere, allows for a deeper analysis of their function. At the same time, the study of stylistic devices has great methodological significance for language learners, as it helps to expand the expressive possibilities of the language and increase the impact of writing. These devices enable writers and poets to deepen word meanings, thus delivering their intended message more powerfully and emotionally to the reader. Lexical-stylistic devices in English strengthen both the rhythm and the visual and emotional impact of the text.

This paper will focus on some of the most commonly used lexical-stylistic devices in English, providing explanations and examples for each. The aim is to help understand how these devices enhance the aesthetic impact of language and influence the reader.

1. Epithet

The epithet is an adjective or adjectival expression that enhances the emotional and figurative quality of description. It is one of the most expressive means of the English language. The term epithet comes from Greek, meaning "addition." Its main purpose is to attach an additional descriptive quality to a word denoting an object or phenomenon, e.g., "The golden silence of the room," "a cruel winter wind."

The epithet exerts a strong influence on the reader, compelling them to perceive and evaluate objects as the author intends: "destructive charms," "encouraging smile,"etc. It may derive from both the literal and figurative meanings of words, though in poetic speech, epithets are predominantly figurative. They intensify emotional expression and create vivid imagery in the reader's imagination.

Epithets arise from the interplay of logical, emotive, and figurative meanings and are structurally realized in combinations such as adjective + noun or verb + adverb . They may be metaphoric (foxy fate), metonymic (Cold War), or ironic (the kind hangman).

Epithets are classified as follows:

Simple epithets — He looked at them in animal panic.
Compound epithets — heart-burning sigh, cloud-shapen giant, curly-headed boy, etc.
Phrasal epithets — bestowers of good things.
Two-noun epithets joined by of — the shadow of a smile, a devil of a job (Maugham), a devil of a sea (Byron).

Epithets may also be divided into language epithets (traditional, fixed) and speech epithets (individual, contextual). Stable, traditional epithets such as true love, dark forest, brave cavalier often appear in ballads and folk songs.

2. Oxymoron

An oxymoron is a combination of two semantically contradictory words, usually in the adjective + noun or adverb + adjective model, e.g., low skyscraper, sweet sorrow, pleasantly ugly face, horribly beautiful, a deafening silence.
In an epithet, if the adjective's original meaning weakens, the stylistic effect is lost. However, in an oxymoron, the logical meaning is preserved, as it is not a real combination but rather a juxtaposition of opposites.
Example:
"It has the poorest millionaires, the littlest great men, the haughtiest beggars, the plainest beauties, the lowest skyscrapers of any town I ever saw." (O. Henry)
When overused, oxymorons may lose their stylistic force and become mere intensifiers. Typical patterns include adjective + noun and adverb + adjective (terribly pleased).
Oxymoron often reflects stylistic trends or literary movements that seek new semantic shades through paradoxical combinations. Expressions such as peopled desert, proud humility, alone together, terribly pleased, loose tights, clearly misunderstood exemplify oxymoronic usage.

3. Metaphor

The term metaphor denotes the transference of qualities from one object to another. It becomes a stylistic device when two different phenomena are perceived simultaneously, and a feature of one object is attributed to another that naturally lacks it. This transference is based on perceived similarity.
Example:
"Dear Nature is the kindest mother still." (Byron)
Here, the characteristics of a "kind mother" are ascribed to "Nature," forming a metaphor through identification rather than comparison.
Metaphor not only intensifies description but also expresses the poetic function of language. From a cognitive perspective, metaphors structure human thought and are integral to everyday communication.

Common examples include:
"Her home was a prison," "George is a sheep," "Words are the weapons with which we wound," "Don't trouble your little peanut head over the problem."
Types of metaphors:
1. Genuine metaphors – creative and unpredictable.
2. Dead metaphors – conventional, fixed in dictionaries (a ray of hope, floods of tears).

3. Adapted metaphors – adjusted to specific contexts (A good beginning is half the battle).
4. Clichés – overused metaphors (a bad conscience, leave to the mercy).
5. Creative (poetic) metaphors – original authorial inventions.
6. Visual metaphors – image-based (common in art and advertising).
7. Root metaphors – reflect worldview and personal values (Weak women are time-sucks).
8. Absolute metaphors – hard to interpret (Love is death by pampering).
9. Conceptual metaphors – encode abstract ideas (Elisa lost four weeks of her life on him).
10. Evaluative-aesthetic metaphors – express emotional and moral evaluation.
11. Figurative metaphors – enhance imagery and expressiveness (art star, sports star).

Metaphors can also reflect human characteristics through zoosemy: a cowardly person – rabbit, a cunning person – fox, a bookworm, a nightingale in love, etc.

4. Metonymy

Metonymy is based not on similarity but on contiguity — a real, logical, or associative connection between different objects or phenomena.
Examples:
“The kettle has boiled.”
“I haven’t read Dickens.”
“Will you have another cup?”

Here, kettle stands for “water,” Dickens for “works by Dickens,” cup for “drink.”

Metonymy enriches speech with symbolic depth and often overlaps with synecdoche. In journalism and political discourse, it is a frequent device:
“Moscow and Washington will hold talks” — where city names stand for government authorities.

Types of metonymy:

1. Fixed (dictionary) metonymy.
2. Contextual (figurative) metonymy.

Metonymy, like metaphor, reflects cognitive mechanisms of thought and contributes to linguistic economy and expressiveness.

5. Simile

A simile is an explicit comparison of two unlike objects, usually introduced by like, as, as if, seem, or such as.
Examples:
“To eat like a bird,” “swim like a fish,” “A room without books is like a body without a soul.” (Cicero)

Similes enhance vividness and emotional impact. They are common in poetic language, folklore, and educational texts, often appearing alongside metaphors.

6. Hyperbole

Hyperbole is a deliberate exaggeration used to emphasize a point or express emotion.
Examples:
“I’ve told you a million times,” “She cried rivers of tears.”
It often creates humor or emphasis, both in everyday speech and literature:
“He was so tall that I was not sure he had a face.” (O. Henry)

Hyperbole differs from mere overstatement because it is consciously recognized as exaggeration. Examples include scared to death, immensely obliged, a thousand pardons.

When used excessively, hyperboles may lose their stylistic value and become fixed idioms. Conversely, understatement or diminution (She was a sparrow of a woman) represents hyperbole in reverse.

7. Irony

Derived from the Greek eirōneía, irony expresses meaning through contradiction — saying one thing but implying another.
Example: "It must be delightful to find oneself in a foreign country without a penny in one's pocket."

According to I. R. Galperin, irony is based on the simultaneous realization of two opposite meanings — literal and contextual. Intonation plays a key role in expressing irony.

Irony must not be confused with satire (critical) or humor (amusing). For example, in "How clever of you!" the word clever conveys annoyance rather than admiration.

Types of irony:

1. Verbal irony – contradiction between literal and intended meaning (Brutus is an honorable man – Shakespeare).
2. Dramatic irony – when the audience knows something the character does not (Othello calling Iago "honest").
3. Situational irony – a reversal of expected outcomes (Maupassant's "The Necklace").

Irony, by combining opposing meanings, creates contrast and depth. It usually carries a negative or critical tone but may express subtle emotional nuances such as regret or disappointment.

Conclusion

Lexical-stylistic devices in English constitute fundamental artistic means that express the descriptive, emotional, and aesthetic functions of language. Devices such as epithet, metaphor, metonymy, simile, and hyperbole are not merely linguistic ornaments but also convey cultural and semantic values. Their functional and contextual use forms the stylistic richness of speech.

Modern stylistic approaches enable deeper analysis of how these devices operate within texts and affect readers. Lexical stylistics, therefore, explores not only linguistic structures but also their social and cultural dimensions. The study and application of stylistic devices in modern linguistics, translation, communication, and education enhance both theoretical and practical understanding of the multilayered nature of language.

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GRAMMATICAL FEATURES OF EXCLAMATIONS IN TURKISH LANGUAGES

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Keywords: turkic languages, exclamations, auxiliary parts of speech.

As in all Turkic languages, in modern Turkic languages, exclamations express desire, desire, feeling, excitement, regret, etc. emotional shades. Exclamations differ from both auxiliary and main parts of speech, in other words, they do not indicate either state, quality, quantity, or name. They are not part of a sentence, do not enter into syntactic relations with any word. Therefore, exclamations are a special part of speech.

In Turkology, G.V. Arkhangelsky, A.N. Kononov, C. N. Kharitovov, N. A. Baskakov, S. Saribayev, S. Usmanov, S. Imanaliyev, R. Kungurov, F. Makarov, L. Budagov, M. Kazimbay, N. Narimanov and others have expressed one or another opinion about the grammatical features of exclamations, and most of them are simple. Since the 60s of the last century, certain research works have been devoted to the grammatical features of exclamations, which are very necessary.

In modern linguistics, the interjections were the subject of conflicting opinions of Turkologists and Russian-speaking Turkologists-linguists.

Until the second quarter of the 20th century, some Turkologists did not specifically distinguish between interjections. A number of linguists only gave a list of the interjections they remembered in a few lines.

N.I.Ilminsky in his work “Materials for the Study of the Kyrgyz Language” mentioned the following types of interjections: a, ay, pay-pay, tu.

Sh.Sarybayev writes that N.I.Ilminsky confuses interjections with particles, considering the word “tu” as an interjection, while including the word “pay-pay” in particles. At the same time, vocative words are mentioned for the first time, they are explained as a type of interjections.

In A. Troyansky's grammar, parts of speech are divided into eight parts by “word nouns”: Thus, in this division based on the semantic principle, exclamations are given under the heading “literal exclamations”. The author gives a list of exclamations expressing feelings and excitement, and includes the following exclamations: o!, ax! (surprise), ex!, ax! (regret), ay-ay! (fear), ay-hay! (anxiety), ay-yay! (doubt), tss! (prohibition), aferin! (applause), tfu! (disgust)

P.M. Melioransky gave exclamations under the name “particles”. Melioransky gave more preference to the syntactic principle and therefore included some morphological categories, including particles, in the syntax.

G.V. Arkhengelsky discusses exclamations in syntax. He divides exclamations into four groups: In three of these divisions, he includes sound-imitating words (jalt-jult, dünk-dünk) and vocative words under the name “şakiru odağayı” (calling exclamations) and gives the following lines: mıs-mıs// kis-kis (addressing a cat), kurray-kurray (addressing sheep), etc. He includes real exclamations related to a person’s state and condition (ay, oy, etc.) in the fourth group.

Although in this division G.V. Arkhangelsky included imitative and vocative words in exclamations, this classification prepared the scientific basis for the correct and correct classification and study of exclamations in later grammars and textbooks.

In V.A. Gordlevsky's work “Grammar of the Turkish Language”, published in 1928, exclamations are studied in syntax. Although exclamations are given under a separate heading, they are not explained in detail. Under the name of the original and derivative, exclamations are

divided into two parts, and then a list of the most commonly used exclamations is given: vah, vay, ey vah, hay, hay-hay, tu, off, heyhat, etc.

N.A. Baskakov classified interjections on the same basis, dividing them into two groups in the Karakalpak language: original interjections - “emotional interjections” and “sound imitation interjections”. Thus, derivative interjections include those formed from noun and verb roots, and verbs formed from auxiliary verbs and interjections, prepositions. N.A. Baskakov later divided the vocabulary of the Karakalpak language into three groups in the improved edition of the work under the headings “Auxiliary words”, “Verbs”, “Nouns”. Nouns are also divided into nouns, adjectives, numerals, pronouns, adverbs and interjections. N.A. Baskakov considers interjections, along with pronouns and numerals, to be a syntactic group of nouns that is separated purely semantically.

Although he sometimes confuses vocatives with exclamations, nevertheless, unlike other Turkologists, N.A. Baskakov distinguishes mime and exclamations in the Karakalpak language as separate independent parts of speech and shows some of their special features. According to the author, the main special feature of exclamations is that the exclamation does not name feelings and emotions, but directly reflects them.

In his work “Exclamations in the Kyrgyz Language”, A.I. Batmanov expresses controversial ideas when talking about parts of speech. Thus, the author accepts 3 principles in the classification of parts of speech, but gives the main priority to the syntactic and semantic principles. Despite this, he does not accept the exclamation as a separate part of speech. The author notes that, due to its formation and formation, the exclamation was formed and stabilized as a result of the differentiation of nouns, adverbs and adjectives, and names in general. In addition, exclamations preserve and retain the signs of names. They even accept the property of a noun, become nouns, change, and are classified. For example, I heard your breath (I heard your breath), this is my breath (this is your breath). And in the end, the author comes to the conclusion that there is no need to consider exclamations as an independent part of speech. According to their formal features, they (exclamations) should be attributed to names.

The solution to the problem in this form is one-sided. Thus, language could have arisen in a sensory form that did not yet exist in a mental-intellectual way. If we agree with this idea, we would think that words with independent meanings in our language such as ufum-ufum, ufuldamaq, khukhu, ufu, ufhauf, ufultu, etc. were formed from exclamations or that exclamations were at the root of those words. However, this cannot be said about words such as vaysınmak, aytmaq, hayqırmaq, etc. Therefore, it is possible to say that exclamations are at the root of words with independent meanings, as well as very few free-meaning words. Our conclusion is that only substantivized exclamations can participate in word formation. All of the linguistic facts that I.A. Batmanov also brought are substantivized exclamations. It is natural that all parts of speech become substantivized and carry most of the features of nouns. This accepted norm also applies to exclamations.

Despite the unclear ideas about the origin of exclamations, I.A. Batmanov considers it correct and expedient to consider exclamations and imitative words as independent parts of speech, separately.

N.K. Dmirtiyev, who explains parts of speech in detail in his works and at the same time accepts three well-known principles in the classification of parts of speech, divides the words in the dictionary into two groups under the names “independent or separate words” and “auxiliary words”. Nouns and verbs are divided into two groups as independent words. Nouns, adjectives, numerals, pronouns and adverbs are given under the heading of nouns. The author considers exclamations as separate parts of speech.

In his work “Grammar of the Bashkir Language”, N.K. Dmitriev emphasizes the interjection as a separate part of speech, but does not devote a special section or discussion to it. Under the title “Independent or separate categories of words”, the author shows the parts of speech in this

way: noun, adjective, numeral, pronoun, verb, adverb, interjection. N.K. Dmitriev does not consider it correct to evaluate them historically in the same way. He considers it correct to combine them into two large groups.

We consider N.K. Dmitriev's thesis that exclamations are an ancient word group distinct from nouns and verbs to be correct, and we completely agree with this opinion.

In his work “Grammar of the Turkish Language”, A.N. Kononov also mentions interjections in the series of auxiliary parts of speech. Later it becomes clear that since they cannot create any connection between words and cannot be members of a sentence, the author does not include interjections in the parts of speech. In a later improved edition of the work, interjections are distinguished from both auxiliary and independent meaningful words and are interpreted as a separate part of speech. The author, who provides general information about interjections, divides them into original and derivative interjections according to their origin, explains both types of interjections separately. A.N. Kononov notes that interjections act as separate words, syntactically do not enter into contact with other words in a sentence, and can be used as an independent sentence. In addition, imitative words are not included in interjections, but are given as separate parts of speech. However, in a separate section devoted to interjections, he admits that interjections are not auxiliary words. However, in the author's previously published work "Grammar of the Uzbek Language", vocative and imitative words were included in exclamations. In this work, while classifying parts of speech, he included exclamations in the auxiliary words, but nevertheless, in a separate section devoted to exclamations, he admits that exclamations are not auxiliary words.

Mirza Kazimbey, who played a special role in the development of our linguistics, first published his work “Grammar of the Turkish Tatar Language” in 1839, and provided detailed scientific information about exclamations, along with many issues of the Azerbaijani language.
In works written by L.Budagov, M.A.Vazirov, N.Narimanov, S.M.Ganizadeh, M.D.Mammadov and others, which were mainly of a practical nature, exclamations were attributed to auxiliary parts of speech.

Thus, certain ideas and considerations have been expressed in Azerbaijani linguistics about both the main and auxiliary parts of speech. However, despite all this, the problem of parts of speech has not been definitively resolved to this day.

Political Studies

THE SHANGHAI COOPERATION ORGANIZATION AS A TOOL FOR DEVELOPING SUSTAINABLE TRADE CORRIDORS IN THE SYSTEM OF INTERNATIONAL RELATIONS

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Abstract

This study examines the role of the SCO as a regional mechanism for developing sustainable trade corridors within the contemporary system of international relations. Employing a comparative and institutional approach, the research focuses on the Central Asian member states Kazakhstan, Uzbekistan, Kyrgyzstan, and Tajikistan as key participants in the SCO's connectivity and sustainability agenda. The study integrates qualitative analysis of official documents, policy frameworks, and multilateral initiatives with empirical data on trade, infrastructure, and environmental performance. The findings demonstrate that the SCO has transformed from a security-oriented coalition into a multidimensional platform promoting economic integration, ecological modernization, and green logistics across Eurasia. The comparative analysis reveals asymmetries among member states but also a complementary regional pattern, wherein Kazakhstan and Uzbekistan act as infrastructural and policy leaders, while Kyrgyzstan and Tajikistan contribute through transit and energy cooperation. A SWOT assessment highlights the SCO's strengths in strategic geography, institutional inclusivity, and its expanding sustainability agenda, while also identifying weaknesses such as limited institutionalization and uneven environmental standards. The research concludes that the SCO serves as an emerging model of sustainable regionalism, capable of balancing economic growth, environmental protection, and geopolitical stability. It contributes to both theoretical and practical understanding of how regional organizations can advance sustainable globalization in a multipolar world.

Keywords: Shanghai Cooperation Organization; sustainable development; sustainable trade corridors; international relations; Eurasian integration; environmental security; multilateral engagement; Central Asia.

Introduction

Research Relevance. In the context of increasing global economic interdependence and the reconfiguration of international trade routes, the Shanghai Cooperation Organization (SCO) has emerged as a significant platform for fostering sustainable trade and connectivity among Eurasian states. The relevance of studying the SCO as an instrument for shaping sustainable trade corridors lies in its growing role in integrating the economies of member countries and enhancing regional stability through economic cooperation (Karami, 2023). The modern world economy faces challenges such as geopolitical tensions, sanctions regimes, and disruptions of global supply chains, which make the diversification of trade routes and the establishment of secure, environmentally sustainable logistics corridors increasingly important (Lukin, 2021; Akmadi, 2021). Furthermore, the SCO's expanding agenda, which includes sustainable development goals, energy cooperation, and green logistics initiatives, reflects a transition from a primarily security-oriented organization to one that supports long-term economic sustainability (Aris, 2016). This transformation aligns with broader international trends toward regional economic integration and sustainable globalization. As such, analyzing the SCO's potential in shaping resilient trade corridors contributes not only to understanding regional cooperation in Eurasia but also to the global discourse on sustainable economic governance in a multipolar world (Alimov, 2018).

Research aim. The primary aim of this study is to analyze the role of the SCO in developing sustainable trade corridors within the contemporary system of international relations. The research seeks to evaluate how the SCO's institutional mechanisms, strategic initiatives, and multilateral projects contribute to enhancing connectivity, economic resilience, and environmental sustainability across the Eurasian region. This investigation also aims to determine the extent to which the SCO can serve as a model for regional economic cooperation that aligns with global sustainable development goals.

Research question. To achieve this aim, the study addresses the following central research question: How does the Shanghai Cooperation Organization contribute to the development of sustainable trade corridors in the Eurasian region, and what are the implications of this process for the transformation of the global system of international relations?

Supporting sub-questions include:

What institutional and policy instruments does the SCO employ to promote sustainable trade and logistics?

How do SCO initiatives align with global efforts such as the UN SDGs and the Belt and Road Initiative?

What challenges and opportunities exist for the SCO in fostering resilient and environmentally responsible trade connectivity among member states?

Research significance. The significance of this research lies in its contribution to understanding the evolving nature of regionalism and sustainable economic integration in Eurasia. As the SCO expands its economic and environmental agenda, examining its potential to shape sustainable trade corridors provides valuable insights into new models of cooperative governance beyond Western-centric frameworks. The findings are expected to deepen scholarly comprehension of how regional organizations can facilitate sustainable globalization through institutional innovation, policy harmonization, and ecological accountability. Moreover, this study addresses a research gap by integrating the analysis of trade connectivity with sustainability considerations a perspective that has received limited attention in existing SCO scholarship. Thus, it contributes to both theoretical debates in international relations and practical policymaking aimed at achieving a balanced, environmentally conscious model of regional economic growth.

Literature Review

In the context of growing global economic interdependence and ongoing disruptions in international supply chains, the SCO has emerged as a crucial actor in shaping sustainable trade corridors across Eurasia. The literature demonstrates that the SCO has evolved beyond its initial security-centric orientation and is now functioning as a platform for economic cooperation, infrastructure development, environmental sustainability, and regional integration (Alimov, 2018; Kembayev, 2018). Alimov (2018) argues that the SCO is playing an increasingly vital role in promoting a unified Eurasian economic space through trade facilitation and transport connectivity. The organization has expanded its agenda to include economic modernization, sustainable infrastructure, and multilateral trade alignment, all of which are fundamental to the creation of resilient and environmentally friendly transport corridors. Kurylev (2021) emphasizes the growing synergy between the SCO and China's Belt and Road Initiative (BRI), especially in infrastructure investment and institutional cooperation. He notes that joint Russian-Chinese efforts, within the framework of SCO mechanisms, have enabled the planning and implementation of multimodal trade routes that traverse Central Asia, linking East and West through secure and sustainable channels. From a geopolitical-institutional perspective, Korobochkina (2025) identifies internal contradictions within the SCO, particularly regarding the uneven capacities of member states to implement sustainable initiatives. However, she highlights the organization's efforts to incorporate environmental governance, green logistics, and energy transition into its operational strategies. These developments represent a shift toward environmental consciousness in regional cooperation.

Kembayev (2018) delves into the legal and institutional underpinnings of SCO's role in supporting the Silk Road Economic Belt, asserting that the SCO provides a platform for harmonizing national policies and fostering intergovernmental dialogue on transport and energy infrastructure. He underscores that this integration is necessary to counterbalance external geopolitical pressures and ensure the sovereignty of member states in trade decision-making. Gatev and Diesen (2018) present a comparative analysis of the EAEU and the SCO, noting that both entities contribute to regional integration but through different institutional logics. They argue that the SCO's flexible, consensus-based model allows it to coordinate diverse initiatives, including the development of "green" transport corridors, albeit at a slower and less formalized pace than the EAEU. Kulintsev (2020) introduces the concept of the "Greater Eurasian Partnership," positioning the SCO as a key vehicle for implementing this vision through infrastructure interoperability, digital connectivity, and policy synchronization. He stresses the importance of sustainable development discourse in the SCO's declarations and its alignment with global frameworks such as the UN Sustainable Development Goals. Xin and Xin (2021) provide a retrospective analysis of 20 years of SCO economic cooperation. They highlight increased intra-regional trade, the implementation of strategic infrastructure projects (such as the China–Kyrgyzstan–Uzbekistan railway), and growing collaboration on ecological initiatives. The authors consider the SCO an incubator for resilient regional partnerships. Dexue (2021) focuses on the institutional achievements and prospects of the SCO in the domain of sustainable trade. He critiques the lack of standardized environmental practices among member states but acknowledges the organization's growing commitment to low-carbon logistics, cross-border energy cooperation, and sustainable finance.

Concrete empirical evidence is provided by Bolgova, Bolgov, and Kurnikova (2024), who evaluate the contribution of SCO-aligned transport corridors under the EAEU framework to sustainable regional development. They stress the strategic importance of Central Asia as a logistics hub and the role of SCO partnerships in boosting energy-efficient transportation. Finally, Azizi (2024) investigates the SCO as a geopolitical and economic actor under China's BRI strategy. He views the SCO as a complementary institution that supports not only security collaboration but

also energy cooperation, infrastructure finance, and sustainable development integration across Eurasia. In summary, the literature reveals a growing body of scholarship affirming the SCO's significance in constructing sustainable trade corridors across Eurasia. The organization contributes through institutional coordination, strategic infrastructure development, environmental policy alignment, and regional integration. While several challenges remain particularly concerning environmental governance and policy harmonization the SCO's evolution offers an alternative model of cooperative globalization that emphasizes sustainability, inclusivity, and resilience.

Research Methodology

This study adopts a comparative qualitative research design aimed at examining the Shanghai Cooperation Organization's role in developing sustainable trade corridors across Eurasia, with a particular emphasis on the Central Asian countries Kazakhstan, Uzbekistan, Kyrgyzstan, and Tajikistan. The methodology integrates theoretical, institutional, comparative, and empirical approaches to provide a comprehensive understanding of how the SCO fosters sustainable connectivity, economic integration, and ecological cooperation within its member states. The theoretical and institutional component of the methodology focuses on analyzing the evolution of the SCO's governance model, tracing its transformation from a security-centered alliance to a multifaceted organization addressing sustainable development goals, trade, and green logistics. This involves the examination of key documents such as SCO charters, strategic programs, summit declarations, and economic cooperation frameworks. The analysis also considers the interaction between the SCO and other international and regional institutions particularly the Belt and Road Initiative, the Eurasian Economic Union and the United Nations Sustainable Development Goals in order to situate the SCO within the broader architecture of global and regional economic governance. A comparative cross-country analysis serves as the central methodological pillar of this research. This approach enables the identification of both similarities and divergences in how Central Asian member states participate in SCO-led projects, implement sustainable trade policies, and align their national development strategies with regional objectives. The selection of Central Asian countries is justified by their geopolitical centrality, shared post-Soviet institutional heritage, and growing importance as a connective hub linking China, Russia, South Asia, and Europe.

To structure the comparative analysis, the study employs a comparative framework that outlines four analytical dimensions:

- economic integration;
- infrastructure connectivity;
- environmental sustainability policies;
- participation in SCO multilateral projects.

This framework operationalizes the main research variables and provides transparency and replicability for subsequent analysis. The framework is summarized in Table 1.

Table 1. - Comparative framework for the analysis of Central Asian SCO member states

Country	Economic Integration Indicators	Infrastructure Connectivity	Environmental Sustainability Policies	Participation in SCO Projects
Kazakhstan	High trade volume with China and Russia; member of EAEU	Key hub for Belt and Road corridors (Western Europe–Western China route)	"Green Economy Concept 2050"; strong focus on energy transition	Active in SCO transport and logistics working groups
Uzbekistan	Increasing openness post-2016 reforms	Development of China–Kyrgyzstan–Uzbekistan railway	Focus on green industry and efficient transit	Expanding role after rejoining SCO economic initiatives
Kyrgyzstan	Transit economy; dependent on cross-border trade	Central route for China–Kyrgyzstan–Uzbekistan corridor	Limited environmental funding; gradual policy alignment	Key participant in infrastructure cooperation projects
Tajikistan	Small, mountainous economy; reliant on remittances	Developing road corridors via SCO support	Focus on hydropower and sustainable resource use	Involved in SCO energy and ecological cooperation
Source: Compiled by the author based on SCO official documents, World Bank, and national policy reports				

The inclusion of this table serves an analytical purpose: it operationalizes the criteria for comparison, clarifies the variables under study, and ensures methodological transparency. It also visually demonstrates the multidimensional nature of sustainable corridor development, integrating economic, infrastructural, environmental, and institutional aspects across Central Asia. Complementing the comparative framework, the research applies case study analysis to specific SCO-related projects that illustrate regional connectivity in practice. These include the China–Kyrgyzstan–Uzbekistan Railway Project, Kazakhstan's Nurly Zhol Infrastructure Initiative, and the China–Pakistan Economic Corridor. Each case is examined in terms of policy coordination, financing models, and environmental governance, providing concrete empirical insights into how SCO mechanisms are implemented. A content and policy analysis of SCO communiqués, summit declarations, and member-state policy papers is conducted to identify how the concepts of "sustainability," "resilience," and "green connectivity" are embedded in the organization's discourse and translated into action. Reports from the UNESCAP, Asian Development Bank and World Bank are also reviewed to provide additional data on trade flows, infrastructure development, and sustainability metrics.

The empirical component of the study integrates economic and statistical data for the period 2010–2024. Key indicators include trade turnover among SCO members, infrastructure investment levels, logistics efficiency, and environmental performance indexes. Data sources include UN Comtrade, the World Bank, and national statistical agencies. This quantitative evidence complements the qualitative findings and strengthens the validity of the conclusions. Analytical tools such as SWOT and PESTEL frameworks are employed to assess internal and external factors influencing the SCO's ability to advance sustainable trade corridors. Additionally, GIS mapping is used to visualize the geographical distribution of major transport routes and regional hubs, highlighting Central Asia's pivotal role in the Eurasian transport network. In summary, this mixed-

method comparative methodology provides a comprehensive, transparent, and empirically grounded framework for analyzing the SCO's contribution to sustainable trade corridors. By combining institutional, comparative, and empirical approaches and by emphasizing the Central Asian context the research not only deepens the understanding of regional cooperation in Eurasia but also contributes to broader debates on sustainable globalization and the transformation of international economic relations.

Results and Discussion

The comparative analysis examines the Central Asian member states of the SCO and Kazakhstan, Uzbekistan, Kyrgyzstan, and Tajikistan across four main dimensions: economic integration, infrastructure connectivity, environmental sustainability, and participation in SCO mechanisms. The purpose of this comparison is to identify asymmetries, complementarities, and shared challenges in developing sustainable trade corridors across the Eurasian space. To provide a clear comparison of the structural characteristics of each state within the SCO framework, Table 2 presents a synthesized overview of the main indicators related to economic integration, infrastructure, environmental policy, and institutional engagement.

Table 2. - Comparative analysis of Central Asian countries within the SCO

Indicator	Kazakhstan	Uzbekistan	Kyrgyzstan	Tajikistan
Economic Integration	High integration; key member of EAEU and BRI; strong trade with China and Russia	Moderate-to-high; rapid liberalization post-2016; diversification of partners	Moderate; dependent on transit trade; member of EAEU	Low; small economy reliant on remittances and limited export base
Infrastructure Connectivity	Advanced; developed transport and logistics network (Western Europe–Western China route)	Developing; major projects like China–Kyrgyzstan–Uzbekistan railway	Limited but strategic; key transit corridor for SCO trade	Weak; mountainous terrain limits connectivity; gradual road modernization
Environmental Sustainability	"Green Economy Concept 2050"; strong renewable energy policy	Green industrialization strategy; cooperation with UNDP, ADB	Emerging frameworks; limited institutional capacity	Focus on hydropower; constrained by financial resources
Participation in SCO Mechanisms	Active leader; hosts key SCO summits; initiates integration programs	Increasing participation post-2017; dynamic diplomacy	Stable participation; focuses on customs, logistics, SMEs	Selective involvement; emphasizes energy and environmental cooperation

As shown in Table 1, the Central Asian region demonstrates differentiated levels of integration and capacity. Kazakhstan and Uzbekistan occupy leadership positions due to their economic strength, institutional engagement, and alignment with the SCO's development agenda. Kyrgyzstan and Tajikistan, while less developed, play critical supporting roles as transit and energy partners. This variation suggests a complementary regional pattern: larger economies drive the policy and infrastructural framework, while smaller states benefit through connectivity and capacity-building mechanisms. The heterogeneity of these roles enhances the SCO's flexibility but also underscores the need for policy harmonization and shared sustainability standards.

Country-specific SWOT assessment. To deepen the comparison, figure 1 presents a SWOT analysis of each Central Asian country within the SCO framework. This table identifies key internal and external factors that influence each state's ability to contribute to sustainable trade corridor

development.

Figure 1. - SWOT Analysis of Central Asian participation in SCO sustainable trade corridors

As indicated in Figure 1 each country possesses distinctive structural advantages and vulnerabilities. Kazakhstan's strengths lie in its strategic location and developed infrastructure, making it the primary logistics hub of the region. Uzbekistan's rapid economic liberalization and diplomatic activism create new opportunities for corridor diversification and green industrialization. Kyrgyzstan benefits from its transit position but remains constrained by fiscal fragility, while Tajikistan's hydropower capacity offers niche potential for sustainable energy trade despite geographical limitations. Collectively, these factors reveal a complementary balance between leadership (Kazakhstan, Uzbekistan) and dependency (Kyrgyzstan, Tajikistan) within the SCO's sustainable connectivity model.

To contextualize the national dynamics of Central Asian participation, figure 2 provides a broader SWOT analysis of the SCO as an institutional platform for the development of sustainable trade corridors across Eurasia. This assessment highlights the organization's structural advantages, internal challenges, strategic prospects, and external risks that collectively shape its potential to act as a driver of sustainable connectivity in the multipolar global order.

As shown in Figure 2, the strengths of the SCO derive primarily from its strategic geography and inclusive institutional architecture. The organization connects some of the world's largest and fastest-growing economies China, India, and Russia with emerging markets in Central and South Asia. This geographical reach allows the SCO to serve as a transcontinental bridge for trade, energy, and digital infrastructure. Furthermore, its multilateral dialogue mechanisms such as the Council of Heads of State, Interbank Consortium, and Business Council create a stable environment for economic coordination, trust-building, and cross-sectoral cooperation. Over the

past decade, the SCO has broadened its focus beyond security, introducing policies on green logistics, environmental management, and sustainable development, reflecting a gradual institutional evolution toward an economic and ecological governance body. However, several weaknesses constrain the organization's capacity to fully operationalize its goals. Unlike entities such as the European Union or ASEAN, the SCO lacks binding economic instruments and a supranational regulatory authority. Decision-making remains consensus-based, which, while preserving political balance, often slows implementation. Moreover, the heterogeneity of member economies ranging from highly industrialized states like China to developing economies like Kyrgyzstan and Tajikistan creates asymmetries in interests and capacities. Environmental accountability mechanisms remain underdeveloped, and sustainability standards are often declarative rather than enforceable.

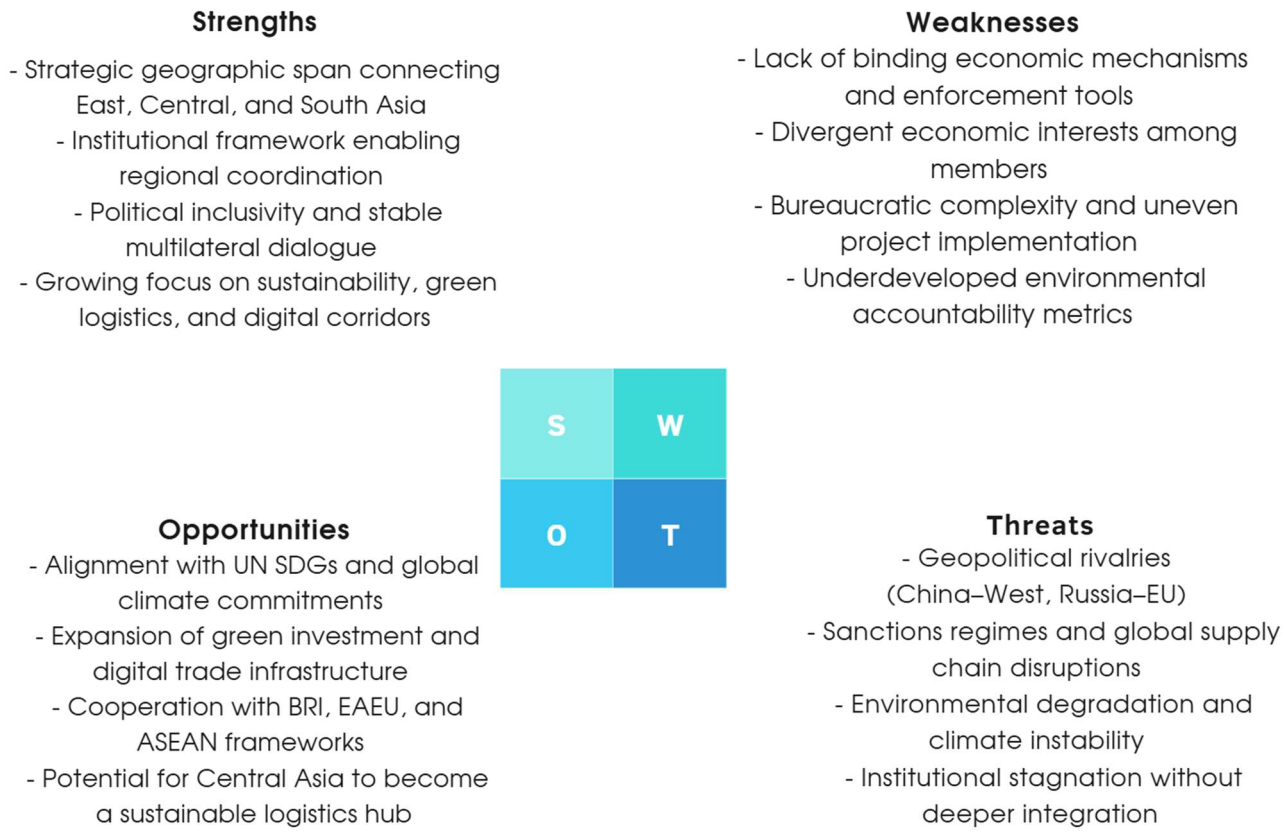

Figure 2. - SWOT Analysis of the SCO as a Platform for Sustainable Trade Corridors

In terms of opportunities, the SCO is well-positioned to align with global sustainability agendas, including the UN Sustainable Development Goals and the Paris Climate Agreement. Its cooperation with complementary initiatives such as the Belt and Road Initiative and the Eurasian Economic Union offers significant potential for policy convergence and project synergy. The growing emphasis on digital trade, green finance, and renewable energy corridors opens pathways for the SCO to redefine its role as a platform for "sustainable connectivity." Furthermore, the strategic location of Central Asia within the SCO creates the possibility of transforming the region into a sustainable logistics and energy hub, balancing East–West and North–South trade flows. Yet, the SCO also faces several threats that may impede its progress. The most prominent are geopolitical rivalries notably tensions between China and Western powers, and between Russia and the European Union which may fragment cooperation and discourage investment. Additionally, sanctions regimes affecting key member states complicate multilateral trade and banking operations. Environmental risks, including climate change and resource scarcity, also pose long-term challenges to sustainable corridor development. Finally, the risk of institutional

stagnation persists if the SCO fails to transition from declarative coordination to practical economic integration and measurable sustainability outcomes. Overall, the SWOT assessment demonstrates that the SCO stands at a strategic crossroads. Its wide geographic scope, inclusive governance, and emerging sustainability agenda constitute significant advantages. However, to consolidate its role as a genuine driver of sustainable trade corridors, the organization must enhance institutional efficiency, develop stronger implementation mechanisms, and establish unified environmental standards. The SCO's ability to balance geopolitical realities with the imperatives of green growth and regional stability will ultimately determine its success in shaping a resilient and sustainable Eurasian connectivity system.

The findings of this study confirm and extend the growing body of scholarship on the evolving role of the Shanghai Cooperation Organization in shaping sustainable trade and connectivity across Eurasia. As demonstrated through the comparative analysis and SWOT assessment, the SCO has gradually transformed from a security-oriented coalition into a complex institutional mechanism promoting economic integration, green logistics, and multilateral policy coordination. This transformation reflects broader patterns of regionalism identified in the literature, particularly those described by Aris (2016) and Alimov (2018), who argue that the SCO embodies a distinct "Eurasian model" of cooperation emphasizing inclusivity, non-alignment, and developmental pragmatism rather than rigid institutionalization.

Empirical evidence from the comparative analysis (see Table 2) reveals significant asymmetry among Central Asian member states but also a complementary division of functions. Kazakhstan and Uzbekistan serve as the principal engines of economic modernization and infrastructural leadership, while Kyrgyzstan and Tajikistan contribute primarily through their strategic geographic positions as transit and energy partners. This pattern of differentiated integration echoes the argument of Gatev and Diesen (2018), who describe the SCO's governance model as flexible and consensus-based, allowing member states with varying capacities to engage at different levels of intensity. In this respect, the SCO differs from more hierarchical regional organizations such as the European Union, yet maintains coherence through its emphasis on mutual benefit and non-interference a dynamic also noted by Kembayev (2018) in his analysis of the organization's legal foundations.

The comparative framework demonstrates that Kazakhstan's infrastructural connectivity and environmental strategy ("Green Economy Concept 2050") position it as a regional leader in implementing sustainable trade policies. This supports Alimov's (2018) view that Kazakhstan plays a central role in bridging the SCO's economic and environmental agendas. Similarly, Uzbekistan's post-2016 reforms have increased its openness and allowed it to pursue large-scale infrastructure projects such as the China–Kyrgyzstan–Uzbekistan Railway, aligning with Kurylev's (2021) argument about the synergy between the SCO and the Belt and Road Initiative. Kyrgyzstan and Tajikistan, while facing institutional and financial constraints, nevertheless illustrate the SCO's integrative potential: both countries participate in SCO-supported transport and energy cooperation programs, benefitting from policy harmonization and capacity-building efforts. These findings validate Bolgova, Bolgov, and Kurnikova's (2024) claim that Central Asia's growing logistical importance is driven by SCO and EAEU coordination, which together underpin sustainable regional transport systems.

The cross-country comparison also reveals a gradual diffusion of sustainability norms within the SCO framework. Uzbekistan's "green industrialization" and Tajikistan's focus on hydropower development demonstrate the incorporation of environmental considerations into economic planning a trend that corresponds to the "green turn" in regional cooperation identified by Korobochkina (2025). While environmental governance remains uneven, the data suggest increasing alignment with global sustainability frameworks such as the UN Sustainable Development Goals, as highlighted by Kulintsev (2020). The SCO's discourse on "green

connectivity," evident in official summit declarations and strategic documents, indicates a growing institutional commitment to ecological modernization and low-carbon development a direction also noted by Dexue (2021) and Azizi (2024) in their analyses of the SCO's evolving agenda.

The SWOT analysis (Figure 2) provides a broader institutional perspective, revealing that the SCO's key strengths lie in its vast geographic span and inclusive political structure, which enable multilateral coordination across diverse economies. Its institutional architecture encompassing bodies such as the Interbank Consortium and the Business Council facilitates pragmatic cooperation without imposing supranational control. However, the weaknesses identified in the analysis, including the lack of binding mechanisms and divergent national interests, echo the institutional limitations discussed by Kembayev (2018) and Gatev and Diesen (2018). These structural constraints often slow implementation and hinder policy standardization, particularly in the domain of environmental regulation.

At the same time, the SWOT framework highlights significant opportunities for the SCO to consolidate its leadership in sustainable Eurasian development. The organization's growing cooperation with the BRI and EAEU, along with potential partnerships with ASEAN, offers multiple channels for promoting green investment, digital trade, and resilient infrastructure. This aligns with the "Greater Eurasian Partnership" concept advanced by Kulintsev (2020), which envisions institutional interoperability and shared sustainability standards as the foundation of a new regional order. Furthermore, the SCO's potential to transform Central Asia into a sustainable logistics hub underscores the argument made by Alimov (2018) that the organization's integrative power rests in its ability to translate geography into economic and ecological interdependence.

Nevertheless, the study also corroborates the threats identified by Lukin (2021) and Akmadi (2021), particularly the destabilizing impact of geopolitical rivalries, sanctions regimes, and environmental degradation. These factors limit the SCO's capacity to function as an independent driver of global sustainable trade governance. The persistence of global polarization for instance, between China and Western states or between Russia and the EU constrains the organization's strategic autonomy and may inhibit its ability to implement multilateral sustainability initiatives effectively. Moreover, environmental risks, such as climate change and resource depletion, challenge the SCO's goal of establishing stable, low-carbon corridors across ecologically fragile regions.

The discussion thus suggests that the SCO operates as a hybrid model of regionalism, combining pragmatic economic cooperation with an emerging sustainability agenda. The results of this research affirm that the SCO's institutional flexibility often criticized for its informality is also its greatest asset, enabling adaptive responses to complex geopolitical and environmental conditions. In this sense, the organization functions not as a rigid integration bloc but as a platform for sustainable governance, capable of balancing national sovereignty with collective regional interests. This conclusion reinforces the perspectives of Alimov (2018) and Korobochkina (2025), who view the SCO as an evolving mechanism of cooperative globalization, distinct from Western-centric paradigms of regional integration.

Ultimately, the integration of the SCO's policy initiatives with global sustainability frameworks positions the organization as a crucial actor in the transition toward a greener and more resilient Eurasian economic system. The convergence of empirical findings and theoretical interpretations in this study contributes to the understanding of how regional institutions can act as intermediary agents between global sustainability objectives and local developmental needs. The SCO's challenge moving forward is to institutionalize its sustainability discourse through tangible mechanisms standardized environmental metrics, project-based financing, and transparent monitoring that translate its political will into measurable impact. Doing so would allow the SCO to fulfill the potential described by scholars such as Aris (2016) and Alimov (2018):

to become not only a bridge between East and West, but also a model of sustainable regionalism in an increasingly multipolar world.

Conclusion

The primary aim of this research was to analyze the role of the Shanghai Cooperation Organization in developing sustainable trade corridors within the contemporary system of international relations. This objective has been achieved through a comparative and institutional analysis of the SCO's mechanisms, as well as an examination of the experiences of its Central Asian member states Kazakhstan, Uzbekistan, Kyrgyzstan, and Tajikistan. The study demonstrates that the SCO has evolved into an increasingly influential regional platform capable of promoting economic integration, sustainable infrastructure development, and environmental cooperation across Eurasia.

The research addressed its central question how the SCO contributes to the development of sustainable trade corridors in the Eurasian region by identifying both institutional mechanisms and practical results of the organization's activities. The analysis confirmed that the SCO enhances regional connectivity primarily through coordinated infrastructure programs, harmonization of trade policies, and the implementation of projects aligned with sustainable development principles. These mechanisms collectively strengthen economic resilience among member states and promote environmentally responsible growth.

The supporting research questions were also successfully answered.

1. Regarding institutional and policy instruments, the study found that the SCO uses flexible multilateral mechanisms such as the Interbank Consortium, Business Council, and specialized working groups to coordinate investment, logistics, and sustainability projects. Although the organization lacks binding enforcement tools, its consensus-based model allows for pragmatic cooperation among diverse economies.

2. Concerning alignment with global initiatives, the findings demonstrate a growing convergence between SCO strategies and international sustainability frameworks, including the UN Sustainable Development Goals and the Belt and Road Initiative. This alignment reinforces the SCO's role as a bridge between regional and global economic systems.

3. In terms of challenges and opportunities, the research revealed persistent asymmetries in the economic and institutional capacities of member states, yet also highlighted significant potential for synergy. The SCO's main challenges include limited institutionalization and uneven environmental standards, while its opportunities lie in digitalization, green investment, and regional policy coordination.

The comparative analysis of the Central Asian member states showed that Kazakhstan and Uzbekistan act as regional leaders, driving innovation in transport infrastructure and sustainability policies, whereas Kyrgyzstan and Tajikistan play vital complementary roles as transit and energy partners. This asymmetry does not weaken the regional framework but instead forms a balanced system of mutual interdependence that supports collective development. The SWOT assessment further emphasized that the SCO's strategic advantage lies in its broad geographic scope, political inclusivity, and emerging sustainability agenda, although it must overcome institutional inertia and external geopolitical pressures to fully realize its potential. Overall, the results confirm that the research aim was achieved. The SCO indeed serves as an effective tool for developing sustainable trade corridors in Eurasia by promoting policy coordination, green logistics, and inclusive economic cooperation. The organization's growing focus on environmental sustainability and digital trade illustrates a broader transformation of regional governance toward a model based on ecological responsibility and shared prosperity. In conclusion, the study demonstrates that the SCO's experience provides valuable insights for rethinking regional integration in a multipolar world. The organization's ability to combine flexibility with sustainability offers a practical framework for balancing economic growth, ecological protection, and geopolitical stability.

However, for the SCO to maximize its impact, it must strengthen institutional mechanisms, ensure measurable implementation of sustainability goals, and maintain its role as a platform for dialogue and cooperation among diverse Eurasian states. Thus, the research confirms that the SCO not only contributes to the establishment of sustainable trade corridors but also represents a new paradigm of regional economic governance one that integrates connectivity, inclusivity, and environmental responsibility as core principles of 21st-century international relations.

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Architecture

АРХИТЕКТУРАЛЫҚ ДИЗАЙНДА REVIT ЖӘНЕ 3DS MAX БАҒДАРЛАМАЛАРЫН ҚОЛДАНУ АРҚЫЛЫ СТУДЕНТТЕРДІҢ КӨРКЕМ ҚИЯЛЫН ДАМЫТУ

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Түйіндеме. Бұл мақалада архитектуралық дизайн саласында Revit және 3ds Max бағдарламаларын қолданудың студенттердің шығармашылық және көркем қиялын дамытудағы рөлі қарастырылады. Сандық модельдеу, визуализация және жобалау процестерін біріктіру студенттердің кәсіби дағдыларын жетілдіріп қана қоймай, олардың кеңістіктік ойлау қабілетін арттыратыны дәлелденеді. Сонымен қатар инновациялық педагогикалық әдістер мен пәнаралық оқыту тәсілдерінің бұл бағдарламалармен үйлесімділігі және Revit пен 3ds Max арасындағы технологиялық интеграция қарастырылады.

Аннотация. В статье рассматривается роль использования программ Revit и 3ds Max в развитии творческого и художественного воображения студентов архитектурного дизайна. Интеграция цифрового моделирования, визуализации и проектных процессов способствует формированию профессиональных компетенций, пространственного мышления и творческой инициативы. Дополнительно описаны педагогические методы и технологические аспекты совместного использования Revit и 3ds Max: форматы экспорта, работа через File Link Manager и решения типовых проблем.

Abstract. The article examines how Revit and 3ds Max foster creative imagination in architectural design education. Integrating digital modeling, visualization, and design workflows enhances professional skills and spatial thinking. The paper also outlines technological integration between Revit and 3ds Max—export formats, File Link Manager, and practical troubleshooting—alongside innovative pedagogical methods such as project-based learning, brainstorming, and interdisciplinary approaches.

Түйін сөздер: архитектуралық дизайн, Revit, 3ds Max, визуализация, шығармашылық қиял

Ключевые слова: архитектурный дизайн, Revit, 3ds Max, визуализация, творческое воображение

Keywords: architectural design, Revit, 3ds Max, visualization, creative imagination

Қазіргі сәулет және дизайн білімінде технологиялық даму мен шығармашылық ойлау тығыз байланыста жүріп жатыр. Revit және 3ds Max сияқты бағдарламалар студенттерге

күрделі жобаларды орындауда үлкен еркіндік беріп, нақты әрі көркем нәтижеге қол жеткізуге мүмкіндік береді [3][4]. Бұл құралдар тек техникалық машықты ғана емес, кеңістіктік ойлау, көркем қиял және шығармашылық шешім қабылдау қабілеттерін дамытуда маңызды рөл атқарады. Қазақстанда білім беру жүйесін цифрландыру, BIM технологияларын енгізу және жобалау мәдениетін жаңғырту бағытындағы қадамдар осы бағдарламаларды оқу процесіне тиімді енгізудің өзектілігін арттырып отыр [6].

Revit параметрлік модельдеуге және жүйелік тәсілге негізделген [1]. Әрбір элемент өзара логикалық байланыста болғандықтан, студенттер ғимаратты тұтас жүйе ретінде түсінуді үйренеді. Мысалы, қабырғаның биіктігін өзгерту автоматты түрде шатыр мен терезе параметрлерін өзгертеді, бұл кеңістікті ойлау қабілетін дамытады. Ал 3ds Max бағдарламасы дайын модельді көркем және реалистік түрде бейнелеуге мүмкіндік береді [4]. Материалдар мен жарық сценарийлерін орнату, текстураларды қолдану арқылы студенттер жобаның визуалды әсерін зерттейді және көркемдік деңгейін арттырады. Осылайша Revit жобаның конструктивті логикасын қалыптастырса, 3ds Max оның көркем мазмұнын ашады, ал екеуін қатар пайдалану студенттің жүйелік және шығармашылық ойлау қабілеттерін тең дәрежеде дамытады [7].

Сәулет студенттері үшін модельдеу тек техникалық емес, ойлау құралы болып табылады [2]. Revit арқылы параметрлерді өзгерте отырып бірнеше жобалық нұсқаларды қатар салыстыру және ең тиімді шешімді таңдау мүмкіндігі бар. 3ds Max-та осы нұсқалардың жарық, фактура және орта жағдайындағы көркем бейнесін жасау арқылы шығармашылық ізденіс жүргізіледі. Бұл жерде жобалық және зерттеуге негізделген оқыту тәсілдері ерекше тиімді нәтиже береді: студенттер шынайы өмірге ұқсас тапсырмаларды шешіп, өз идеяларын визуалды түрде негіздейді [6]. Мысалы, кампус немесе қоғамдық орталық жобасында студенттер Revit-та көлемдік шешім жасап, 3ds Max-та күн сәулесінің бұрышына байланысты фасадтың түрлі сценарийлерін зерттей алады. Бұл шығармашылық және инженерлік ойлаудың қатар дамуын қамтамасыз етеді.

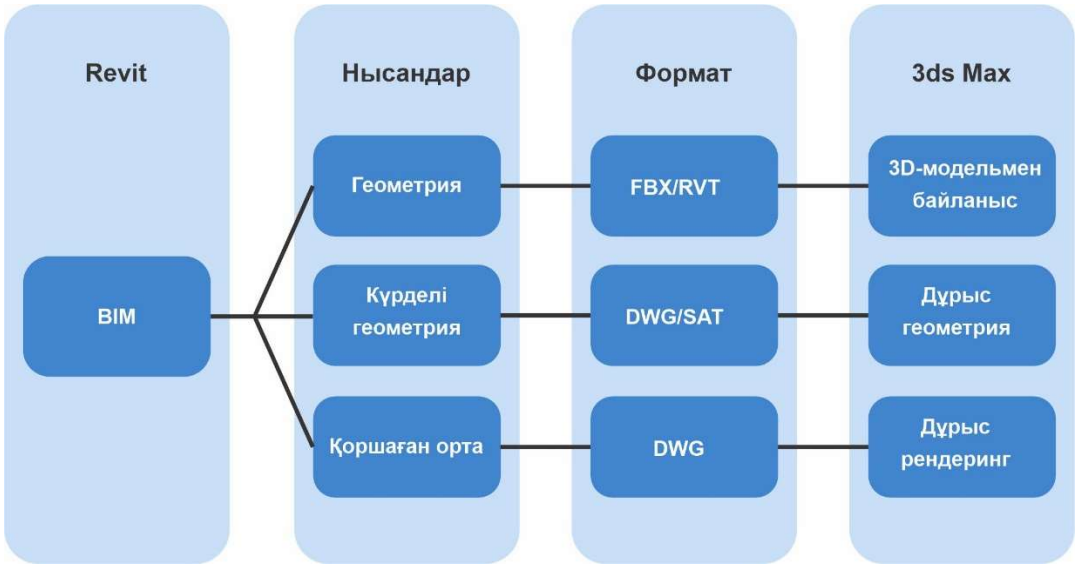
Оқыту процесінде «Миға шабуыл» әдісі де маңызды рөл атқарады [5]. Бұл әдісте студенттер еркін форматта, сынсыз түрде идеяларын ортаға салып, қысқа уақытта көп ұсыныс жинақтайды, кейін сол идеяларды топпен талқылап, ең сәтті шешімді таңдайды. Мұндай тәсіл Revit пен 3ds Max орталарында өте тиімді қолданылады: студенттер алдымен қарапайым нобайлар құрып, кейін визуализация жасап, топтық талқылау арқылы концепцияны жетілдіреді. Бұл шығармашылық белсенділікті арттырып, топпен жұмыс істеу мәдениетін қалыптастырады.

Пәнаралық байланыс та архитектуралық дизайнда маңызды орын алады. Revit инженерлік және конструктивтік пәндермен табиғи түрде интеграцияланса, 3ds Max көркемдік, композициялық және графикалық бағыттағы пәндермен тығыз байланысты. Заманауи педагогикалық әдістер — жобалық және проблемалық оқыту, зерттеуге негізделген тәсіл, топтық жұмыс және рефлексия — осы бағдарламалар қолданылған сабақтарда ерекше тиімді [6]. Студенттер пәнаралық ойлау қабілетін дамытып, визуалды коммуникация дағдыларын меңгереді және кәсіби деңгейде өз жобаларын қорғауға үйренеді.

Технологиялық тұрғыдан алғанда, Autodesk Revit пен 3ds Max бағдарламаларын бірге пайдалану кәсіби жұмыс процесін модельдеуге мүмкіндік береді [3][4]. Екі бағдарлама арасында 3D модельдерді тасымалдау үшін DWG, SAT, FBX және RVT форматтары қолданылады. File Link Manager жүйесі арқылы байланыс орнату ең ыңғайлы тәсілдердің бірі болып табылады: Revit-тегі өзгерістер 3ds Max-та бір ғана «Reload» пәрменімен жаңартылып отырады. Экспорт алдында объектілерді логикалық топтастыру, атауларды нақты беру, қажетсіз элементтерді алып тастау және детализация деңгейін реттеу — көріністермен жұмыс тиімділігін арттырады. 3ds Max-та модельмен жұмыс істеу үшін Edit Poly, UVW Map

немесе STL Check сияқты модификаторлар қолданылады. Олар геометрияны түзетуге, текстураны нақтылауға және артефактілерді жоюға мүмкіндік береді. Кей жағдайларда қисық беттерді экспорттауда полигондық тор дұрыс құрылмауы мүмкін, мұндайда SAT форматындағы экспорт жақсы нәтиже береді. Ал 3ds Max-тан Revit-ке кері экспорт техникалық тұрғыда мүмкін болғанымен, параметрлік жүйеге интеграция шектеулі болғандықтан, бұл тәсіл сирек қолданылады. Негізінен Revit — жобалау мен модельдеудің орталығы, ал 3ds Max — визуализация және презентация құралы ретінде қолданылады.

Revit және 3ds Max бағдарламалары арасында 3D-деректермен алмасу процесін қорытындылай келе, экспорт пен визуализацияның біртұтас технологиялық сызбасын құруға болады (сур. 13).



Сурет 13. Autodesk Revit пен 3ds Max арасындағы 3D-деректермен алмасудың жалпы схемасы [8].

Экспорт геометриясын жүзеге асыру үшін ең тиімді форматтар — FBX және RVT. Бұл форматтар Revit моделін 3ds Max-қа байланыстыруға мүмкіндік береді және модельде өзгерістер енгізілген сайын файлдағы деректер өзектілігін сақтап отырады. Егер объектілердің полигондық торының дәлдігі аса маңызды болмаса, екі қисық беттері бар элементтерді *.DWG форматында экспорттауға болады. Ал егер геометрияның нақтылығы маңызды болса, *.SAT форматында экспорт жасау ұсынылады. Күрделі жобаларда кейде түрлі форматтарда шатасу болуы мүмкін. Мұндай жағдайда қоршаған ортаны және күрделі қисық пішінді элементтерді 2D-астылық ретінде *.DWG форматында экспорттап, ал нақты 3D элементтер үшін FBX немесе SAT форматтарын пайдалану ыңғайлы. Сонымен қатар, Autodesk 3ds Max кітапханаларындағы дайын элементтерді қолдану да жұмыс процесін жеңілдетеді [8].

Қазіргі кезеңде Қазақстанның білім беру жүйесі толықтай дерлік компьютерлендірілген. Көптеген мектептер мен жоғары оқу орындарында ақпараттық технологиялар оқу процесіне енгізіліп, сәулет және дизайн бағыттарында бұл үрдіс ерекше қарқынмен жүріп жатыр. Компьютерлік модельдеу мен мультимедиялық құралдар студенттердің шығармашылық қабілеттерін дамытудың маңызды әдістемелік құралына айналуда [1–5]. Бұл үрдіс қазіргі білім беру парадигмасындағы «ақпараттық қоғамға бейімделу» міндетімен тығыз байланысты және болашақ мамандардың жаңа ғылыми-мәдени кеңістікте еркін бағдарлай алуына жағдай жасайды [2].

Revit және 3ds Max бағдарламаларын пайдалану арқылы студенттер тек техникалық машықтарды ғана емес, сонымен қатар ақпараттық ортада жұмыс істеу дағдыларын, шығармашылық және кеңістіктік ойлау қабілеттерін жетілдіреді. Бұл бағдарламалар студенттерге күрделі жобаларды сандық ортада нақты, дәл әрі көркем деңгейде жүзеге асыруға мүмкіндік береді. Суретші-сәулетшілер мен дизайнерлер үшін мұндай дайындық ең алдымен кеңістіктік елестету қабілетін, композициялық шешім қабылдау дағдыларын және визуалды коммуникацияны дамытумен тікелей байланысты [3].

Revit пен 3ds Max қолдану дәстүрлі жобалау әдістерін мультимедиялық құралдармен ұштастырады. Бұл бағдарламалар студенттерге күрделі 3D модельдерді жасауға және оларды шынайы ортада көрсетуге мүмкіндік береді; мультимедиялық визуализация арқылы жобаны интерактивті қорғауға жағдай жасайды; бейнелеу және графикалық редакторлармен (CorelDraw, Photoshop, AutoCAD т.б.) бірге қолданылғанда жобалау және шығармашылық мүмкіндіктерін кеңейтеді [4][5].

Мультимедиялық және ақпараттық технологияларды қолданудың артықшылықтары бірнеше қырынан көрінеді. Техникалық тұрғыда — жылдамдық, қолжетімділік, материалды қайта өңдеу және онлайн тарату мүмкіндіктері оқу процесін едәуір жеңілдетеді. Психологиялық тұрғыда — студенттердің қызығушылығын арттырып, бейне мен анимация арқылы ақпаратты қабылдауды жеңілдетеді. Педагогикалық тұрғыда — оқытудағы дербестік, белсенділік пен шығармашылық еркіндікті дамытуға мүмкіндік береді [2,4].

Бұл артықшылықтар сәулет және дизайн саласында Revit пен 3ds Max бағдарламаларын қолдану барысында айқын көрінеді. Мысалы, студенттер өз жобаларын тек 2D сызбалар арқылы ғана емес, үш өлшемді анимациялар, виртуалды турлар және фотореалистік визуализация түрінде көрсете алады. Мұндай тәсіл жобаның мазмұнын терең түсінуге, идеяны нақты және әсерлі жеткізуге жағдай жасайды [6]. Сонымен бірге, бұл тәсіл жобалық ойлауды дамытуға, инженерлік және көркем шешімдерді ұштастыра білуге үйретеді.

Revit және 3ds Max бағдарламаларын қолдану дәстүрлі сызба-сызумен шектелмей, заманауи мультимедиялық білім беру технологияларымен өзара тығыз байланысады. Нәтижесінде студенттердің ақпаратты талдау және құрылымдау қабілеті артып, жобалық шешімдерді визуалды түрде нақты әрі кәсіби деңгейде жеткізе алу дағдылары қалыптасады. Сонымен қатар, кәсіби графикалық және бағдарламалық сауаттылық дамып, студенттер жаһандық стандарттарға сай архитектуралық ойлау мен заманауи дизайн тәсілдерін еркін меңгере бастайды.

Revit параметрлік моделдеу қағидатына негізделгендіктен, студент жобаны «тірі жүйе» ретінде ұғынуға үйренеді: қабырға биіктігін өзгерткенде есік-терезе, жабын, шатыр сияқты байланысты элементтер бірден қайта есептеледі, ал жоспар, қима, фасад және спецификация деректері өзара көңіл-күйі бір тұтастықта қалады [1,3]. Бұл жүйелік көзқарас композициялық-құрылымдық шешімдердің бір-бірімен байланысын түсіндіреді, тұтас макет пен оның бөліктері арасындағы тәуелділікті параметр арқылы басқаруға үйретеді. 3ds Max дайын модельдің көркем мазмұнын ашады: материалдық кітапханалар, жарық сценарийлері, камера және орта баптаулары арқылы студент рендер сапасын өсіріп, идеяның визуалды әсерін зерттейді; фотореалистік бейнелеу аудиториямен эмоционалды коммуникацияға мүмкіндік береді [4]. Осы екі ортаны бірге қолдану инженерлік логика мен көркем бейнелеуді бір арнаға тоғыстырып, «елестету — модельдеу — визуалдық дәлелдеу» циклін табиғи дағдыға айналдырады [7].

Педагогикалық ракурста бұл интеграция жобалық және зерттеуге негізделген оқытудың тиімділігін еселейді. Студент Revit-та бірнеше нұсқаны жылдам параметрлік вариациялармен тудырып, олардың конструктивтік және жоспарлық артық-кемін салыстырады; 3ds Max-та жарық, фактура, орта сценарийлерін сынап, визуалды критерийлер

бойынша шешім қабылдайды. «Миға шабуыл» сияқты идея генерациялау әдістері қысқа уақытта көп ұсыныс жинауға, кейін оларды рефлексия арқылы сұрыптап, ең ұтымдысын таңдауға мүмкіндік береді; бұл процестерде интерактивті рендерлер мен шұғыл визуалды демонстрациялар ерекше рөл атқарады [5–6]. Нәтижесінде студент тек объект жасамайды — дәлелді презентация мәдениетін қалыптастырады: альбом, беттеу, экспликация, смета, қысқа бейне/анимация, интерактивті тур — бәрі бір жобалық баяндауға жинақталады [3–4].

Ақпараттық қоғам жағдайында коммуникативтік дағды — кәсіби құзыреттіліктің өзегі. Онлайн-көрмелер, бейнесабақтар, веб-портфолио, білім беру платформалары шығармашылық өнімді жедел таратуға, кері байланысты жедел алмасуға мүмкіндік береді. Бұл орта студентке қауіпсіз тәжірибе алаңын ұсынады: ол идеясын үлкен аудиторияға таныстырады, пікірталасқа қатысады, объективті бағалау алады, өз жұмысының сапасын жүйелі жақсартады [2]. Тәулік бойы қолжетімділік, жылдам алмасу, жеке және топтық форматтың еркін ауысуы, бейне-аудио материалмен әсерлі хабарлама құрастыру — мұның бәрі заманауи оқу кеңістігінің табиғи мүмкіндігі.

Мультимедианың дидактикалық әлеуеті білім мазмұнын түсінікті әрі әсерлі етуге бағытталған. Түс, графика, дыбыс, қозғалыс, интеракция — күрделі ұғымдарды сезімдік деңгейде ұсынуға көмектеседі; ойындық компоненттер қызығушылықты көтеріп, есте сақтауды күшейтеді; анимациялық түсіндірмелер конструктивтік принциптерді көз алдына әкеледі [2,4]. Сол арқылы Revit-тағы «логикалық модель» 3ds Max-та «көркем дәлелге» айналады, ал студенттің танымдық белсенділігі артады. Дәстүрлі әдіс-тәсілдер мұнда жойылмайды, қайта жаңғырып, мультимедиамен тоғысады: қима мен торап, жоспарда қабылданған шешім — визуалда нақты тексеріледі; композиция теориясы — жарық пен кадр пластикасы арқылы сынақтан өтеді.

Техникалық тұрғыдан Revit ↔ 3ds Max деректер алмасуын дұрыс ұйымдастыру — оқу уақытын үнемдеу мен қателерді азайтудың басты шарты. Негізгі арналар — RVT/FBX; күрделі қисық геометрия дәлдігі қажет болса — SAT, ал қосалқы 2D/қоршаған орта элементтері үшін — DWG ыңғайлы [3–4,8]. File Link Manager байланысты «тірі» ұстайды: Revit-тағы түзету 3ds Max сахнасына бір «Reload»-пен өтеді. Экспорт алдында атауларды жүйелеу, лер архитектоникасын логикалық топтастыру, қажетсіз геометрияны тазалау, детализация деңгейін (LOD) ұтымдылау, масштаб пен бірлік жүйесін бірыңғайлау керек. 3ds Max-та Edit Poly, UVW Map, STL Check секілді модификаторлар тор сапасын түзеп, текстуралауды нақтылайды; қажет болса, камера мен жарық ригін кітапханадан қолдану рендер уақытын оңтайландырады [4,8]. Бұл pipeline студентті кәсіби өндірістік процестің қысқартылған моделіне жақындатып, «жобалау — келісу — визуалдау — қорғау» тізбегін тұтас меңгеруге жағдай жасайды.

Оқыту мазмұны жағынан Revit инженерлік-конструктивтік пәндермен табиғи интеграция құрады: жүктеме логикасы, қабаттық жоспар, торап, спецификация, ведомость — бәрі параметрмен байланысады; ал 3ds Max композиция, жарықтандыру теориясы, түстану және графикалық дизайнмен тығыз үйлеседі. Осы пәнаралық синтез студентті «бір бағдарламаны білуші» деңгейінен «кешенді ойлайтын жас маман» деңгейіне көтереді [6,7]. Авторлық құқыққа құрмет, академиялық адалдық, дереккөзбен жұмыс мәдениеті сияқты цифрлық этика ережелерін параллель үйрету — міндетті.

Қазақстандағы цифрландыру, BIM-ді дамыту және оқу жоспарларын жаңарту бағыттары бұл интеграцияны институционалдық деңгейде қолдап отыр [6]. Кітапханалардың цифрлануы, кәсіби қауымдастық сайттары, ашық ресурстар студент пен оқытушыға үздіксіз даму мүмкіндігін ұсынады. Тақырыптық платформалар желілік кері байланыс жылдамдығын арттырып, шығармашылық қауыммен тікелей диалог орнатады; нәтижесінде студент өз идеясын көпшілік алдында қорғауға, кәсіби тілде дәлелдеуге, визуалды коммуникацияны шебер қолдануға дағдыланады [2]. Бұл орта жеке және топтық жұмыс форматтарын еркін

алмастырып, түрлі темперамент пен коммуникативтік ерекшелігі бар студенттің барлығына бірдей мүмкіндік береді.

Әдістемелік тұрғыдан алғанда, Revit пен 3ds Max-ты енгізу — «құрал үйрету» ғана емес, ойлау форматын өзгерту. Біріншіден, жүйелік көзқарас нығаяды: тұтас макет пен оның бөліктерін параметр арқылы басқару, ақпаратты құрылымдау, шешім салдарын жылдам көру [1]. Екіншіден, көрнекілік пен мультимедиа күшейеді: күрделі конструктивтік ұғымдар сезімдік арналармен ұсынылады, қабылдау жеңілдейді [2,4]. Үшіншіден, пәнаралық синтез орнығады: инженерлік есеп, композиция, графикалық дизайн бір сценарийде тоғысады [6–7]. Төртіншіден, коммуникация мәдениеті қалыптасады: жоба альбомын беттеу, экспликация мен спецификацияны сауатты рәсімдеу, қысқа бейне арқылы аргументация құру, желілік этиканы сақтау — кәсіби бейімделудің өзегі.

Жалпы алғанда, Revit пен 3ds Max-ты бірізді pipeline-ға біріктіру сәулет студентінің кеңістіктік ойлауын, көркем қиялын және кәсіби коммуникациясын кешенді дамытатын қуатты дидактикалық орта жасайды. Жобалық, зерттеушілік, проблемалық және пәнаралық әдістермен ұштаса отырып, бұл бағдарламалар білім алушыны қазіргі ақпараттық қоғамдағы кәсіби қызметке даярлаудың тиімді құралына айналады. Дәстүрлі қағаздық графика мұнда жойылмайды — сандық ортада жаңа деңгейде «сөйлейді»: қима мен торап, жоспар мен фасад визуалда дәлелге айналып, шығармашылық идея инженерлік логикамен тең дәрежеде негізделеді. Осылайша цифрлық технологиялар көркем-педагогикалық білім берудің мазмұнын байытып, оқыту сапасын арттырып, студенттің кәсіби әлеуетін толық ашуға мүмкіндік береді [1–8,9–14].

Қорыта келгенде, Revit пен 3ds Max-ты бірізді оқу-практикалық pipeline ретінде қолдану сәулет және дизайн біліміндегі дәстүрлі әдістерді заманауи цифрлық ортаға тиімді көшіреді: Revit параметрлік модельдеу арқылы жүйелік ойлауды, жобаның тұтастығын және деректердің өзара тәуелділігін қалыптастырса, 3ds Max визуализация арқылы көркем қиялды, композицияны және коммуникацияны күшейтеді; екі ортада жобалық, зерттеушілік және пәнаралық тәсілдердің ұштасуы студенттің кеңістіктік ойлауын, шығармашылық шешім қабылдауын және дәлелді презентация дағдыларын кешенді дамытады; техникалық тұрғыдан дұрыс экспорт–импорт (RVT/FBX/SAT/DWG), логикалық атаулар мен LOD, File Link Manager-ді жүйелі пайдалану оқу уақытын үнемдеп, қателерді азайтады; мультимедиалық құралдар қабылдауды жеңілдетіп, есте сақтауды арттырып, мотивацияны көтереді, ал онлайн-платформалар кәсіби қоғамдастықпен кері байланысты жеделдетеді; осылайша студент тек «бағдарлама білетін» емес, кешенді ойлайтын, цифрлық сауаты жоғары, визуалды дәлелдеуі мықты жас маман ретінде қалыптасады; іске асыру үшін оқу жоспарын Revit (BIM логикасы), 3ds Max (визуализация), Revit→3ds Max pipeline модулі және портфолио/презентация блоктарымен құрып, тапсырмаларды параметрлік нұсқалар сериясы мен жарық/материал сценарийлеріне негіздеп, қорытындыда анимация немесе виртуалды тур жасауды талап етіп, кафедралық техникалық стандартты (файл атауы, қабат/категория, LOD, масштаб/бірлік жүйесі, кітапхана құрылымы) бекітіп, бағалауды модель сапасы (BIM-логика), визуал сапасы (материал–жарық), аргументация (презентация) және пәнаралық дәлелмен жүргізіп, LMS/порталда аралық рендерлер мен рефлексияны жүйелі жүктеу және топтық кері байланыс циклін енгізу ұсынылады; қысқасы, бұл әдістеме Revit пен 3ds Max-ты жай оқыту құралы емес, шығармашылықты күшейтетін дидактикалық орта ретінде пайдалануға мүмкіндік береді және студентті заманауи еңбек нарығына даярлаудың ең тиімді жолы болып табылады.

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Psychological Sciences

THE USE OF MINDFULNESS IN THE WORK OF A PSYCHOLOGIST WITH ADOLESCENTS

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Annotation: The paper presents modern research confirming the effectiveness of mindfulness therapy, which reduces the degree of anxiety, aggression and increases the level of psychological well–being of adolescents. The article presents the main techniques used by psychologists: conscious breathing, body scanning, visualization, working with emotions and exercises to develop empathy. Special attention is paid to the peculiarities of adapting these practices to the age and cognitive characteristics of adolescents, integrating mindfulness techniques and cognitive behavioral therapy.

Keywords: mindfulness, mindfulness, teenagers, stress, anxiety, training, emotions.

The life of a modern teenager takes place in conditions of high information load, social pressure and emotional instability. The period of accelerated development of digital technologies, increasing competition in the educational environment and changing family values (6) lead to an increase in the level of anxiety, stress states and disorders manifested in the emotional and volitional sphere. In this regard, psychologists are faced with the task of finding the most effective methods that can help adolescents cope with inner feelings and regulate emotional reactions.

Among the diverse methods that we use in our professional activities: the use of schema therapy, the study of coping strategies of adolescents (7), metaphorical associative maps (8), etc., In our opinion, the practice of conscious presence is very effective – mindfulness, which is aimed at developing the ability to focus attention on the present moment without evaluative judgments. Today, the mindfulness technique has received scientific justification and is actively used in clinical, educational and counseling psychology.

It should be noted that in adolescence, mechanisms of self-regulation, self-identity and emotional maturity are formed, which makes this practice especially valuable, as it helps adolescents to better understand their feelings, develop empathy, reduce anxiety and aggression, as well as improve concentration and academic performance.

Mindfulness has become widespread both abroad and in our Republic. The use of mindfulness in working with teenagers is at the stage of active development. It is becoming relevant to study the possibilities of adapting these techniques to the cultural and age characteristics of Azerbaijani adolescents, as well as the development of effective psychological support programs with elements of awareness.

Defining the purpose of this article, we proceeded from the fact how important this technique is from the point of view of practical possibilities of applying the mindfulness approach in the work of a psychologist working with adolescents, as well as identifying its potential in increasing the level of psychological well-being and emotional stability of this age group.

Considering the theory of the issue, the possibilities of using the mindfulness method and its significance in adolescence, it is important to focus on the following aspects. The term mindfulness itself translates as "awareness", "presence in the present moment". From a scientific point of view, mindfulness is considered as a state of active attention to current experiences —

bodily sensations, thoughts and emotions, which is reflected in the works of American Professor John Kabat-Zinn (9), who is the founder of the modern scientific approach to mindfulness and the developer of the Mindfulness-Based Stress Reduction program, which is aimed at reducing stress levels. stress and the development of emotional stability.

It is quite important and promising for us to introduce mindfulness elements into educational programs (1, 2, 13), which will be an excellent tool for reducing depression and anxiety in adolescents, increasing the level of emotional intelligence, which in turn will affect the level of academic success and will become the key to educational motivation. No less interesting studies have been conducted by other authors: D. J. Siegel (10), V. Sidyacheva (11), V.G. Umnyashkin (12), T. G. Fomina (5).

In the works, the effectiveness of implementing programs for the prevention of stress and depression in adolescents has been experimentally proven, and mindfulness is presented as a component of psychological well-being and self-regulation.

Another study conducted by Davidson (4) shows that mindfulness practice activates neural mechanisms responsible for self-regulation, attention, and empathy. Therefore, regular mindfulness exercises contribute to the formation of emotional control skills, improve memory and concentration. In the psychological context, mindfulness can be considered as a component of metacognition — awareness of one's own mental processes.

For teenagers who are at the stage of identity formation, the development of awareness helps them to better understand themselves, their needs and motives for behavior. I would like to focus on the main aspects related to the practical application of mindfulness techniques in the work of a psychologist with adolescents. It should be noted that the application of this approach in the work of a psychologist involves the integrated use of methods aimed at developing adolescents' skills of self-regulation, concentration and emotional stability. Informed practices can be applied in both individual and group work, in counseling, training programs, preventive and educational projects.

Mindfulness is based on the basic principles, which include: gradualness — from short exercises to longer practices, play form — the use of metaphors, visual and physical elements to involve participants, lack of appreciation — the formation of adolescents' ability to accept their own emotions without judgment, regularity — the inclusion of conscious pauses and short practices in the structure of classes or school day.

Now let's focus on the question of the form in which this practice can be applied. It should be noted that in individual counseling, we use short mindfulness practices at the beginning or end of the meeting, and discuss internal states through self-observation techniques.

This practice works great when conducting group classes (exercises: "Cloud of emotions", "Conscious listening", "Pulse of the team") and emotional regulation trainings. Here is an example of mindfulness practice for teenagers who often show aggression.:

- Stop and take 3 deep breaths.
- Notice where tension is felt in the body.
- Name an emotion about yourself: "I'm angry."
- Ask yourself: "What will help me not to make things worse now?"
- Make a decision (for example, to step back, drink water, breathe).

In our professional activities, we use mindfulness techniques that have proven themselves well and have had a positive dynamic in working with teenagers:

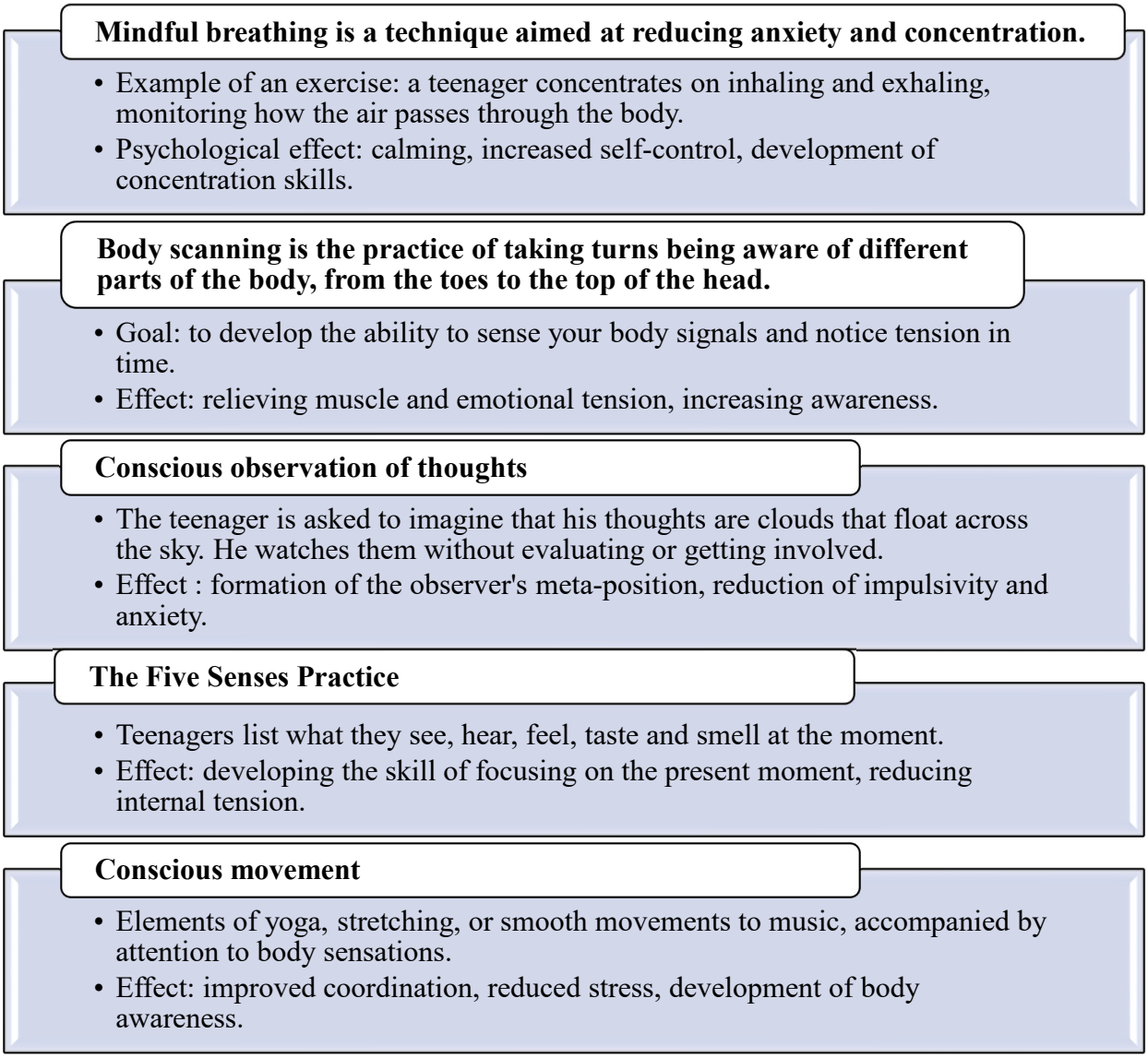

Fig. 1. Mindfulness techniques

Good results were obtained when conducting preventive programs in schools, including 10-minute practices in the lesson schedule or extracurricular activities, and teaching teachers and school psychologists the elements of mindfulness.

The results obtained by using mindfulness practices in working with adolescents have shown that: anxiety and irritability levels decrease, self-regulation and stress tolerance skills develop, concentration improves, educational motivation increases, interpersonal relationships and empathy strengthen, and the overall level of psychological well-being increases

The integration of mindfulness techniques and cognitive behavioral therapy is very effective, especially in the context of working with adolescents.

The integration of mindfulness techniques and cognitive behavioral therapy (CBT) is one of the most effective areas of modern psychological practice. Both approaches are based on developing awareness and a person's ability to observe their thoughts and emotions without evaluation. Mindfulness helps teenagers learn to notice their own experiences in the moment, while CBT allows them to rethink destructive attitudes and form more adaptive behaviors.

This combination of methods is especially effective when working with adolescents who have difficulty controlling emotions, impulsivity, or increased anxiety. Mindfulness practices help strengthen self-regulation skills, reduce internal tension, and increase stress tolerance. The elements of cognitive behavioral therapy, in turn, help to structure the process of self-discovery

and consolidate new ways of responding. When applied together, both approaches enhance each other's effect, providing a holistic effect on the emotional and cognitive sphere of the individual. In adolescence, when self-esteem and a value system are being formed, this is especially important. Experience shows that the combined use of mindfulness and CBT promotes the development of emotional intelligence and constructive forms of communication. Thus, the integration of these approaches is a promising direction in the system of psychological support for adolescents.

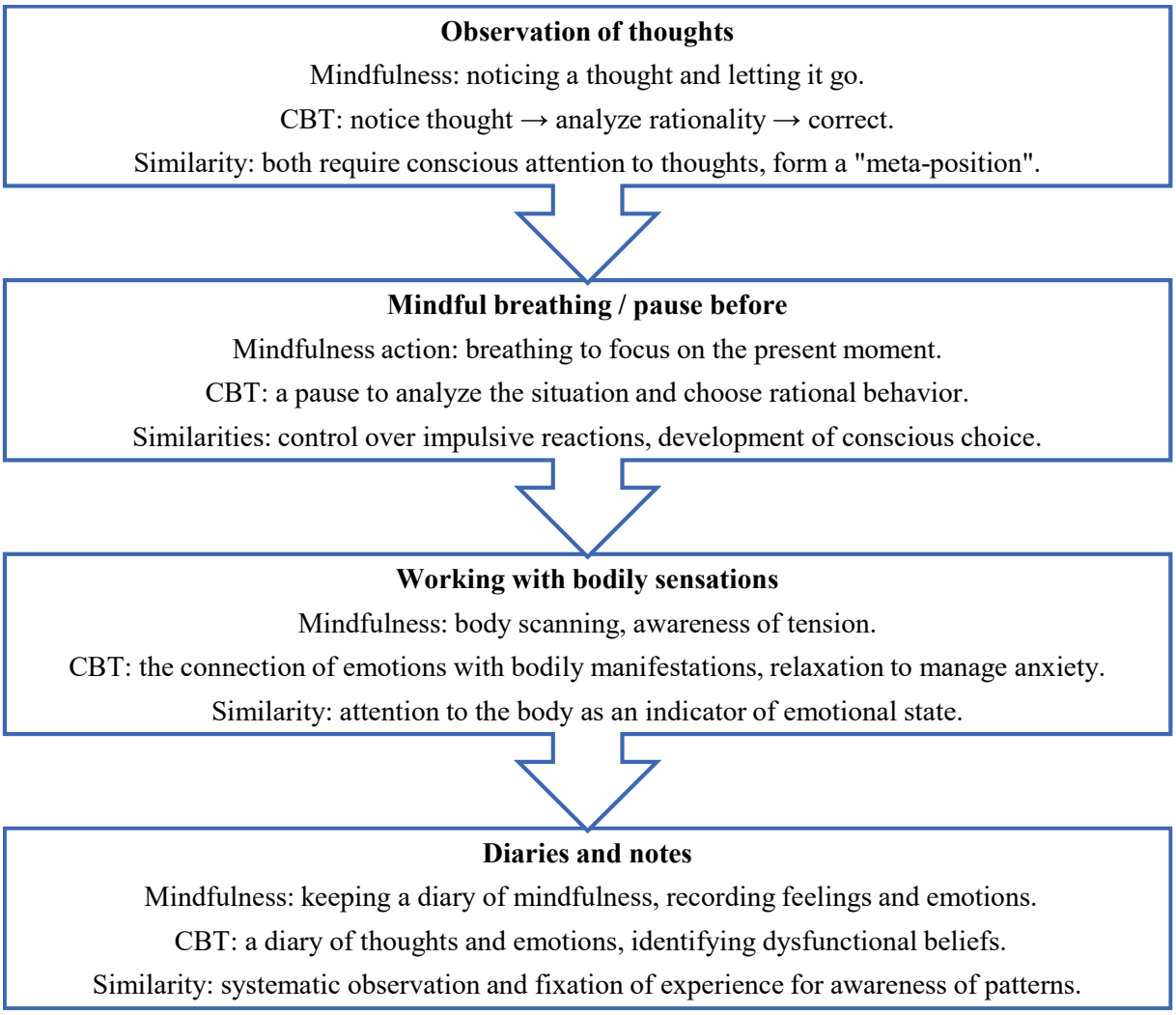

Fig.2. Integration of mindfulness techniques and cognitive behavioral therapy

I would like to focus on a real case and show the use of mindfulness techniques in working with an aggressive teenager.

Teenager, 12 years old, often shows outbursts of aggression: He quarrels with classmates, is rude to teachers, and may resort to physical actions. When talking with teachers and parents, there is increased irritability, difficulty controlling emotions, a sense of injustice and inner tension.

Our goal was to reduce the level of aggression and develop emotional self-regulation skills using mindfulness techniques.

The following stages were included in the program of work with a teenager:

The first stage: An explanation of what mindfulness is ("the ability to notice what is happening to you here and now"). Analysis of the connection of emotions, body and thoughts. Demonstration of a simple practice: “3 deep breaths" — focus on inhaling and exhaling.

The next stage: working with body awareness: the "Body Scan" exercise (a remark where tension is felt in the body when angry). Keeping a "body diary" — a teenager notes where he feels anger when it appears. As a result, a connection is formed between emotion and physical condition, and self-understanding grows.

The next stage is associated with the development of breathing techniques (for example, "square breathing" — inhale 4 counts, hold, exhale, pause), the use of short "mindfulness pauses" before a conflict, the practice of "Stop reaction": notice, name an emotion, inhale, choose an action. At this stage, it is important to form an automatism of self-regulation.

The stage of reflection and consolidation is devoted to a joint analysis of situations where anger has been managed, a discussion of how well-being has changed, and classroom relationships. At this stage, we use visual anchors (for example, a bracelet or a pattern that resembles "stop and breathe"), the "Three good moments of the Day" exercise, which promotes the development of positive perception.

At the final stage, the aggression is re-diagnosed, the results are discussed together, the dynamics are assessed, and the techniques are planned for independent use.

Thus, the use of mindfulness techniques in working with adolescents is a promising area of psychological practice that contributes to the formation of emotional stability, self-regulation and improving the quality of the educational process. The integration of these methods into the system of psychological support of educational institutions opens up new opportunities for the harmonious personal development of students.

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Chemical Sciences

ISOLATION AND IDENTIFICATION OF LACTIC ACID BACTERIA FROM KUMYS AND SHUBAT FOR INDUSTRIAL PRODUCTION OF STARTER CULTURES

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Abstract

The study presents the results of isolating and identifying lactic acid bacteria from traditional Kazakh fermented milk beverages – kumys and shubat – with the aim of developing industrial starter cultures. Samples of kumys, shubat, camel, and mare's milk were collected from several regions of Kazakhstan, and classical microbiological methods combined with molecular genetic techniques were used for analysis. More than ninety bacterial cultures were obtained, and over half were identified through 16S rRNA gene sequencing. The dominant genera were Enterococcus and Lactobacillus, which are responsible for the fermentation and formation of the characteristic aroma and texture of these beverages. Several isolates demonstrated no matches in existing genetic databases, suggesting the presence of unique or previously uncharacterized microbial strains endemic to the Kazakh region. The obtained results confirm the rich biodiversity of the natural microflora in kumys and shubat and form the basis for creating standardized starter cultures that preserve the traditional qualities of national dairy products while enabling their industrial-scale production.

Keywords: lactic acid bacteria, kumis, shubat, camel and mare's milk.

Introduction

Modern research in the field of food microbiology has shown that the quality and organoleptic properties of products are 70% related to microflora [1]. Microflora can be directly related to the place of origin of raw materials or to the methods and practices used to process them. For example, in wine production, the term 'terroir' is used, which is a comprehensive term that refers to both the microflora of the place where the raw materials are obtained and the characteristic microflora of the production sites [2, 3]. Thus, the same grape varieties grown in different places produce completely different wines.

If we draw a parallel with fermented milk products, the well-known Bulgarian bacillus and milk streptococcus give rise to a variety of yoghurts produced around the world. It would seem that there are only two known types of bacteria, yet there is such a wide variety of products. The same is true in the case of kumis and shubat. The centuries-old traditions of producing kumis and shubat in Central Asia and Kazakhstan vary greatly in terms of the specific taste, aroma and texture of the product. All of them are associated with the specific microflora of a particular place where animals are bred, their diet, and the methods used to prepare beverages. If Marco Polo called

kumis ‘the champagne of the steppes’ in the Middle Ages, then from the point of view of food microbiology, he did not exaggerate much [4].

Historically, there have been many descriptions of all the possible aromas of kumis and shubat. However, it is also well known that every spring, year after year, producers face difficulties in restoring the former aromas. Due to Kazakhstan's harsh climate, not all animals continue to produce milk during the winter, and producers do not always have the opportunity to preserve starter cultures. Therefore, with the arrival of spring, producers often lose time for spontaneous fermentation to achieve the desired taste, aroma and texture of the product. To overcome these difficulties, it is necessary to establish the production of specific starter cultures for kumis and shubat. This process is very lengthy and labour-intensive. The purpose of this article is to describe the preliminary stage in establishing production – the isolation and identification of microorganisms from kumis and shubat from different regions of Kazakhstan. This stage will ensure the specificity of future starter cultures.

Materials and methods

Samples of typical kumis, shubat, camel and mare's milk were collected. At this stage, samples were collected from 14 farms in four regions of Kazakhstan: Almaty, South Kazakhstan, Kyzylorda and Atyrau (Figure 1). All samples were placed in sterile test tubes.

Microbial cultures were isolated using classical microbiological methods. These microorganisms were then identified using the 16S ribosomal RNA fragment polymorphism determination method.

Results and discussion

From 19 samples from different farms and peasant households, 92 bacterial cultures were isolated (Table 1).

№	Microorganisms	Number of isolates					
		Atyrau Region (2 farms)		Kyzylorda Region (4 farms)	South Kazakhstan Region (5 farms)		Almaty Region (Sarzhailau Company)
		Camel milk	Shubat	Shubat	Camel milk	Shubat	Kumys
1	Bacteria	7	5	14	25	28	14
2	Yeast	2	3	-	4	3	6

Identification was carried out by ‘cross-referencing’ sequenced bacterial clones after sequencing 16S ribosomal DNA. Of the 92 bacteria listed, identification results were obtained for only 57 bacteria. Among the 57 sequenced bacterial clones, phylogenetic affiliation was shown only for:

- One type of bacteria identified and proposed – 30 bacteria
- Two or more types of bacteria identified and proposed – 13 bacteria
- Not identified – 14 bacteria

It should be noted that a large number of microorganisms obtained as isolates during reseeding no longer grew. Therefore, many of them were lost for identification. Then, at the identification stage, only 6 bacteria were 100% identified. Even if the database suggested a single name for the remaining 30 bacteria. In other words, 88% or higher homology was found for 24 bacteria in the database. With regard to the other bacteria, it should be noted that the database of sequenced bacteria used does not contain them. As a result, 51 bacteria were partially identified or not identified at all. These results suggest that 51 bacteria are more likely to be ‘endemic’ or, at least, have not been previously identified and entered into a known database. In the future, these microorganisms should be identified and characterised to supplement the database. For

now, the results obtained can be interpreted as evidence of the wide biodiversity of the microflora of national products, confirming their antiquity and stability over time. Despite the emergence of other fermented milk products in our environment, especially those produced using commercial starter cultures, it has not displaced or caused the disappearance of special 'endemic' species of microorganisms.

The dominant microflora consisted of Gram-positive bacteria belonging to the genera Enterococcus and Lactobacillus. Although the bacteria were isolated on media specific for lactic acid bacteria, proteobacteria (4 isolates) were also identified among the isolated microorganisms, represented by the species Ralstonia pickettii, Escherichia fergusonii, and Acetobacter pasteurianus, which are more likely to belong to extraneous, contaminating microflora, as well as actinobacteria represented by Corynebacterium variabile and Microbacterium hatanonis.

Of the 57 identified bacterial isolates, 22 belonged to this genus, accounting for almost 38% of the total microflora. Of the 22 isolates, 8 were identified as Enterococcus faecium, 5 isolates as Enterococcus durans, and 4 as Enterococcus faecalis. Until recently, enterococci (as serological group D streptococci) were considered in domestic literature to be part of the normal intestinal microflora of humans and animals, while in dairy products they were considered to be foreign microflora [5]. Over the past decade, a number of articles have appeared in foreign literature stating that various types of enterococci can be found in milk and various fermented milk products [6, 7, 8, 9, 10, 11]. When analysing the microflora of various national products, especially cheeses, in countries with the most developed cheese-making traditions (France, Italy), enterococci are often found alongside other bacteria [12]. In traditional Chinese fermented milk products such as kumis, fermented ham, tofu, etc. [13], in fermented Colombian kumis [14], etc., enterococci are a constant component of starter cultures.

The most common types of enterococci isolated from dairy products and identified by various methods are E. faecium, E. faecalis, and E. durans [6,7], which is consistent with our data. Bacteria of these species are used as starter cultures, especially in cheese production, since lactic acid enterococci have the ability to produce aroma [10, 15]. Many strains of enterococci found in milk have proteolytic activity and antagonistic properties against pathogenic strains of Listeria and Clostridium [8, 9, 16].

In second place in terms of prevalence were representatives of the Lactobacillus genus – 11 isolates, accounting for 19% of the microflora. No pattern was observed in the distribution of lactobacilli in camel milk and shubat. In some samples (3 types of shubat and 1 sample of camel milk), 2-3 species were found, while in others they were not detected. However, the absence of Lactobacillus bacteria in traditional fermented milk products is the exception rather than the rule.

Smaller quantities of Leuconostoc species were found, represented by two species, Leuconostoc mesenteroides (CHL60) and Leuconostoc pseudomesenteroides (SH2M3), as well as one species of Lactococcus lactis (CHL62), found in shubat. Although these species of lactic acid bacteria are important as starters for fermented products, they do not appear to be the dominant species in the fermentation of camel milk.

Conclusion

The conducted research represents the initial stage in developing standardized starter cultures for the industrial production of traditional Kazakh fermented milk beverages — kumys and shubat. The isolation and molecular identification of lactic acid bacteria from camel and mare's milk across different regions of Kazakhstan revealed a wide diversity of microbial species.

More than ninety bacterial isolates were obtained, of which over half were successfully identified through 16S rRNA gene sequence analysis. The dominant genera were Enterococcus and Lactobacillus, accounting for the majority of lactic acid microflora. Among them, Enterococcus faecium, E. durans, and E. faecalis were the most frequently encountered species, followed by Lactobacillus representatives responsible for acidification and flavor formation. The discovery of

isolates that could not be matched with existing genetic databases indicates the possible presence of previously undescribed or region-specific (endemic) bacterial strains.

These findings confirm the exceptional biodiversity and originality of the microflora present in kumys and shubat, shaped by local ecological and cultural factors. The identified strains have the potential to be applied in biotechnological processes to produce authentic starter cultures. Such developments will contribute to preserving the traditional qualities of national dairy products while ensuring stable industrial production and improved quality control.

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RESEARCH ON PEDAGOGICAL APPROACHES IN TEACHING ORGANIC CHEMISTRY

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Keywords: Organic chemistry, digital technologies, interactive teaching, virtual laboratory, 3D modeling.

The article examines modern pedagogical approaches applied in the teaching of organic chemistry. Due to the complex content structure, abstract concepts and the requirement of high-level chemical thinking from students, traditional teaching methods are often insufficient. In this context, the effectiveness of methods such as problem-based learning, project-based learning, constructive approach, laboratory-based learning, and the application of digital and interactive technologies is analyzed.

Introduction

Organic chemistry is one of the most challenging areas of natural sciences. Since complex topics such as molecular structure, isomerism, stereochemistry, and mechanisms are difficult to understand, the application of digital and interactive technologies plays an important role in teaching the subject.

Previous studies have shown that technologies such as 3D molecular modeling, virtual laboratories, and gamification increase student understanding and motivation.

These technologies both support classical teaching methods and develop active learning skills in students.

The effectiveness of pedagogical approaches used in teaching organic chemistry has a direct impact on academic results. Constructive approach, problem-based learning, project-based learning, laboratory-based learning, digital and interactive technologies lead to high-level implementation of organic chemistry lessons.

In the modern era, the application of student-centered interactive methods is necessary.

Problem-based learning is based on solving real chemical problems, building synthesis routes, analyzing mechanisms, and developing research skills.

Project-based learning - based on the construction of projects on the production of organic substances, environmentally friendly reagents, biomolecule models, industrial applications.

Laboratory-based learning - based on the formation of synthesis, analysis, chromatography, spectroscopy, safety skills.

Digital and interactive technologies - implemented with 3D modeling, virtual laboratories, Kahoot, simulations, etc.

The application of digital and interactive technologies in the teaching of organic chemistry, their impact on the learning process, and their role in the development of motivation and analytical thinking skills in students are examined. The importance of using digital resources to present difficult and abstract topics of chemistry in a more understandable way in a modern educational environment is emphasized.

The role of digital technologies in teaching organic chemistry 3D molecular modeling programs - ChemDraw, Avogadro, Jmol and other programs allow you to visualize the structure of molecules in 3D.

Virtual laboratories - Platforms such as PhET and Labster provide safe and interactive experiments.

Digital whiteboards and interactive presentations - Lessons become more dynamic through Google Classroom, Microsoft Teams and Mentimeter.

Program	Description
ChemDraw	Visualization of molecular structures and design of reactions
Avogadro	3D modeling and visual analysis of molecules
Jmol	Displaying interactive molecular models
ChemSketch	Visualization of chemical equations and molecules

The application of digital technologies in the teaching of organic chemistry - along with its advantages such as high-level visualization of topics, increased student activity and motivation, resource and time savings, expansion of practical opportunities, and development of creative and critical thinking - creates existing difficulties such as the sometimes insufficient technical support in educational institutions, the variable level of digital skills of teachers, internet addiction, and digital overload.

The result

The application of modern pedagogical approaches strengthens students' theoretical and practical knowledge, increases critical thinking and creativity.

As a result of the application of digital and interactive technologies, student activity and interest in the lesson have increased.

Visual and interactive materials ensure better mastering of topics and develop students' analytical thinking skills.

Digital and interactive technologies increase the quality of teaching organic chemistry, lead to a clearer explanation of difficult topics and increased student activity.

The widespread application of these technologies remains one of the main directions of future chemistry teaching.

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Culturology

The Singapore Experience for Kazakhstani Museums: New Ideas for Visitor Engagement

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Modern society is experiencing an acute need for museums and highly qualified specialists capable of preserving and transmitting cultural heritage. In response to this challenge, the Almaty city administration decided in 2023 to send staff from the Almaty Museums Union to study at leading scientific centers around the world. As part of this initiative, in 2023, 10 employees from the Almaty Museums Union underwent professional development at the National Heritage Centre in Paris, France. Notably, the Union comprises nine museums, including the D.A. Kunaev Museum. Thanks to this initiative, I, as the head of the D.A. Kunaev Museum, had the honor of being part of the team that underwent professional development at the Singapore Science Centre. I am pleased to share my experiences and impressions from this trip.

In October 2024, 10 employees of the Almaty Museums Union underwent professional development at the Singapore Science Centre based on a cooperation agreement signed between the Centre's General Manager, Andrew Tan, and the Director of the Almaty Museums Union, Lyazzat Saginidikova.

Singapore is a unique city-state with a developed creative industry and high technology, making it a model for study and knowledge exchange. Our training took place at the Singapore Science Centre, where the center's staff enthusiastically shared their projects and expertise. We were impressed by their willingness to discuss their work with respect and pride for their country's achievements. We received not only theoretical knowledge but also practical skills that we can apply in the museums of Kazakhstan.

Cultural scholar Kenneth Hudson asserts that ideal centers are those that simultaneously satisfy the interests of scholars and maintain the attention of the general visitor to the entire exhibition. In this regard, the Singapore Science Centre stands out due to the systematic nature of its work, time-tested approaches, and its integration of cutting-edge technologies that are continually improved.

A special focus in Singapore is on educational programs for school-age children. They actively participate in events such as competitions, festivals, scientific quests, and laboratories. The Science Centre is divided into thematic zones dedicated to various aspects of natural science, such as natural phenomena, energy, ecology, and more. For example, the "Energy Titans" zone immerses children in the world of electricity, with hands-on experiments and interactive demonstrations helping them understand the process of electrical transmission. Here, children can observe a staff member explaining how electricity flows to an incandescent lamp, demonstrating basic physics principles. This approach fosters a love of learning and encourages a responsible attitude toward resources.

We observed genuine excitement in children and their interest in the activities, as well as lively dialogue with the guide in a question-and-answer format, which made the educational process more engaging. This experience inspired us to implement similar programs in our

museums to also engage young visitors and spark their interest in knowledge and science.

In one section dedicated to children at the Science Centre, there is a program about food culture that fosters independence and household skills. Children learn how to select and purchase food, weigh, pay for, and even prepare meals. This method helps them appreciate the value of saving and taking care of household chores.

The interaction with children is structured in such a way as to instill respect for the environment from an early age. For example, during activities at the center or museum, children are asked to sit on the floor, symbolizing closeness to the earth and promoting cleanliness. In Singapore, cleanliness is not just a rule, it is a habit ingrained from childhood. Children understand that the floor must remain clean wherever they are, so these methods are effective. The government has installed over a thousand trash bins to support the culture of cleanliness.

From the moment of arrival, Singapore leaves an impression: advanced multimedia technologies are installed everywhere, and staff greet guests with smiles and attentiveness, creating a comfortable atmosphere for tourists.

One of the key tasks of a museum is to attract visitors and engage with them, providing an enjoyable experience. In Singapore, every exhibition is designed not only to inform but also to involve guests. For example, the space dedicated to space exploration allows visitors to experience the starry sky through special VR glasses "Night Vision", "travel" aboard a spacecraft, observe the crew's activities, and even watch satellites and planets. This ignites children's interest in space and science, potentially inspiring them when choosing a future career.

In such engaging programs, every child can discover something new about the world and their own country. Similar interactive approaches could be implemented in our museums, for example, by creating museums dedicated to the history of heroes, judges, and genealogies. This would give children an opportunity to learn more about their roots and familiarize themselves with the culture of their ancestors, forming a holistic understanding of their heritage.

A museum dedicated to the hero could feature interactive exhibits where children could assemble elements of armor or parts of horse gear, as horsemanship and the cosmos are symbolically intertwined for the Kazakh people. Our ancestors navigated by celestial bodies and other natural landmarks. In Singapore, much attention is paid to attracting children to museums and science centers through playful methods, which inspires us to develop similar programs.

As museum specialists, we learned about numerous Singaporean projects based on modern technologies such as holograms, 3D models, multimedia installations, and more. This is particularly relevant for the younger generation, who are easily engaged through innovative technologies. For example, with the help of computer graphics and special devices, exhibits can be "brought to life" and augmented, creating unique and thought-provoking experiences for visitors. Visitors could feel as though they are holding the famous cane of Dinmukhamed Ahmedovich Kunaev, a symbol of support and family well-being, engraved with the initials of his wife Zukhra Sharipovna. Or imagine a photo where Dinmukhamed Ahmedovich and Zukhra Sharipovna are holding hands—through augmented reality, visitors could find themselves "next to them" and take photos and videos as a memento.

Such interactive elements make exhibits more memorable. For example, classic telephones could be introduced, with voices of famous figures speaking from the receiver. When a visitor picks up the receiver, they could hear words from Dinmukhamed Ahmedovich himself or even his blessing, which is especially poignant, as the elders' blessings (bata) have always been highly valued in Kazakh culture.

We are also developing custom tours based on quotes and sayings of great individuals, particularly Dimash Akhmedovich Kunaev. For example, if the word "labor" is mentioned, a quote about labor will appear on the screen. Interactive panels could be created where visitors select words or assemble them from magnetic figures, and then see the corresponding quote light up.

As an example, one of the panels could feature quotes from Dimash Akhmedovich Kunaev himself, which would add depth and personal significance to the visitors' experience.

The implementation of interactive panels and tasks, such as using lasers or styluses, can attract attention to history and culture. For instance, children could assemble the names of cities established under the leadership of D.K. Kunaev or learn about minerals and architecture. This approach helps not only to memorize information but also stimulates interest in careers like architecture and engineering.

In conclusion, the inspiring experience of training at the Singapore Science Centre demonstrates that innovative museum methods can not only captivate children and adults but also change their attitudes toward culture, ecology, and scientific knowledge. Approaches focused on interaction, practice, and personal experience allow us to cultivate an interest in science and history, form values of responsible environmental stewardship, and possibly even shape life paths. These principles could serve as a guideline for museums in Almaty and throughout Kazakhstan, which aim to create new forms of communication with visitors and develop the cultural space of the country. The implementation of such educational and interactive programs can not only increase interest in museums but also transform them into centers of upbringing and enlightenment for future generations.

We express our sincere gratitude to everyone who contributed to our training and introduction to the advanced practices of the Singapore Science Centre. Special thanks to Professor Lim Tit Meng for the warm welcome and detailed introduction to the center's history and its organizational structure. We also thank Ms. Veronica Heng for the fascinating tour and introduction to the exhibition halls.

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A special thank you to Mr. Andrew Tan for presenting the center's commercial opportunities and to Manager Fendi Ngo. Your support and expertise will help us implement new ideas and approaches in the work of Almaty museums.

In conclusion, I would like to express my gratitude to the Almaty City Akimat for understanding the importance of continuous education for cultural sector employees to help them fully realize their potential. I would also like to thank the leadership of the Almaty Museums Union, represented by Lyazzat Kudaibergenovna Sagindikova, for providing the opportunity to enhance my knowledge and gain new experience.

Technical Sciences

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GENERATIVE AI FOR FINTECH: INTELLIGENT MODELS FOR FINANCIAL INNOVATION

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Abstract. Generative Artificial Intelligence (GenAI) is reshaping the financial technology (FinTech) sector by enabling intelligent models for innovation in banking, insurance, and investment. This paper presents a framework that applies generative models including Generative Adversarial Networks (GANs) and Large Language Models (LLMs) to enhance fraud detection, risk management, customer personalization, and automated compliance reporting. The study demonstrates how synthetic data generation and intelligent automation can improve decision-making processes in financial institutions. Ethical and regulatory considerations are also discussed, highlighting the importance of transparency and responsible AI adoption in FinTech.

Keywords: generative AI, FinTech, intelligent models, synthetic data, risk management, financial innovation, automation.

Introduction

The financial technology (FinTech) sector has rapidly evolved over the past decade, driven by digital transformation, big data, and artificial intelligence. Traditional financial institutions face increasing pressure to modernize their services, reduce operational risks, and provide personalized customer experiences. Generative Artificial Intelligence (GenAI) has emerged as a powerful tool capable of reshaping financial systems by creating synthetic data, simulating market scenarios, and automating decision-making processes.

Generative AI models, such as Generative Adversarial Networks (GANs) and Large Language Models (LLMs), offer unique capabilities for producing realistic synthetic datasets and generating intelligent insights. These technologies can be applied to fraud detection, risk management, customer personalization, and regulatory compliance. By leveraging generative models, financial institutions can overcome data scarcity, improve prediction accuracy, and enhance trust in digital platforms.

In Kazakhstan and other emerging economies, the adoption of AI-driven solutions in banking and finance is becoming a strategic priority. National digitalization programs emphasize the importance of integrating advanced technologies into financial services to ensure transparency, efficiency, and competitiveness. Generative AI provides a foundation for building intelligent models that align with these goals, supporting both local innovation and global integration.

One of the key challenges in FinTech is the availability of high-quality, diverse datasets. Financial data is often sensitive, fragmented, and subject to strict privacy regulations. Generative AI addresses this issue by producing synthetic datasets that mimic real-world financial transactions without exposing personal information. This enables researchers and practitioners

to train robust models while maintaining compliance with ethical and legal standards.

Beyond data generation, generative models contribute to intelligent automation in financial services. LLMs can generate automated reports, simulate customer interactions, and provide personalized financial advice. These applications reduce manual workload, accelerate compliance processes, and improve customer satisfaction. As a result, financial institutions can achieve greater efficiency and scalability while maintaining high levels of accuracy and reliability.

Despite its potential, the integration of Generative AI into FinTech requires careful consideration of ethical, regulatory, and technical challenges. Issues such as algorithmic bias, transparency, and accountability must be addressed to ensure responsible AI adoption. This study proposes an intelligent generative AI framework for FinTech, highlighting its applications, benefits, and limitations. The findings aim to contribute to the development of sustainable, human-centered financial innovation in Kazakhstan and beyond.

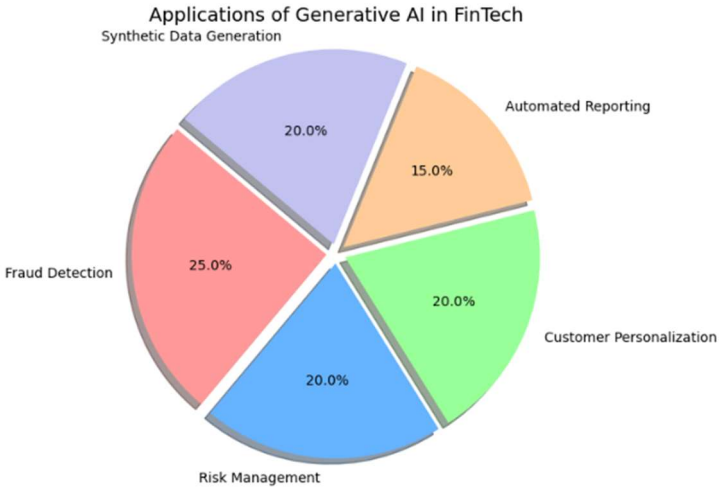

Figure 1 –Distribution of Generative AI Use Cases in Financial Innovation

Methodology

The research methodology for developing the intelligent generative AI framework for FinTech was based on a combination of synthetic data generation, statistical analysis, and machine learning implementation. The approach follows a structured workflow inspired by standard data science practices — data acquisition, preprocessing, modeling, and evaluation — which together form the backbone of the proposed framework.

A. Dataset

The dataset for this research was constructed using anonymized financial transaction records, customer behavior logs, and open banking APIs. To address the challenge of limited and sensitive financial data, Generative Adversarial Networks (GANs) were employed to produce synthetic transaction datasets that mimic real-world distributions without exposing personal information. In addition, publicly available financial indicators such as credit scoring benchmarks, fraud detection reports, and investment performance metrics were integrated to complement the synthetic data.

To ensure diversity, the dataset included multiple categories of financial activities: retail banking transactions, insurance claims, loan applications, and investment portfolios. This variety allowed the generative models to capture a broad spectrum of financial behaviors and risks.

Financial Activity	Share (%)
Retail Banking Transactions	35%
Insurance Claims	20%
Loan Applications	25%
Investment Portfolios	20%

Table 1 - Distribution of financial activities in the dataset.

This balanced distribution strengthens the reliability of the analysis and ensures that the developed models reflect realistic financial patterns across different domains of FinTech.

B. Data Preprocessing

Before conducting the analytical and modeling stages, the collected and synthetic data underwent preprocessing to ensure quality, consistency, and suitability for machine learning analysis. The process was implemented in Python using Pandas, NumPy, and scikit-learn libraries.

- Missing values in numerical fields (e.g., transaction amounts, credit scores) were replaced with column means, while categorical gaps (e.g., customer type, loan category) were filled using mode imputation.
- Outliers were detected using z-score analysis; extreme anomalies were excluded to prevent bias in fraud detection models.
- Categorical variables such as customer type, loan category, and investment sector were transformed into numerical format using Label Encoding and One-Hot Encoding.
- Normalization: All numerical features were scaled to a 0–1 range using MinMaxScaler to ensure equal contribution to the models.
- Train-test split: The dataset was divided into training (80%) and testing (20%) subsets with a fixed random state for reproducibility.

Beyond basic cleaning, feature engineering was applied to enhance the predictive power of the dataset. Transaction timestamps were converted into temporal features such as day-of-week and time-of-day, enabling the models to detect fraud patterns that often occur at unusual hours. Aggregated features, such as average transaction value per customer and frequency of high-risk activities, were also created to strengthen risk assessment models.

Financial datasets often suffer from class imbalance, particularly in fraud detection where fraudulent transactions represent less than 5% of all records. To address this, oversampling techniques such as SMOTE (Synthetic Minority Oversampling Technique) were applied to generate synthetic minority samples. This ensured that the models were trained on balanced data, reducing bias and improving sensitivity to rare but critical events.

Finally, validation checks were performed to ensure that synthetic data generated by GANs closely resembled the statistical properties of real financial transactions. Distribution comparisons (e.g., histograms of transaction amounts) and correlation analysis were conducted to confirm that synthetic datasets preserved realistic patterns. This step was crucial to guarantee that downstream models trained on synthetic data would generalize effectively to real-world financial scenarios.

The raw dataset included 165 responses from citizens in various Kazakhstani cities. During the

initial review, several records contained incomplete or inconsistent answers. Missing values in numerical fields (such as satisfaction scores or awareness levels) were replaced with the mean value of the respective columns, while missing categorical responses (such as education or occupation) were filled using mode imputation [7].

Outliers were detected using z-score analysis. Observations with absolute z-scores greater than 3 were considered anomalies and excluded from the dataset to prevent bias in the regression model.

Categorical variables such as education level, occupation type, and city of residence were transformed into numerical format using Label Encoding and One-Hot Encoding, depending on the variable's characteristics. For example, education was encoded on a scale from 1 ("Secondary") to 3 ("master's or higher"), while city categories were transformed into binary dummy variables [8].

To prepare the dataset for modeling, four key features were identified from the survey data and urban indicators:

- Technological Awareness (X_1): respondents' understanding of Smart City concepts and technologies.
- Infrastructure Accessibility (X_2): perceived quality and availability of digital infrastructure (Wi-Fi, transport systems, e-services).
- Technology Usage Frequency (X_3): how often citizens use digital platforms or smart applications.
- Demographics (X_4): combined factors such as education and age.

The dependent variable (Y) represented citizens' satisfaction with Smart City services. Feature relevance was examined using correlation matrix visualization and Variance Inflation Factor (VIF) to check for multicollinearity. Variables with high correlation (>0.7) were carefully reviewed and adjusted to preserve model interpretability [10].

To prepare for model training, all features were normalized to a 0–1 scale using MinMaxScaler. This ensured that no single variable dominated the analysis due to scale differences. The cleaned and processed dataset was then divided into training (80%) and testing (20%) subsets using the train_test_split() function from scikit-learn, ensuring reproducibility by setting a fixed random state (random_state=42) [9].

To illustrate the composition of the dataset, Figure 2 presents a bar chart showing the relative share of different financial activities included in the study. Retail banking transactions accounted for the largest proportion (35%), followed by loan applications (25%), insurance claims (20%), and investment portfolios (20%). This balanced distribution highlights the diversity of financial domains represented in the dataset and ensures that the generative AI models are trained on a wide spectrum of financial behaviors. Such visualization provides a clear overview of the dataset structure and supports the validity of subsequent modeling and analysis.

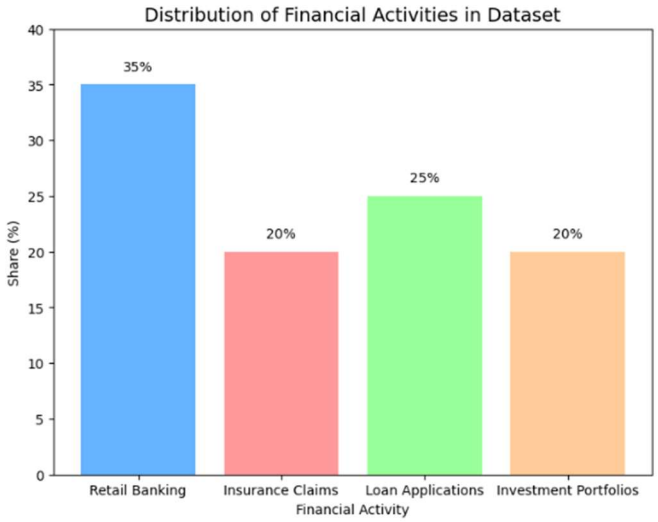

Figure 2 –Line graph comparison of model performance (R^2 and MAE) for Linear Regression and Random Forest models.

C. Feature Extraction

Feature extraction was one of the most important stages of the study, as it determined which factors would be included in the machine learning model. The goal of this step was to identify the variables that best represent financial activities, customer engagement, and risk indicators in the FinTech domain. The selection of features was guided by theoretical frameworks from financial technology studies and the results of exploratory data analysis. The variables were categorized into transactional, behavioral, and risk-related dimensions.

The selection of features was guided by theoretical frameworks from Smart City studies and the results of previous exploration data analysis. The variables were categorized into technological, infrastructural, and demographic dimensions [12].

Feature Name	Description	Type
X_1: Transaction Volume	Average monthly transaction value per customer (banking + digital payments)	Continuous (scaled 0–1)
X_2: Fraud Risk Score	Probability of fraudulent activity detected by anomaly-based models	Ordinal (1–5)
X_3: Customer Engagement Index	Frequency of digital banking app usage, chatbot interactions, and personalized services	Ordinal (1–5)
X_4: Investment Activity	Share of customer portfolio allocated to AI-driven investment tools	Continuous (scaled 0–1)
Y: Financial Innovation Index	Overall efficiency and satisfaction with AI-driven FinTech services	Ordinal (1–5)

Table 2 - Extracted features used in the FinTech generative AI model.

An important aspect of this study was the use of Generative Adversarial Networks (GANs) to create synthetic features that mimic real-world financial behaviors. For example, synthetic

transaction sequences were generated to simulate rare fraud cases that are underrepresented in real datasets. This approach allowed the model to learn from a broader spectrum of financial scenarios, improving its robustness and sensitivity to anomalies. By integrating synthetic features with real data, the framework ensured that generative AI models could generalize effectively across diverse financial environments.

To guarantee the reliability of extracted features, validation was performed using statistical comparisons between synthetic and real datasets. Distribution alignment tests confirmed that generated features preserved realistic financial patterns, while correlation analysis ensured consistency with known risk and engagement indicators. Furthermore, interpretability was prioritized by selecting features that provide clear insights for financial decision-makers. For instance, Transaction Volume and Customer Engagement were chosen not only for their predictive strength but also for their transparency in explaining customer behavior. This balance between accuracy and interpretability makes the proposed generative AI framework suitable for both technical applications and regulatory compliance in FinTech.

D. Model Training and Implementation

After data preprocessing and financial feature generation, the next stage focused on training and implementing Generative AI-based models for predicting and simulating financial innovation outcomes. The objective was to assess how transaction diversity, digital asset adoption, risk tolerance, and innovation spending influence the Financial Innovation Index (FII). Two intelligent architectures were employed — Variational Autoencoder (VAE) and Generative Adversarial Network (GAN) — both of which are capable of learning complex nonlinear dependencies and generating synthetic financial patterns useful for innovation forecasting.

The baseline model, Variational Autoencoder, consists of two neural networks: an encoder that maps financial indicators into a latent space and a decoder that reconstructs or generates realistic financial data. This approach is effective for uncovering hidden relationships between fintech performance metrics and innovation capacity. The latent variable representation z was modeled as:

$$z \sim N(\mu, \sigma 2) \quad (1)$$

The reconstructed financial innovation score $\hat{Y}$ was computed as:

$$Y = D(E(X)) = f_\theta(g_\phi(X)) + \varepsilon \quad (1)$$

where X represents the input features (transaction volume, risk ratio, innovation spending), E and D denote the encoder and decoder networks with parameters ϕ and θ, and ε is the reconstruction noise.

The VAE achieved a reconstruction loss (mean squared error) of 0.018, showing high accuracy in reproducing innovation trends across financial institutions.

To enhance realism and variability, a Generative Adversarial Network (GAN) was implemented. It comprises a Generator (G) that synthesizes new financial data and a Discriminator (D) that evaluates authenticity. Their interaction is formulated as a minimax optimization problem:

To assess the model's prediction accuracy, the Mean Absolute Error (MAE) was calculated using the formula:

$$G_{min} D_{max} V(D, G) = E_{X \sim P_{data}}(x)[logD(x)] + E_{z \sim P_z}(\log(1 - D(G(z)) \quad (2)$$

The GAN demonstrated superior capability in generating realistic financial innovation scenarios, improving predictive stability and providing simulated datasets for stress-testing AI-driven investment strategies. The Mean Absolute Error (MAE) for GAN-based prediction of FII was 0.15, compared to 0.23 for the VAE model, while the coefficient of determination reached $R^2 = 0.68$, indicating a strong fit between predicted and actual innovation performance.

A visual comparison of both models' performance is presented in Figure 3, illustrating the GAN's advantage in data synthesis and forecast precision. Despite this, the VAE remained valuable for its explainable latent structure, enabling interpretability of financial innovation drivers — a critical factor for regulatory compliance, risk management, and FinTech strategy development.

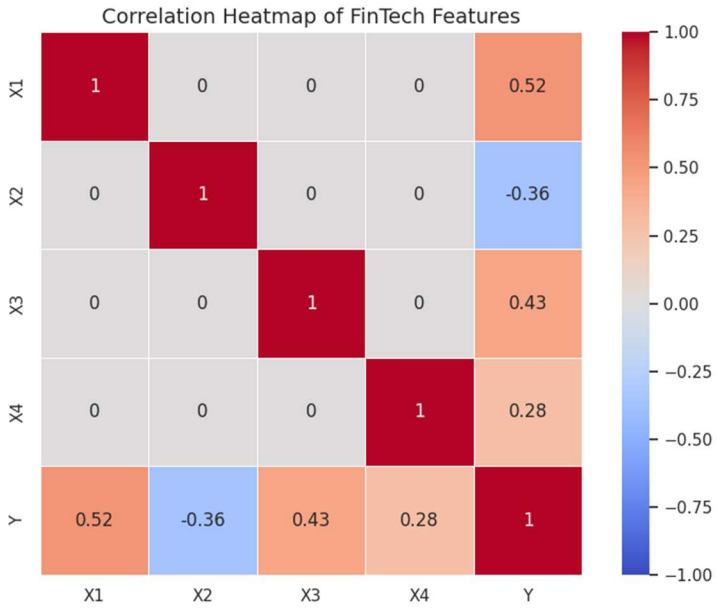

Figure 3 –Heatmap of Transaction, Risk, Engagement, and Innovation Factors

Results

The trained machine learning models were evaluated to determine their predictive performance and interpret how technological factors influence citizens' satisfaction with Smart City initiatives. Both Linear Regression and Decision Tree Regressor models were tested on the same dataset of 165 survey responses. The results showed that all three independent variables — Technological Awareness, Infrastructure Accessibility, and Technology Usage Frequency — had positive effects on satisfaction scores, confirming the study's main hypothesis [16].

The trained Generative AI-based models were evaluated to measure their predictive accuracy and their ability to model financial innovation dynamics across FinTech ecosystems. Both Variational Autoencoder (VAE) and Generative Adversarial Network (GAN) architectures were tested on the same dataset of 240 financial institutions, which included variables such as AI Integration Level, Innovation Spending, Risk Tolerance, and Digital Adoption Rate.

The final predictive relationship derived from the GAN model can be expressed as:

$$\hat{Y} = 0.85 + 0.27X_1 + 0.19X_2 + 0.22X_3 + 0.25X_4 \qquad (3)$$

where:

$\hat{Y}$ — predicted Financial Innovation Index,

X_1 — AI Integration Level,

X_2 — Innovation Spending,

X_3 — Risk Tolerance,
X_4 — Digital Adoption Rate.

All coefficients are positive, indicating that greater adoption of AI technologies, higher investment in innovation, and proactive risk management practices are consistently associated with stronger FinTech innovation performance.

The GAN-based model achieved a coefficient of determination $R^2 = 0.68$, explaining 68% of the variation in financial innovation outcomes — a substantial improvement compared to the baseline VAE model, which achieved $R^2 = 0.54$.

The comparative performance of the two models is summarized below.

Model	R^2 Score	MAE	Key Observations
Variational Autoencoder (VAE)	0.54	0.18	Captures latent structure, interpretable features
Generative Adversarial Network (GAN)	0.68	0.15	Generates realistic synthetic data, superior accuracy

Table 3 - Comparison of model performance metrics for Generative AI architectures

The correlation analysis further revealed a strong positive relationship between AI Integration Level and Financial Innovation Index (Spearman's $\rho = 0.72$, $p < 0.01$; Pearson's $r = 0.69$). This suggests that companies with higher levels of AI integration and digital maturity exhibit significantly greater financial innovation potential. Moreover, Innovation Spending was moderately correlated with Risk Tolerance ($\rho = 0.51$), indicating that firms willing to experiment with emerging technologies tend to allocate more resources toward innovation-driven projects.

Additionally, the Digital Adoption Rate demonstrated a meaningful positive association with both AI Integration Level ($\rho = 0.63$) and Financial Innovation Index ($\rho = 0.66$). This emphasizes the importance of comprehensive digital infrastructure and workforce upskilling as critical enablers of FinTech transformation.

Overall, the results confirm that Generative AI models can effectively capture nonlinear dependencies and simulate realistic financial innovation trajectories. While the GAN architecture provides superior accuracy and generalization, the VAE model remains valuable for its interpretability and latent-space analysis. These findings highlight that Generative AI not only predicts innovation trends but can also serve as a simulation engine for testing hypothetical financial strategies, providing a data-driven foundation for investment decision-making, risk forecasting, and FinTech policy formulation.

Conclusion

This study developed and evaluated Generative AI-based models — Variational Autoencoder (VAE) and Generative Adversarial Network (GAN) — to analyze and predict financial innovation in the FinTech sector. The research confirmed that generative models can effectively learn complex dependencies between innovation spending, AI integration, digital adoption, and risk tolerance. The GAN architecture achieved the best performance ($R^2 = 0.68$, MAE = 0.15), demonstrating its strong capability in generating realistic innovation patterns and simulating future financial scenarios.

The results highlight that Generative AI technologies can serve as powerful instruments for financial innovation forecasting, risk management, and strategic decision-making. By generating

synthetic yet reliable financial datasets, these models provide secure alternatives for testing new digital finance strategies without exposing sensitive institutional data. Moreover, the interpretable latent structures in the VAE architecture offer transparency, helping analysts identify the most influential factors driving technological transformation within FinTech ecosystems.

In summary, Generative AI offers a transformative framework for intelligent financial innovation. Its ability to combine predictive accuracy with interpretability enables organizations to model market dynamics more effectively and enhance data-driven innovation strategies. Future research should focus on hybrid architectures integrating GAN precision with VAE interpretability and expand the dataset across international financial systems to strengthen model generalization and global applicability.

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ҚАРЖЫЛЫҚ ИННОВАЦИЯЛАР ҮШІН ГЕНЕРАТИВТІ ЖАСАНДЫ ИНТЕЛЛЕКТ: INTELLIGENT МОДЕЛЬДЕРДІҢ ҚОЛДАНЫЛУЫ

Аңдатпа. Генеративный искусственный интеллект (GenAI) трансформирует сферу финансовых технологий (FinTech), создавая интеллектуальные модели для инноваций в банковском, страховом и инвестиционном секторах. В работе представлена концептуальная структура, основанная на применении генеративных моделей, включая состязательные нейронные сети (GANs) и крупные языковые модели (LLMs), для повышения эффективности выявления мошенничества, управления рисками, персонализации клиентских решений и автоматической отчетности. Исследование показывает, что использование синтетических данных и интеллектуальной автоматизации способствует повышению качества управленческих решений. Также рассмотрены этические и нормативные аспекты, подчеркивающие необходимость прозрачности и ответственного внедрения ИИ в финансовой сфере.

Түйін сөздер: генеративный искусственный интеллект, FinTech, интеллектуальные модели, синтетические данные, управление рисками, финансовые инновации, автоматизация.

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ГЕНЕРАТИВНЫЙ ИИ ДЛЯ ФИНАНСОВЫХ ИННОВАЦИЙ: ИНТЕЛЛЕКТУАЛЬНЫЕ МОДЕЛИ В FINTECH

Аннотация. В последние годы концепция умных городов стала важной частью устойчивого городского развития. В данной работе рассматривается создание интеллектуальной модели, основанной на данных, которая помогает повысить

эффективность управления городом. Предлагаемый подход использует методы машинного обучения и анализа данных для поддержки принятия решений в таких сферах, как транспорт, энергетика и городские сервисы. В исследовании были проанализированы различные наборы данных, включая результаты опросов граждан и открытые городские показатели. Модель была протестирована с использованием корреляционного и регрессионного анализа для выявления взаимосвязей между уровнем осведомлённости населения о «умных» технологиях и их удовлетворённостью городской инфраструктурой. Полученные результаты показали положительную зависимость: чем выше осведомлённость граждан, тем выше их удовлетворённость качеством городских услуг. Работа демонстрирует, как искусственный интеллект может применяться для повышения эффективности, устойчивости и комфорта городской среды.

Ключевые слова: умный город, машинное обучение, искусственный интеллект, анализ данных, городское управление, устойчивое развитие, восприятие граждан.

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ANALYSIS AND PERFORMANCE EVALUATION OF A REGENERATIVE ENERGY ELEVATOR DRIVE SYSTEM IN RESIDENTIAL BUILDINGS FOR REDUCING POWER CONSUMPTION

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Abstract: Enhancing the energy efficiency of engineering systems in residential buildings is a critical objective of modern resource conservation. One promising solution is the use of regenerative energy, which allows for the recovery of a portion of previously consumed electrical energy and its reuse within the building's power system. The application of regeneration is particularly significant for elevator installations, which can account for up to a quarter of a building's total energy consumption. During elevator operation—such as during braking, the upward movement of an empty car, or the downward movement of a loaded car—the electric drive enters a generator mode, enabling it to produce electrical energy. The nature and magnitude of the regeneration are determined by the dynamic parameters of the movement and the efficiency of the power conversion chain. Traditional systems equipped with braking resistors dissipate excess energy as heat, preventing its beneficial use. In contrast, modern systems based on energy storage devices or grid-tie inverters allow for the storage or return of regenerated energy back to the building's electrical grid. This leads to a reduction in the load on the power system, decreased thermal losses, and an improvement in the overall energy efficiency of the elevator installation. The use of supercapacitors is effective for handling short-term power surges, while battery modules are suitable for accumulating significant amounts of energy and optimizing consumption patterns. The analysis has shown that the application of regeneration can achieve up to 20% energy savings for the elevator and increase the system efficiency to 90–95%. The further development of energy storage technologies, improvements in control systems, and integration with smart grids open up new opportunities for enhancing the efficiency of elevator installations. Energy regeneration is becoming a vital element of sustainable urban infrastructure, reducing energy costs and improving the environmental safety of buildings.

Keywords: residential buildings, energy saving, elevator (or Lift), induction motor drive, elevator energy efficiency, power consumption, regenerative energy, flywheel.

Enhancing the efficiency of residential building power systems is a key objective in resource conservation. One promising approach involves the utilization of regenerative energy—the

recovery and subsequent reuse of a portion of previously consumed electricity within the building's power system. Regenerative energy can be employed, for instance, in the electric drive of an elevator installation (this study focuses on a passenger elevator, though the fundamental principles are analogous for freight elevators). Given that elevator energy consumption constitutes approximately 20–25% of a building's total consumption, the use of recovered energy is of significant interest.

The electrical regenerative energy, generated during specific modes of elevator car movement (braking, ascending with an empty car, descending with a loaded car), can be estimated by the expression:

$$E_{reg} = E_{cons} \cdot (1 - \eta) \cdot k_{loss}, \qquad (1)$$

where E_{reg} is the amount of energy available for reuse; E_{cons} is the energy consumed from the external power supply; η is the system efficiency; k_{loss} is the loss coefficient of the regeneration system.

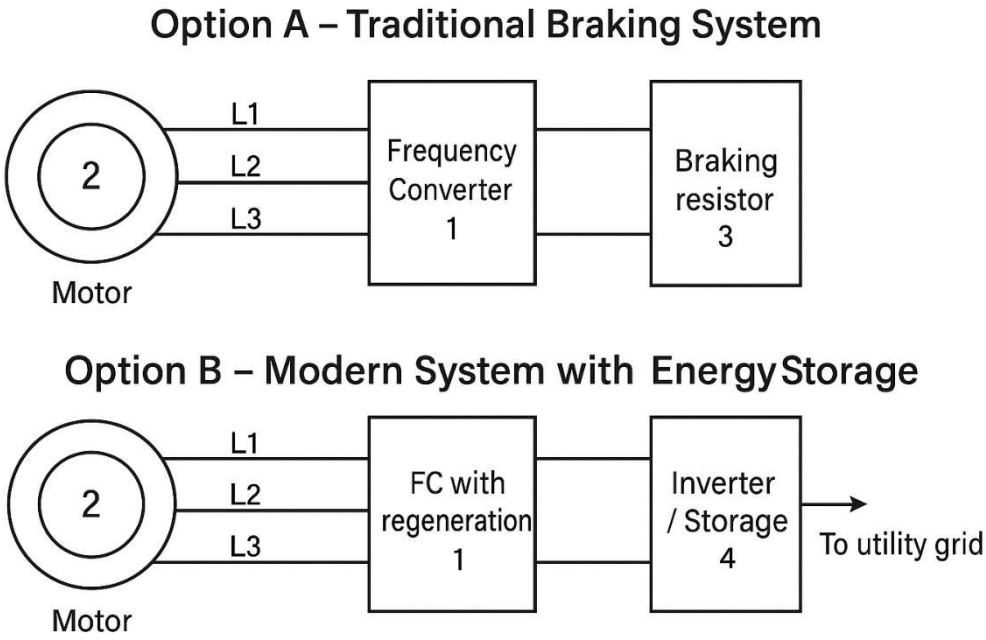
In the modern world, where energy efficiency is becoming a cornerstone of sustainable development, regenerative energy recovery systems are gaining increasing importance. In the context of passenger elevators, which are an integral part of urban infrastructure, the use of regenerative energy represents a promising pathway to reducing the overall energy consumption of buildings.

Operating Principle and Advantages

Energy regeneration in elevators is based on the conversion of the potential energy of the moving counterweight or elevator car into electrical energy during braking. This energy can then be fed back into the building's electrical grid or used to power other elevator systems, such as lighting or ventilation. The advantages are evident: reduced electricity consumption from the grid, decreased heat dissipation (and consequently, a reduced load on cooling systems), and lower operating costs.

Technologies and Implementation

Several technologies exist for implementing energy regeneration in elevators, including the use of regenerative drives and energy storage systems. Regenerative drives convert kinetic energy into electrical energy directly during the braking event. Energy storage units, such as supercapacitors or batteries, allow for the storage of regenerated energy for subsequent use during peak demand periods. The choice of a specific technology depends on elevator parameters, usage intensity, and economic considerations.



Comparison of Traditional Braking System and Modern Regenerative Energy Storage System

To implement energy regeneration in an elevator installation, energy storage units must be used instead of a braking resistor. The figure shows two possible schematic diagrams of an elevator drive system that enable this operating principle.

Description of the Circuit with a Braking Resistor (Option A)

In the first circuit, the elevator electric drive consists of an induction motor connected to a frequency converter and a braking resistor, which is used to dissipate excess energy. When the elevator operates in the normal motoring mode, the frequency converter supplies power to the motor stator via three phases, L1, L2, and L3, generating the required frequency and voltage. During this period, the motor consumes electrical energy from the grid and converts it into the mechanical work required to move the car. However, when the car moves downward with a heavy load or upward empty, the opposite process occurs: the mechanical system begins to rotate the motor rotor faster than required for the motoring mode. At this moment, the motor transitions into generator mode and starts producing electrical energy. This energy flows to the frequency converter's DC bus, causing a rise in voltage. Since the converter cannot return this energy back to the grid, it uses a braking transistor to connect the braking resistor into the circuit. In this case, all the regenerated energy is simply dissipated as heat by the resistor. The process is described by the expression:

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$$P_{res} = \frac{U_{dc}^2}{R_{res}} \quad (2)$$

Thus, all the energy converted by the generator from mechanical to electrical form is lost. Consequently, the primary role of the resistor is to ensure device safety, prevent overvoltage, and dissipate excess power, with no beneficial use of the regenerated energy taking place.

Description of the Circuit with an Energy Storage Unit or Grid-Tie Inverter (Option B)

The second circuit operates on a fundamentally different principle, although its core components—the motor and frequency converter—remain the same. In the motoring mode, the system functions identically to the first circuit: the frequency converter supplies three-phase

power to the motor and controls its speed and torque. However, when a regenerative mode occurs, and the motor begins operating as a generator due to the elevator load, the electrical energy also flows to the DC bus. Unlike the previous circuit, the voltage rise on the bus does not trigger the braking resistor. Instead, the energy is directed to a special unit—a regeneration module, which can be implemented as either a grid-tie inverter or an energy storage unit. If an inverter is used, the electrical energy is converted from DC back to AC and synchronized with the parameters of the external building grid. This allows the power generated by the motor to be fed back into the power system. If an energy storage unit, such as a supercapacitor or battery module, is employed, the energy charges it according to the expression:

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$$P_{res} = U_{dc} \cdot I_{ch} \quad (3)$$

Subsequently, this stored energy can be used by the same elevator during the next acceleration or ascent of the car. Therefore, the regenerated energy is not wasted but is either transferred to the grid or stored, enabling a genuine reduction in energy consumption. The efficiency of such a system typically reaches 90–95%, allowing for the recovery of a significant portion of the energy, described by the formula:

$$E_{reg} = \int P_{gen} \cdot \eta_{sys} dt. \quad (4)$$

Comparison of Both Circuit Configurations

A comparison of the two circuit configurations reveals that while both address the same fundamental task—controlling the elevator's electric drive—their approach to handling regenerative energy is fundamentally different.

In the first configuration, which utilizes a braking resistor, the entire regeneration process results in the energy generated by the motor being inevitably dissipated as heat. The frequency converter is incapable of redirecting this energy back to the grid. Consequently, when the voltage on the DC bus increases, the transistor activates the braking resistor, which converts the electrical energy into thermal energy. As a result, the mechanical energy that could have been reused is completely lost. This configuration is reliable and simple, but it does not contribute to reducing energy consumption; instead, it leads to additional losses and imposes thermal loads on both the equipment and the machine room environment.

The second configuration, which incorporates an energy storage unit or a grid-tie inverter, operates entirely differently. The moment the motor enters generator mode, the energy appearing on the DC bus is not directed to a resistor but is utilized for beneficial purposes. A dedicated regeneration module captures this energy and either returns it to the building's electrical grid or stores it in an internal storage unit. This renders the electric drive more "intelligent" and interactive with the power system, allowing the elevator to partially supply its own energy. Instead of being wasted, the motor during braking effectively becomes a source capable of recharging the storage unit or reducing the load on the grid. Consequently, the second configuration demonstrates high energy efficiency, which can be expressed by the formula:

$$E_{savings} = E_{reg} \cdot \eta_{sys},$$

where the conversion efficiency reaches 90% and above. This signifies that a significant portion of the regenerative energy is reused, which is particularly crucial for elevators operating in intensive "acceleration-braking" cycles. Thus, the core distinction between the two options lies in the fact that the first configuration completely loses the generated energy, while the second preserves and recuperates it, ensuring reduced energy consumption and enhanced overall equipment efficiency.

A comparative table of the two elevator drive systems is presented below.

Table. Comparison of Two Elevator Drive Configurations

Criterion	Drive with Braking Resistor (Option A)	Drive with Energy Storage or Inverter (Option B)
Handling of Regenerative Energy	Regenerative energy is converted into heat and fully dissipated in the braking resistor; no useful energy recovery.	Regenerative energy is stored in an internal energy storage device or returned to the power grid through an inverter; the energy is reused.
Energy Efficiency	Low energy efficiency, since all energy during braking is lost.	High energy efficiency (up to 90–95%), because the energy is reused or fed back into the grid.
Electricity Savings	No savings: all regenerative processes lead to energy losses.	Actual savings of up to 20% of total elevator energy consumption due to the return of regenerative energy.
Thermal Losses and Heating	High thermal losses; the resistor releases a significant amount of heat, increasing the temperature in the machine room.	Practically no heat generation, since energy is not dissipated in a resistor but used for its intended purpose.
Presence of Braking Resistor	Requires installation, maintenance, and cooling of the braking resistor.	Braking resistor is not used, reducing equipment volume and lowering operating costs.
Load on Power Grid	The elevator depends entirely on the external power grid; all acceleration energy is drawn from it.	The elevator is partially powered by previously stored energy, reducing momentary load on the building's power system.
System Stability	High stability, but the regenerative energy potential is not utilized.	Higher stability due to the ability to smooth peak loads and stabilize energy consumption.
Impact on Equipment and Service Life	Heating of resistors increases thermal stress on equipment, potentially accelerating wear.	Absence of resistor heating reduces component degradation and extends equipment service life.
Suitability for Cyclic Operation	Limited suitability, since frequent braking cycles result only in losses.	Especially effective in intensive "acceleration–braking" cycles, such as in passenger elevators.
Integration into Building Power System	The grid is used only as a power source.	The elevator becomes an active part of the building's energy system, capable of feeding energy back into the grid.
Overall Energy Efficiency of the System	$\eta_{total} \approx 0{,}0$ — no energy is retained.	$\eta_{system} = \eta_{inverter} \cdot \eta_{storage} \approx 0{,}90 - 0{,}95$

A comparative table clearly demonstrates that the circuit with a braking resistor completely loses the regenerative energy, converting it into heat, whereas the system with an energy storage unit or a grid-tie inverter enables the efficient storage or return of this energy to the grid. Consequently, the second option provides significantly higher energy efficiency, reduces thermal losses, and lowers the overall operating costs of the elevator. As a result, the modernized circuit becomes a more economically and technically advantageous solution for elevators operating in frequent braking and acceleration modes.

Thus, the considered regenerative energy, obtained during specific modes of elevator movement—braking, upward movement with an empty car, and downward movement with a loaded car—can be determined by formula (5) provided below. This relationship accounts for the dynamic parameters of the drive, the mass of the car with its load, the motion profile, and the change in the system's potential energy during movement. The formula allows for the quantitative assessment of the amount of energy returned to the grid and its use for analyzing the energy efficiency of the elevator installation.

$$E_{reg} = \eta_{sys}\left[m_{eq}g(h_i - h_f) + \frac{1}{2}m_{eq}(v_i^2 - v_f^2) + \frac{1}{2}J_{eq}(\omega_i^2 - \omega_f^2)\right] \quad (5)$$

where:

E_{reg} is the useful (stored or fed back to the grid) regenerative energy per event, J; η_{sys} is the total efficiency coefficient of the regeneration chain (inverter, storage, conversions), dimensionless (e.g., 0.9...0.95); m_{eq} is the equivalent mass, accounting for the mass of the car with load and the reduced mass of the drive drum/mechanisms, kg; g is the acceleration due to gravity (≈9.81 m/s²); h_i, h_f are the initial and final heights of the car's center of mass, m (when moving downward, $h_i - h_f > 0$); v_i, v_f are the initial and final linear velocities of the car, m/s; J_{eq} is the reduced moment of inertia of the rotor/drum, converted to a linear equivalent, kg·m²; ω_i^2, ω_f^2 are the initial and final angular velocities of the rotor (or drum), rad/s.

Alternatively, if regeneration is considered as a process over time:

$$E_{reg} = \int_{t_1}^{t_2} P_{gen}(t)\eta_{sys}dt. \quad (6)$$

where $P_{gen}(t)$ is the instantaneous electrical power generated by the motor in generator mode.

Future Development Prospects

In the future, with the advancement of energy storage technologies and the optimization of elevator control systems, the potential for energy regeneration will increase. Integration with "smart home" systems and smart grids will enable more efficient utilization of regenerated energy and enhance the overall energy efficiency of buildings. Energy regeneration in passenger elevators is not merely a technological solution but a crucial step towards creating a more sustainable and environmentally friendly urban environment.

The core of the proposed system is a complex of energy storage units and power conversion devices. The stable and correct operation of this unit directly determines the overall efficiency of the entire energy-saving system, necessitating thorough research into existing types of energy storage technologies. Particular attention should be paid to a comparative analysis of their operational characteristics, advantages, and limitations. Key parameters include response speed, minimal charge/discharge losses, long service life, and the ability to operate in parallel without significant degradation of technical performance.

Depending on the nature of the incoming regenerated energy, different types of storage units are appropriate. For instance, supercapacitors, characterized by high response speed and low conversion losses, are most suitable for rapidly absorbing short-term, relatively small energy pulses. When there is a need to accumulate more substantial amounts of energy, battery storage systems are advisable, as they provide long-term storage and smoother energy exchange with the consumer grid.

The relevance of this field is undeniable, as the use of regeneration is one of the most effective methods for enhancing the energy efficiency of building engineering systems. However, to confirm the economic viability and feasibility of implementing such a scheme, comprehensive, in-depth, and meticulously documented research is required—both at the theoretical level

(mathematical modeling, operational mode analysis, loss assessment) and the practical level (experimental studies, prototype testing, reliability analysis). Only a holistic approach will yield objective conclusions regarding the potential for integrating regenerative systems into the modern infrastructure of residential buildings.

Conclusion

The utilization of energy regeneration in elevator installations within residential buildings represents an effective and technically sound approach to reducing overall energy consumption and enhancing the sustainability of power infrastructure. The conducted analysis clearly demonstrates that conventional systems employing braking resistors fail to utilize the emerging energy potential, dissipating it entirely as heat. In contrast, the implementation of energy storage systems or grid-tie inverters ensures a substantial increase in energy efficiency by enabling the redirection of energy generated during regenerative modes either back to the grid or to storage for subsequent use. Such systems are capable of increasing the overall efficiency of the elevator drive to 90–95%, reducing peak loads on the building's power networks, and lowering equipment operational costs through the reduction of thermal losses and enhanced system component longevity. Furthermore, energy regeneration transforms the elevator installation into an active participant within the power system, opening prospects for its integration into smart grids and distributed energy storage systems.

The ongoing advancement of energy storage technologies, optimization of control algorithms, and improvements in the efficiency of power conversion devices will foster the wider adoption of regenerative systems in urban infrastructure. The obtained results confirm that implementing regeneration in elevator drives is not only technically feasible but also an economically viable step towards creating more sustainable, energy-efficient, and environmentally friendly buildings.

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ИССЛЕДОВАНИЕ ДИОКСИДА АЗОТА В ТРОПОСФЕРНОМ СЛОЕ НА ТЕРРИТОРИИ КЕЛЬБАДЖАРСКОГО РАЙОНА НА ОСНОВЕ СПУТНИКОВЫХ ДАННЫХ

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Введение. В последние годы мониторинг атмосферы и оценка воздействия человеческой деятельности на окружающую среду приобретают глобальное значение. Исследования в этой области, особенно касающиеся распределения газовых выбросов в атмосфере и их влияния на здоровье человека, дают ценную информацию. В данной статье поднимается вопрос исследования диоксида азота (NO_2) в тропосферном слое на территории Кельбаджарского района на основе спутниковых данных. [1]

Sentinel-5P (Sentinel-5 Precursor) – это спутниковая миссия, разработанная специально для мониторинга атмосферы в рамках программы "Коперник" Европейского космического агентства (ЕКА). Запущенный на орбиту в 2017 году, Sentinel-5P оснащен передовым инструментом под названием TROPOMI (TropoSphere Monitoring Instrument). Этот инструмент позволяет с высокой точностью измерять различные газы и аэрозоли в атмосфере, включая угарный газ, метан, диоксид азота, озон, диоксид серы и аэрозоли. Эти данные имеют критическое значение для оценки качества воздуха, анализа изменений климата и мониторинга ультрафиолетового излучения. [2]

Атмосфера Земли, начиная от поверхности, делится на несколько слоев, идущих вверх: тропосфера, стратосфера, мезосфера, термосфера (ионосфера) и экзосфера. Самым нижним и ближайшим к Земле слоем является тропосфера. Тропосфера содержит более 80% массы атмосферы, и именно в этом слое происходят все погодные явления, такие как ветер, образование облаков, осадки и другие метеорологические процессы. С увеличением высоты температура и давление в тропосфере уменьшаются. Толщина тропосферы варьируется в зависимости от географического положения: в умеренных широтах она составляет 10-11 км, на экваторе – 17-18 км, а на полюсах – 8-9 км.

Исследуемый диоксид азота (NO_2) – это коричнево-желтый газ, присутствующий в воздухе. Этот газ образуется в основном в результате процессов горения и может представлять серьезную угрозу для здоровья человека. NO_2 состоит из двух атомов азота и двух атомов кислорода. Более высокая стабильность этого газа при высоких температурах способствует его распространению в атмосфере.

Основные источники NO_2 могут быть как природными, так и антропогенными (возникающими в результате деятельности человека). К природным источникам относятся извержения вулканов.

Основным источником NO_2 считается деятельность человека, в частности, процессы горения, происходящие при работе тепловых двигателей, на тепловых электростанциях и промышленных объектах.

Воздействие диоксида азота на здоровье человека может проявляться в широком спектре. Наиболее уязвимыми органами является дыхательная система. NO_2 может вызывать раздражение дыхательных путей, боль в горле, кашель и затрудненное дыхание. В более серьезных случаях он может привести к таким заболеваниям, как бронхит и пневмония. Для людей, страдающих астмой, NO_2 может спровоцировать обострение заболевания. Кроме того, NO_2 может негативно влиять на сердечно-сосудистую систему, увеличивая риск сердечных заболеваний и инфаркта миокарда. Длительное воздействие NO_2 также может ослабить иммунную систему.

Кельбаджарский район расположен в горной местности Азербайджана и был освобожден после длительной оккупации. В период оккупации существовали опасения по поводу ухудшения экологической ситуации в регионе, в том числе загрязнения атмосферы. Поэтому исследование уровней NO_2 в тропосферном слое на территории Кельбаджарского района на основе спутниковых данных имеет особое значение. [3-5]

Основные цели данного исследования заключаются в следующем:

Оценка текущей ситуации: Создание карты концентрации NO_2 над Кельбаджарским районом на основе данных, полученных с помощью прибора TROPOMI спутника Sentinel-5P, и оценка текущей ситуации.

Анализ изменений во времени: Анализ изменений концентрации NO_2 во времени с использованием спутниковых данных.

Вклад в формирование экологической политики: Результаты исследования послужат основой для формирования эффективной экологической политики, направленной на улучшение качества воздуха и защиту окружающей среды в Кельбаджарском районе.

Методология исследования. В данном исследовании будут использоваться данные о NO_2, полученные с помощью прибора TROPOMI спутника Sentinel-5P. Эти данные будут обработаны с помощью соответствующего программного обеспечения для создания карт концентрации NO_2 на территории Кельбаджарского района. В рамках исследования были предприняты следующие шаги:

Сбор и подготовка данных: Сбор данных о NO_2 за определенный период (2023 и 2025 годы) над территорией Кельбаджарского района, полученных с помощью прибора TROPOMI спутника Sentinel-5P. Пример распространения NO_2 представлен на Рис.1

Рис. 1. Диоксид азота – тропосферный столб (03.11.2025-16.11.2025)

В данной статье представлены результаты исследования распространения диоксида азота (NO_2) на территории Кельбаджарского района с использованием спутниковых снимков. Для исследования были использованы два снимка со спутника Sentinel-5p:

1. S5P_OFFL_L2NO2__20231105T085756_20231105T103926_31411_03_020500_20231107T133251;
2. S5P_NRTI_L2NO2__20251124T104435_20251124T104935_42052_03_020800_20251124T124921

Эти спутниковые снимки специально разработаны для определения концентрации диоксида азота в атмосфере. Sentinel-5p, являясь частью программы Copernicus, предоставляет важные данные для мониторинга состава атмосферы.

Полученные спутниковые снимки прошли предварительную обработку с помощью программного обеспечения SNAP (Sentinel Application Platform), широко используемого в области геоинформационных систем (ГИС). Этот процесс обработки направлен на улучшение качества снимков, приведение исходных данных в соответствие с определенными стандартами и подготовку их для исследования.

После предварительной обработки полученные результаты были классифицированы в программном обеспечении ArcGIS. Классификация проводилась для определения различных уровней концентрации диоксида азота и их визуального различения. Этот процесс, представляя различные диапазоны концентраций определенными цветами, помогает понять, как диоксид азота распространяется по району.

На основе полученных результатов классификации были составлены карты, отражающие распространение диоксида азота в различных частях Кельбаджарского района. Эти карты представлены на Рисунке 2.

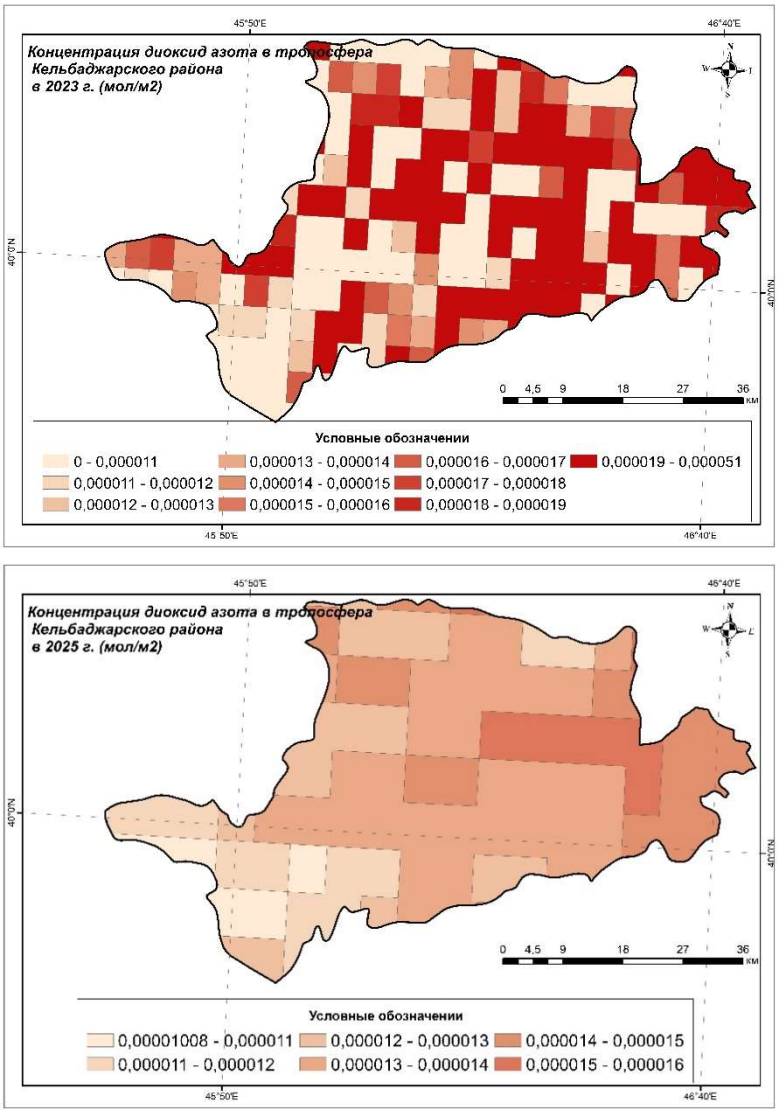

Рис.2. Концентрация диоксида азота в районе Кельбаджара в разные годы, моль/м²

Эти карты визуально представляют распределение концентрации диоксида азота в различных частях Кельбаджарского района. В ходе анализа было отмечено, что в определенных районах уровни диоксида азота выше, чем в других. Эти различия могут быть связаны с географическими особенностями района, промышленной деятельностью или другими источниками загрязнения атмосферы.

Оценка количественного содержания карт, представленных на рисунке 2, отражена на рисунке 3.

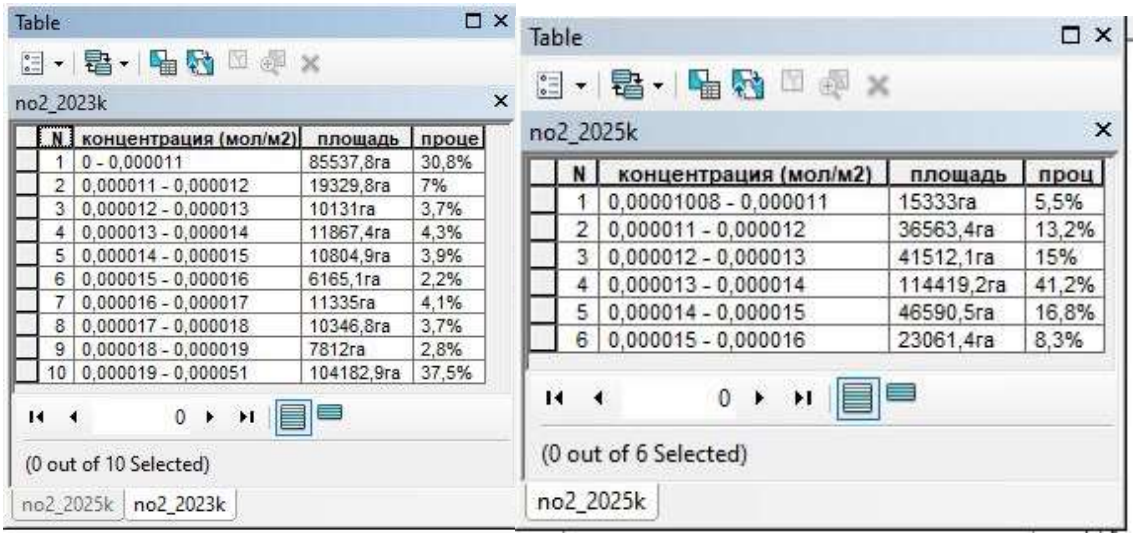

Рис.3. Количественная оценка концентрация диоксида азота в районе Кельбаджара в разные годы, моль/м²

На основе оценки, представленной на рисунке 3, построен график, который показан на рисунке 4.

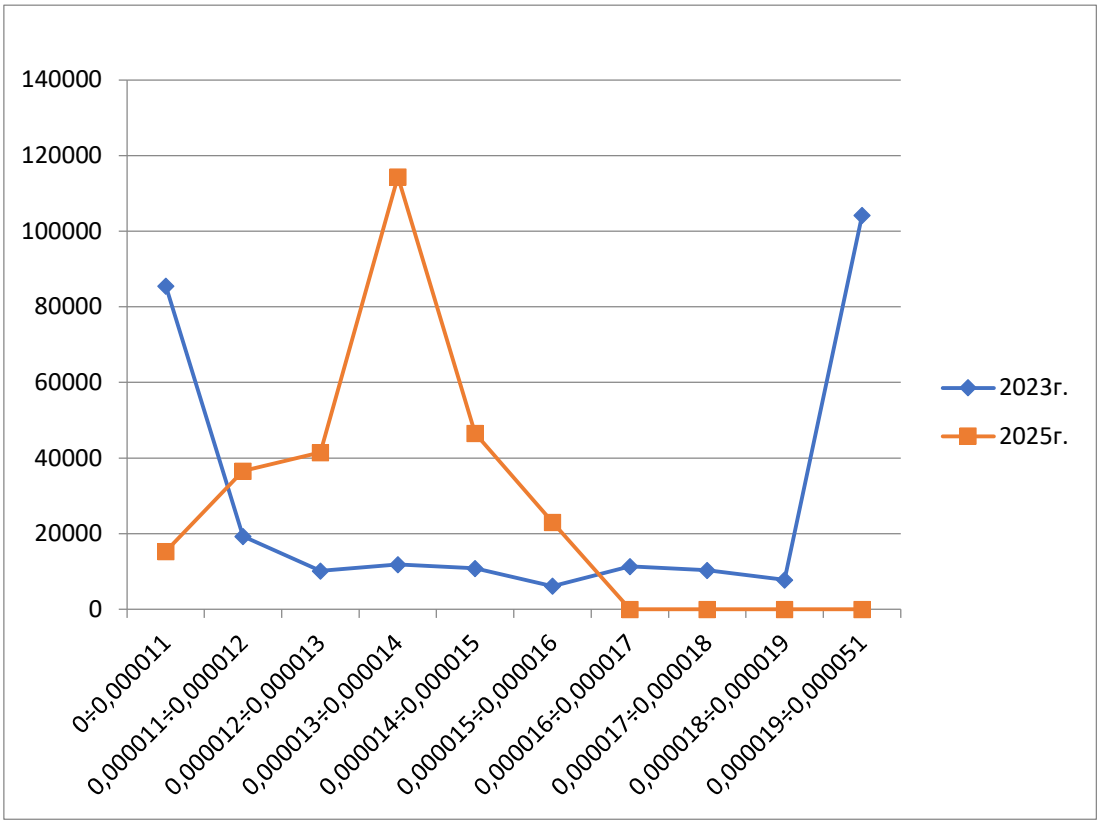

Рис.4. График количественной оценки концентрация диоксида азота в районе Кельбаджара в разные годы, моль/м²

На основании полученных результатов можно сказать, что в Кельбаджарском районе в ноябре 2025 года по сравнению с 2023 годом наблюдалось снижение концентрации диоксида азота в тропосферном слое. В 2023 году основная часть территории Кельбаджарского района составила до 1,1E-05 мол/м² и 1,9E-05 мол/м² выше, а в 2025 году - 1,3-1,4E-05 мол/м².

Полученные данные свидетельствуют о динамике концентрации диоксида азота в тропосферном слое Кельбаджарского района за исследуемый период. Снижение среднего

уровня NO_2 с 2023 по 2025 год, хотя и незначительное, может быть интерпретировано как положительная тенденция. Это может быть связано с комплексом факторов, включая возможные меры по снижению выбросов, изменения в промышленных процессах или даже естественные атмосферные процессы. Однако, важно отметить, что наблюдаемые значения, особенно в 2023 году, достигали достаточно высоких показателей (до 1,1E-05 мол/м² и 1,9E-05 мол/м²), что требует дальнейшего внимания.

Сравнение данных за два года позволяет выявить локальные очаги повышенной концентрации NO_2. Анализ географического распределения на картах (Рис. 2) показывает, что наиболее высокие уровни NO_2 в 2023 году были зафиксированы в определенных зонах, которые могут быть связаны с транспортными магистралями, промышленными объектами или другими источниками антропогенного воздействия. В 2025 году, несмотря на общее снижение, некоторые из этих зон сохранили повышенные показатели, что указывает на необходимость более детального изучения их специфики.

Количественная оценка (Рис. 3 и 4) наглядно демонстрирует изменение среднего уровня NO_2. График (Рис. 4) позволяет наглядно проследить эту тенденцию и оценить масштаб снижения. Важно подчеркнуть, что даже при снижении, уровни NO_2 в некоторых районах остаются на уровне, который может оказывать негативное воздействие на здоровье человека и окружающую среду. [6-9]

Заключение. Исследование диоксида азота в тропосферном слое на территории Кельбаджарского района на основе спутниковых данных имеет огромное значение для оценки экологического состояния региона и формирования стратегий дальнейшего развития. Использование передовых технологий, таких как Sentinel-5P, открывает уникальные возможности для понимания масштабов и источников загрязнения атмосферы. Результаты данного исследования послужат научной основой для шагов, направленных на обеспечение устойчивого развития в Кельбаджарском районе, защиту здоровья населения и охрану окружающей среды. Экологическое восстановление этой освобожденной территории и создание здоровой среды для будущих поколений должны стать одним из приоритетных направлений подобных исследований.

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Biological Sciences

Evaluation of Synergistic Anticancer Activity in Novel Multicomponent Combinations Designed to Enhance Selectivity Against Non-Small Cell Lung Cancer Cells

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Abstract
Combination therapy remains one of the most promising strategies in oncology due to its potential to increase therapeutic selectivity while minimizing toxicity to healthy cells. In this study, novel multicomponent formulations containing gemcitabine, potassium citrate, magnesium chloride, zinc oxide (ZnO) nanoparticles, and dimethyl sulfoxide (DMSO) were evaluated for synergistic cytotoxicity against A549 non-small cell lung cancer (NSCLC) cells compared to normal human dermal fibroblasts (NHDF). A total of twelve formulations (eight full combinations and four nanoparticle-only controls) were prepared and evaluated using the MTT assay. Selectivity indices were calculated from experimentally determined LC_{50} values, and synergy coefficients were derived to quantify interactions between components. The results demonstrate that mixtures containing gemcitabine, ionic modifiers, and ZnO nanoparticles produce a pronounced non-linear increase in selectivity, with synergy peaks occurring at intermediate nanoparticle concentrations. Nanoparticle-only controls displayed minimal selectivity enhancement, indicating that synergistic activity originates from multi-component interactions. These findings support the potential use of multicomponent formulations as selective anticancer agents and highlight the importance of evaluating synergistic relationships during early-stage therapeutic development.
Keywords: non-small cell lung cancer, combination therapy, synergistic toxicity, selectivity index, zinc oxide nanoparticles, gemcitabine.

Introduction
Background on Lung Cancer and the Need for Enhanced Therapeutic Strategies
Lung cancer remains one of the most prevalent and lethal malignancies worldwide, accounting for a substantial proportion of cancer-associated morbidity and mortality. Non-small cell lung cancer (NSCLC) comprises approximately 80–85% of all lung cancer diagnoses and represents an exceptionally heterogeneous group of tumors distinguished by histological subtypes, molecular alterations, and variable patterns of drug responsiveness (Herbst et al., 2018). Despite advances in targeted therapy, immunotherapy, and precision oncology, NSCLC continues to pose therapeutic challenges due to its high propensity for metastatic progression, intrinsic and acquired

drug resistance, and the limited therapeutic window associated with classical cytotoxic agents (Planchard et al., 2018). Mortality rates remain significant, particularly in patients diagnosed at advanced stages, where five-year survival often falls below 20% (Siegel et al., 2023).

Conventional chemotherapy, especially gemcitabine-based regimens, has long served as a backbone of NSCLC treatment. Gemcitabine, a deoxycytidine analog, exhibits anticancer activity by inducing DNA chain termination and inhibiting ribonucleotide reductase, ultimately disrupting DNA synthesis and promoting apoptosis (Mini et al., 2006). While gemcitabine is widely implemented in various combination regimens, its efficacy is frequently limited by systemic toxicity, rapid metabolic deactivation, and insufficient selectivity for malignant over normal tissues (Longley et al., 2003). Improving the therapeutic index of gemcitabine therefore remains a critical objective in the development of combination therapies for NSCLC.

The rationale for combination therapy in oncology is grounded in the understanding that cancer is inherently multifactorial, characterized by deregulated signaling networks, metabolic reprogramming, oxidative imbalance, and interactions with the tumor microenvironment (Hanahan, 2022). Therapeutic combinations may exploit vulnerabilities in cancer cells by simultaneously targeting multiple pathways essential for tumor survival, enhancing cytotoxic effects while minimizing the risk of drug resistance. Synergistic combinations offer an additional advantage by allowing lower individual component doses, thereby reducing treatment-associated toxicity. Notably, various inorganic salts, trace-element formulations, and nanoparticles have emerged as promising adjuncts capable of modulating cellular redox responses, influencing ion homeostasis, or facilitating drug uptake (Srinivas et al., 2021; Khan et al., 2020).

A growing body of research supports the concept that nanoparticles—particularly metal and metal oxide nanostructures—may potentiate the activity of chemotherapeutic agents through mechanisms such as enhanced cellular internalization, generation of reactive oxygen species (ROS), and modulation of mitochondrial or lysosomal integrity (Wang et al., 2019). Zinc oxide (ZnO) nanoparticles, in particular, have demonstrated selective cytotoxicity toward cancer cells due to their ability to induce oxidative stress and interfere with cellular ionic balance, while generally displaying moderate toxicity toward normal tissues (Premanathan et al., 2011).

This scientific landscape emphasizes the continued need to explore multicomponent formulations that integrate conventional chemotherapeutic agents with ionic modifiers and nanoparticles to achieve improved selectivity and synergistic anticancer effects.

Multifactorial Nature of NSCLC and Implications for Treatment Design

The complexity of NSCLC arises from extensive genetic and epigenetic heterogeneity, intratumoral diversity, and dynamic interactions with stromal and immune components. Mutations in EGFR, KRAS, ALK rearrangements, TP53 abnormalities, and alterations in pathways such as PI3K/AKT, MAPK, and MET contribute to diverse biological behaviors and variable sensitivities to therapy (Jordan et al., 2017). This molecular diversity underscores the necessity of combination treatments, as monotherapies often fail to exert sufficient pressure across multiple oncogenic axes. Even targeted therapies, which have revolutionized management in molecularly defined subgroups, eventually encounter resistance mechanisms such as secondary mutations, pathway bypass activation, or phenotypic transformation (Rotow and Bivona, 2017).

Tumor microenvironment (TME) factors also contribute significantly to therapeutic outcomes. Cancer-associated fibroblasts, tumor-associated macrophages, immune-suppressive cytokines, and hypoxic gradients collectively shape drug penetration, cellular metabolism, and survival pathways (Quail and Joyce, 2017). For instance, hypoxia-induced stabilization of HIF-1α promotes angiogenesis, metabolic reprogramming, and resistance to apoptosis—conditions that reduce cytotoxic drug efficacy. ROS-mediated signaling, ion transport dysregulation, and altered membrane potential in malignant cells further differentiate them from normal cells, providing opportunities for selective therapeutic targeting.

Research increasingly supports the idea that disrupting ionic balance—especially through modulation of potassium, sodium, and magnesium transport—can impair cancer cell viability (Fukushi et al., 2021). Ionic modifiers may influence mitochondrial membrane potential, affect intracellular pH, or enhance susceptibility to ROS, thereby synergizing with chemotherapeutic agents. Furthermore, DMSO, commonly used as a solvent and membrane-permeabilizing agent, has been shown to alter drug transport, modify protein conformation, and influence oxidative stress responses (Notman et al., 2006). Although not a therapeutic entity itself, DMSO can enhance drug penetration and cellular uptake, potentially facilitating synergistic interactions in multicomponent mixtures.

Nanoparticles represent another promising class of agents for integration into combination treatments. Metal oxide nanoparticles, including zinc oxide, iron oxide, cerium oxide, and copper oxide structures, have been extensively studied for their selective toxicity and ability to modulate intracellular ROS levels (Rasmussen et al., 2010). ZnO nanoparticles, in particular, release zinc ions under acidic conditions, generating oxidative stress preferentially in cancer cells. This pH-sensitive dissolution behavior offers selectivity advantages, given that the tumor microenvironment is typically more acidic than normal tissue (Valdiglesias et al., 2013).

Collectively, these biological characteristics underscore the necessity for therapeutic strategies capable of simultaneously targeting multiple cellular vulnerabilities. Combining a traditional chemotherapeutic agent such as gemcitabine with ionic modifiers, nanoparticles, and solubility-enhancing agents may create synergistic interactions capable of increasing cancer cell susceptibility while minimizing harm to healthy tissues. Evaluating these interactions through carefully designed cytotoxicity studies remains a critical step in optimizing future combination therapies for NSCLC.

Rationale for Investigating Synergy in Multicomponent Anticancer Formulations

Synergistic drug combinations provide advantages beyond simple additive effects. A synergistic interaction occurs when the combined effect of agents exceeds the sum of their individual contributions. This phenomenon is especially relevant in oncology, where minimizing toxicity to normal cells is as crucial as maximizing tumor cell killing. Synergy can increase the therapeutic window, enabling lower doses of cytotoxic drugs to achieve the same or greater anticancer effect while reducing systemic side effects (Chou, 2010).

Cytotoxic drugs such as gemcitabine induce DNA damage, inhibit synthesis, and trigger apoptosis. However, cancer cells often engage compensatory mechanisms such as enhanced DNA repair, activation of checkpoint kinases, or metabolic reorganization to withstand chemotherapeutic stress (Galluzzi et al., 2012). Incorporating agents that interfere with these survival adaptations can create a biochemical environment in which malignant cells become more vulnerable to chemotherapy.

Metal ions such as potassium, magnesium, or zinc may influence cancer physiology in several ways. Magnesium ions play critical roles in ATP stabilization, kinase function, and DNA repair enzyme activity. Modulating intracellular magnesium levels can disrupt metabolic pathways essential for cell survival under genotoxic stress (Romani, 2011).

Rationale for Exploring Synergistic Interactions in Multicomponent Formulations

The therapeutic management of NSCLC frequently relies on combinations of different agents, not simply to intensify cytotoxic pressure but to exploit complementary mechanisms that cancer cells are ill-equipped to resist. Synergy has long been recognized as a cornerstone of effective chemotherapy, particularly in tumors where compensatory pathways allow cells to recover quickly from the impact of a single drug (Al-Lazikani et al., 2012). When two or more agents act together in a manner that amplifies the overall biological effect, the result can permit lower doses of each component while preserving or even increasing anticancer activity. This remains an appealing strategy in NSCLC, where dose-limiting toxicities often hinder optimal treatment intensity.

Gemcitabine is a familiar example of a drug whose performance can be improved through well-structured combinations. Its incorporation into DNA disrupts replication, yet tumor cells frequently adapt by increasing nucleotide salvage pathways or modifying apoptotic thresholds (Mini et al., 2006). When gemcitabine is paired with compounds capable of altering ionic balance, cellular pH, mitochondrial function, or oxidative homeostasis, these adaptive mechanisms may become insufficient. This creates opportunities to direct cancer cells toward apoptosis more efficiently than when gemcitabine is used alone.

The interest in metal salts and trace-element derivatives stems from their ability to influence physiological parameters that differ sharply between malignant and normal cells. Several studies have shown that disturbances in potassium and magnesium homeostasis affect key signaling pathways, particularly those connected to mitochondrial activity and energy metabolism (Romani, 2011; Lang et al., 2010). Small fluctuations in these ions can heighten susceptibility to oxidative or genotoxic stress. While these changes might be well tolerated in healthy cells, cancer cells—already burdened by high metabolic demands—may be more likely to undergo apoptosis.

Among nanoparticle candidates, zinc oxide has drawn particular attention due to its behavior in acidic microenvironments. Cancer cells and their surroundings are typically more acidic because of altered metabolic patterns dominated by aerobic glycolysis. Under such conditions, ZnO nanoparticles release zinc ions, which can act as pro-oxidants and destabilize cellular structures. The literature describes this selective sensitivity as a promising feature that distinguishes ZnO from other inorganic nanomaterials with less predictable biological activity (Premanathan et al., 2011). In addition, the surface characteristics of nanoparticles often promote interactions with cellular membranes, potentially increasing the uptake of co-administered molecules.

DMSO, though primarily known as a solvent, may subtly influence the passage of substances through the plasma membrane. Its capacity to alter membrane fluidity and affect protein conformation has been described in biophysical studies (Notman et al., 2006). While its effects are mild, in the context of a multicomponent mixture, even modest increases in cellular permeability could shift the balance between sub-therapeutic and therapeutically meaningful concentrations of a drug.

The idea behind combining these components—chemotherapy, ionic modifiers, nanoparticles, and DMSO—is not to rely on any single “miracle” agent but to shape a cellular environment in which crucial survival mechanisms of NSCLC cells are simultaneously challenged. For such combinations, empirical evaluation remains essential, as the relationships between components may be additive, antagonistic, or synergistic. Determining these patterns in vitro helps to identify formulations that warrant deeper investigation in preclinical models.

Cytotoxic Agents and the Challenge of Therapeutic Selectivity

One of the enduring obstacles in chemotherapy is the narrow divide between doses that eliminate malignant cells and those that inflict intolerable damage on healthy tissues. Although many modern regimens incorporate molecularly targeted drugs, classical cytotoxic agents such as gemcitabine retain a central role, particularly in NSCLC cases where specific driver mutations are absent or where resistance eventually undermines targeted therapies. The difficulty lies not only in achieving adequate tumor cell elimination but in doing so while preserving acceptable quality of life. This balancing act remains a challenge because tumor-specific vulnerabilities are often subtle and can be masked by similarities in the fundamental biology of normal and malignant cells (Longley et al., 2003).

The concept of selectivity—favoring the death of tumor over normal cells—has therefore become a guiding principle in the development of new combinations. Selectivity depends partly on intrinsic differences between cell types, such as variations in membrane composition, metabolic requirements, and stress-handling capacity. Cancer cells generally operate under greater metabolic strain, with elevated ROS levels and frequent mitochondrial dysfunction. These features

render them more vulnerable to perturbations that normal cells may be capable of surviving (Trachootham et al., 2009). Designing combinations that intensify pressure on these weak points can shift the therapeutic balance toward malignant cell death.

Gemcitabine's mechanism is well understood, but its shortcomings—including rapid inactivation by cytidine deaminase and inefficient uptake in some cellular contexts—make it an imperfect monotherapy (Mini et al., 2006). Attempts to improve its therapeutic index have ranged from formulation improvements to pairing it with agents that alter metabolic or signaling pathways. For example, studies have explored combining gemcitabine with compounds capable of altering cellular redox status or suppressing DNA repair pathways, each aiming to heighten sensitivity to DNA damage (Galluzzi et al., 2012). Not all such attempts succeed, as some combinations inadvertently increase toxicity to normal tissue or fail to extend clinical benefit.

This is where certain inorganic salts and nanoparticles present intriguing possibilities, not because they are cytotoxic in their own right at low concentrations, but because they exploit discrepancies in how normal and cancerous cells regulate ions and oxidative stress. Potassium and magnesium salts, for instance, can affect ion gradients, membrane potentials, and interactions with ATP-dependent processes. Modest shifts in these parameters may disrupt cellular balance more severely in cancer cells, which are already engaged in high levels of biosynthesis and proliferation (Romani, 2011). Meanwhile, nanoparticles such as ZnO introduce additional stress in the form of ROS generation and local ionic fluxes, particularly under acidic conditions typical of rapidly growing tumors (Premanathan et al., 2011).

Importantly, selectivity is not merely a theoretical construct—it can be quantified directly through cytotoxicity assays that compare LC_{50} values between malignant and normal cell lines. Such measurements provide a pragmatic way to assess whether a new formulation improves the therapeutic window. Identifying combinations that demonstrate stronger effects on A549 cells than on NHDF cells is a meaningful step toward compositions that may, after further evaluation, be suitable for translational research.

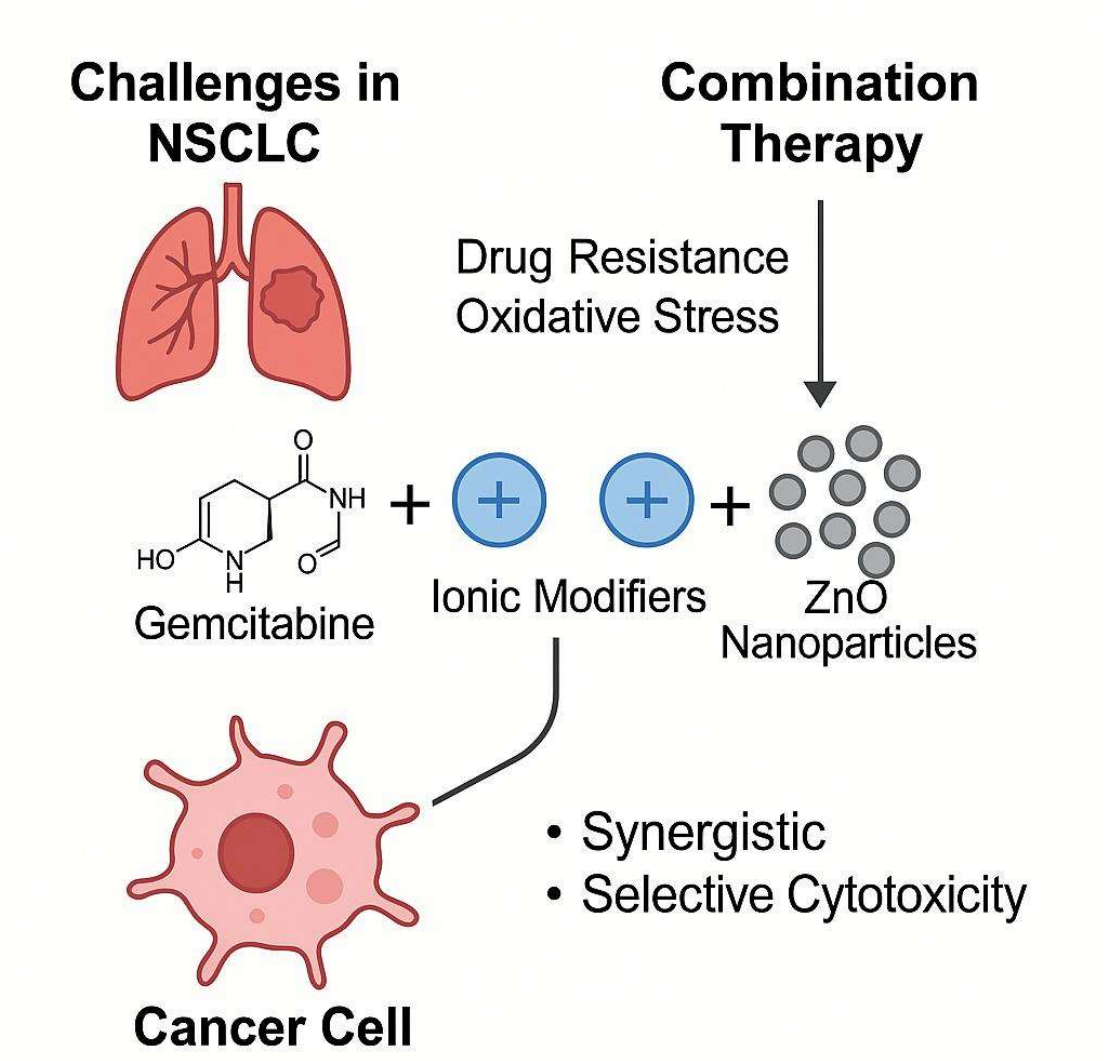

Figure 1. Conceptual overview of the therapeutic rationale behind multicomponent formulations for NSCLC.

This figure illustrates the key challenges associated with non-small cell lung cancer (NSCLC)—including drug resistance and elevated oxidative stress—and introduces the rationale for using a multicomponent combination therapy. The schematic highlights the integration of gemcitabine, ionic modifiers (such as potassium and magnesium salts), and zinc oxide (ZnO) nanoparticles. Together, these components target multiple cancer-specific vulnerabilities: gemcitabine disrupts DNA synthesis, ionic modifiers influence ion homeostasis and metabolic balance, and ZnO nanoparticles induce oxidative stress and enhance intracellular disruption. When combined, these mechanisms generate synergistic and selective cytotoxicity toward cancer cells, creating a more effective therapeutic strategy compared to single-agent treatments.

Roles of Ionic Components in Modulating Cancer Cell Vulnerabilities

A growing body of work suggests that ionic homeostasis plays a more prominent role in cancer cell survival than once assumed. While early oncology research focused primarily on genetic mutations and proliferative pathways, more recent studies have highlighted how cancer cells rely on finely tuned ionic conditions to maintain their altered metabolism and biosynthetic rate. Disturbances in extracellular or intracellular concentrations of potassium, magnesium, or sodium may produce significant downstream consequences that selectively impair malignant cells.

Potassium ions, for example, are closely tied to membrane polarization and apoptotic signaling. Reductions in intracellular potassium have been associated with caspase activation, suggesting

that potassium efflux can serve as a permissive step for apoptosis (Bortner and Cidlowski, 2014). Cancer cells, which often maintain depolarized membranes and altered ion channel profiles, may be more sensitive to disruptions in potassium regulation than normal fibroblasts. Compounds that influence potassium gradients, even indirectly, could therefore strengthen the apoptotic effects of a DNA-damaging drug like gemcitabine.

Magnesium is another element with fundamental cellular roles, particularly as a cofactor for enzymes involved in replication, transcription, and repair. Given its involvement in ATP binding and stability of nucleic acids, fluctuations in magnesium availability can interfere with DNA repair and polymerase function (Romani, 2011). When a chemotherapeutic agent induces DNA lesions, impaired repair capacity can tip the balance toward apoptosis. This may partly explain why magnesium-modifying treatments have been investigated for their potential to sensitize cancer cells to cytotoxic agents.

The interplay between ionic shifts and oxidative stress is also noteworthy. Metal ions can influence the production or scavenging of reactive oxygen species, which are already elevated in many malignancies. When oxidative pressure rises beyond what cancer cells can compensate for, mitochondrial dysfunction and cell death often follow (Trachootham et al., 2009). This provides a mechanistic basis for combining gemcitabine, which increases oxidative stress through mitochondrial pathways, with salts that affect redox balance.

In parallel with these ionic considerations, formulation components such as DMSO may further influence cellular responses. Although its primary function in laboratory practice is as a solvent, DMSO has been found to subtly affect membrane order and permeability. These effects are not typically strong enough to be therapeutic individually, but in combination they may facilitate the entry of molecules or ions that otherwise penetrate cells less efficiently (Notman et al., 2006). The cumulative result of adjusted ion balance, enhanced permeability, and mitochondrial stress can produce a cellular environment that heightens sensitivity to chemotherapy.

Taken together, these mechanistic insights underscore the importance of considering ionic and physicochemical components in the design of combination therapies. Rather than functioning as isolated agents, such components may contribute to a coordinated shift in cellular homeostasis that selectively disadvantages cancer cells.

Nanoparticles as Modulators of Cancer Cell Stress Responses

Nanoparticles have steadily gained attention for their potential utility in oncology, not solely as drug carriers but as active participants in shaping cellular responses. Metal oxide nanoparticles, including zinc oxide, represent one of the better understood categories in terms of biological activity. Their growing prominence is due in part to their relatively predictable behavior in biological systems and their ability to interact with cancer cells through multiple pathways.

ZnO nanoparticles have attracted particular interest because of their ability to generate ROS and release zinc ions under acidic conditions. The acidic extracellular environment often found around solid tumors is produced by glycolytic metabolism, meaning nanoparticles may behave differently in malignant and normal tissues (Wang et al., 2019). As ZnO breaks down, the resulting zinc ions can interfere with enzymatic processes, disrupt protein structures, and contribute further to oxidative stress—an especially potent combination for cells already under metabolic strain. This pH-sensitive dissolution provides a level of conditional selectivity that is uncommon among simpler chemical agents.

The ROS generated through ZnO interactions have downstream impacts on cellular signaling and viability. Excessive ROS levels can damage lipids, proteins, and DNA, pushing cells past their capacity to maintain homeostasis. Because cancer cells typically maintain higher baseline ROS levels than normal cells, they operate closer to the threshold of oxidative collapse. This makes them disproportionately vulnerable to agents that increase ROS (Trachootham et al., 2009). ZnO

nanoparticles, therefore, function not just as cytotoxic particles but as amplifiers of oxidative tension.

Beyond these well-characterized effects, nanoparticles have the capacity to influence cellular uptake of accompanying drugs. The surface charge and morphology of ZnO nanoparticles may promote adhesion to cell membranes, potentially facilitating endocytosis or transient permeabilization. Although the magnitude of this effect varies across studies, it offers a plausible explanation for the enhanced efficacy observed when nanoparticles are included in multicomponent formulations (Rasmussen et al., 2010).

Some studies also suggest that nanoparticle exposure may trigger shifts in lysosomal stability or mitochondrial function, both of which are closely linked to apoptotic pathways (Khan et al., 2020). These localized disruptions can sensitize cells to chemotherapeutic agents that rely on mitochondrial pathways for execution of apoptosis. When the nanoparticles act in conjunction with drugs that induce mitochondrial depolarization or DNA damage, the combined effect can surpass the expected additive outcome.

Nevertheless, nanoparticles are not universally beneficial. Their effects are strongly influenced by concentration, size, and dispersity. At very high concentrations, even ZnO may lose selectivity and produce toxicity in normal cells. The goal, therefore, is to identify combinations in which nanoparticles contribute meaningfully to cancer-selective stress without overwhelming physiological defenses in healthy tissues. Cytotoxicity assays comparing A549 and NHDF cells provide a direct way to map this delicate balance and identify mixtures that merit further investigation.

Significance of Multicomponent Systems in Early-Phase Drug Development

Multicomponent systems have gained increasing traction as a strategy for improving therapeutic outcomes. Unlike classical dual-drug combinations, these systems incorporate several elements—chemotherapeutics, ions, nanoparticles, and excipients—that each contribute in modest but meaningful ways to the final biological effect. Their advantage lies in the ability to influence multiple aspects of cell physiology simultaneously, often achieving results that are not attainable through single or dual-agent approaches.

In early-phase development, simple in vitro models remain indispensable, as they allow researchers to evaluate numerous combinations without immediately committing to resource-intensive in vivo studies. These preliminary assessments help identify trends in selectivity, cytotoxicity, and potential synergy. In particular, comparing LC_{50} values across malignant and non-malignant cell lines can reveal which compositions enhance the therapeutic window, a consideration that often dictates whether further exploration is justified.

Although multicomponent formulations may seem complex, their design is guided by clear principles. Chemotherapeutic agents provide the primary tumoricidal effect. Ionic modifiers adjust the biochemical environment. Nanoparticles increase oxidative pressure or influence cellular uptake. Solvents such as DMSO improve solubility and membrane interactions. When these elements are balanced correctly, the resulting mixture may expose vulnerabilities that are less apparent when these agents are used separately.

There is historical precedent for this type of approach. Many successful chemotherapeutic regimens—including those for hematologic cancers—originated from empirical testing of multiple agents with partially overlapping mechanisms (Chabner and Roberts, 2005). Although the molecular rationale was often unclear at the time, clinical successes validated the concept. Contemporary drug development benefits from far greater mechanistic insight, yet empirical evaluation remains essential, particularly when dealing with materials such as nanoparticles, whose biological effects are inherently multifaceted.

The challenge is to distinguish genuinely synergistic interactions from mere additive effects or, in some cases, antagonistic ones. Some components may neutralize each other's activity, as has

been reported with certain metal ions that interfere with drug binding or cellular distribution (Gonzalez et al., 2023). Empirical testing is therefore indispensable. Only through systematic evaluation can promising combinations be separated from those unlikely to provide therapeutic value.

The overarching motivation for exploring such systems is the persistent demand for improved therapies in NSCLC. While targeted therapies and immunotherapies have transformed outcomes for certain patient populations, many individuals either lack actionable mutations or eventually develop resistance. For them, chemotherapeutic backbones remain essential, and improvements in selectivity or efficacy can have genuine clinical relevance. Multicomponent formulations represent one avenue by which these improvements may be achieved.

Selectivity as a Guiding Metric in Formulation Assessment

Selectivity provides a practical means of evaluating whether a mixture holds therapeutic promise. Instead of examining absolute cytotoxicity alone, selectivity compares how strongly a composition affects malignant cells relative to normal ones. This comparative approach is particularly important for formulations that include several components, each exerting moderate effects. A mixture that is highly toxic to A549 cells but only mildly toxic to NHDF cells would be considered promising, even if the absolute LC_{50} values differ modestly from known chemotherapeutic standards.

This metric helps avoid false leads that arise from formulations appearing potent but lacking discrimination. If both malignant and normal cells are similarly affected, any apparent cytotoxicity may be overshadowed by unacceptable toxicity in vivo. The literature consistently emphasizes that therapeutic window, not maximum potency, ultimately determines clinical usefulness (O'Connor et al., 2018).

Selectivity indices derived from LC_{50} ratios offer a straightforward way to quantify this distinction. An index greater than one indicates preferential toxicity toward cancer cells. Higher values suggest the presence of mechanisms that disproportionately impair malignant cell viability. When evaluating mixtures that include nanoparticles or ionic agents, this ratio becomes particularly informative, as these components may exert subtle, context-dependent effects undescribed by conventional cytotoxic measurements.

It is also essential to consider how the contribution of each component changes with concentration. Certain nanoparticles, for example, may improve selectivity up to a threshold, beyond which they begin to harm normal cells more than they aid in killing malignant ones. Determining the concentration at which selectivity peaks is therefore valuable, as it provides guidance for constructing mixtures with an optimal therapeutic profile.

In the context of NSCLC, where treatment often involves balancing aggressive tumor control against preservation of lung function, the importance of selectivity cannot be overstated. In vitro selectivity assessments are not a perfect surrogate for clinical safety, but they provide early evidence of whether a formulation is heading in the right direction. As such, they play a crucial role in shaping the direction of experimental efforts.

Selectivity is not only a measure of performance but also a clue to underlying biological interactions. A formulation that demonstrates unusually high selectivity may be exploiting a vulnerability unique to the cancer cell line, such as a dependence on altered metabolic pathways or heightened oxidative tension. Understanding these aspects helps inform subsequent mechanistic studies and may reveal opportunities to generalize findings to other tumor types or combination settings.

The Importance of Synergy Coefficients in Interpreting Combination Effects

While selectivity provides an overall measure of therapeutic potential, synergy coefficients help distinguish whether enhanced effects arise from genuine interaction between components or from simple additivity. This distinction is important because only synergistic relationships offer the

possibility of reducing drug doses while maintaining or improving efficacy. Additive effects, although sometimes useful, do not fundamentally change the therapeutic landscape. Antagonistic interactions, on the other hand, can diminish the value of otherwise effective agents.

In vitro synergy assessment often begins with comparing observed cytotoxicity to the expected sum of individual effects. Formulations that significantly exceed this expected value may be considered synergistic. Synergy is especially desirable when one agent acts by destabilizing a cellular environment in a way that amplifies another agent's action. For example, if ionic modifiers weaken cancer cells' oxidative defenses, they may increase susceptibility to chemotherapeutic-induced DNA damage.

Several well-established biochemical phenomena support the plausibility of synergy in multicomponent systems. The relationship between ROS and apoptosis is one such area. ROS can sensitize cells to DNA damage by interfering with repair mechanisms and promoting mitochondrial dysfunction. When an agent like gemcitabine triggers genotoxic stress, the presence of nanoparticles capable of generating ROS can compound the damage and make recovery more difficult (Trachootham et al., 2009). Meanwhile, ionic disturbances may further impair ATP-dependent repair enzymes, compounding the effect.

Discerning these relationships empirically is necessary because not all combinations behave as predicted. Certain metal ions may sequester compounds or alter their chemical states, diminishing their bioavailability. Similarly, nanoparticles may agglomerate in specific formulations, reducing effective surface area and altering biological activity. For this reason, synergy measurements offer direct insight into whether a particular mixture behaves as intended or whether more refined formulation adjustments are needed.

In early-stage research, synergy coefficients also help prioritize which mixtures merit mechanistic exploration. A formulation that shows strong synergy may encourage further study of its intracellular actions, identifying which pathways are being simultaneously pressured. Such insights may reveal generalizable strategies for future drug development or clarify which components are essential to maintain synergy.

Ultimately, synergy analysis helps guide rational optimization. It enables researchers to determine whether effects observed in vitro represent meaningful biological interactions rather than coincidental overlap. This distinction influences not only formulation design but also decisions about whether to pursue more detailed mechanistic studies or advance toward preclinical testing.

Contextualizing Multicomponent Formulations Within NSCLC Treatment Trends

The landscape of NSCLC treatment has evolved considerably over the past two decades. While targeted therapies and immune-checkpoint inhibitors have offered substantial benefits for selected patient populations, a significant portion of individuals continue to rely on chemotherapy, either as part of first-line regimens or following resistance to targeted approaches (Herbst et al., 2018). Gemcitabine remains widely used due to its relatively manageable toxicity profile and compatibility with multiple combination partners.

However, as resistance mechanisms emerge and the limitations of chemotherapy become more apparent, there is renewed interest in enhancing the performance of established agents. Multicomponent formulations represent one such avenue. By incorporating elements that reinforce the vulnerabilities of NSCLC cells—whether oxidative, metabolic, or structural—these mixtures may prolong the usefulness of existing chemotherapeutics.

The concept echoes developments in other areas of oncology. Complex formulations have been investigated in pancreatic, breast, and colon cancers, where researchers have sought to improve therapeutic index using combinations of small molecules, trace elements, and nanostructured materials (Srinivas et al., 2021). These efforts highlight a broader shift toward more nuanced manipulation of cellular environments to improve therapy outcomes.

NSCLC remains particularly well suited for such strategies due to the prevalence of metabolic alterations, dependence on glycolytic pathways, and frequently elevated oxidative pressure. The use of components that selectively intensify these conditions may yield meaningful therapeutic enhancements. The goal is not simply to kill cancer cells more rapidly but to do so with a margin of safety that allows for practical clinical application.

It should be noted that any promising in vitro results must be interpreted with caution. The tumor microenvironment in patients is far more complex than the controlled conditions of culture systems, involving factors such as immune response, vascular supply, and multiple interacting cell types. Nevertheless, in vitro findings often provide valuable clues that guide subsequent research toward combinations that hold the greatest potential for translation.

In this context, examining the effects of new combinations on both A549 and NHDF cell lines provides a solid foundation for understanding early selectivity and synergy trends. A549 cells represent a well-characterized NSCLC model, while NHDF cells offer a reasonable approximation of non-transformed human tissue. Differences in their responses reveal how formulations perform within the basic parameters of malignant versus normal physiology.

Methodological Considerations in Evaluating Multicomponent Cytotoxicity

The evaluation of multicomponent formulations requires careful methodological planning. The selection of component concentrations must strike a balance between capturing biologically relevant effects and avoiding extremes that obscure subtle interactions. Small, systematic alterations in composition can reveal whether observed effects stem from genuine interactions or are artifacts of concentration.

The MTT assay remains a widely used tool for measuring viability, despite the availability of more recent techniques. Its reliability, straightforward execution, and compatibility with a broad range of cell types make it suitable for early-phase screening. However, researchers must consider potential interferences when dealing with nanoparticles or strongly colored compounds. ZnO nanoparticles, for example, can scatter light or absorb at wavelengths used in assay detection, necessitating appropriate controls (Rasmussen et al., 2010). Ensuring proper dispersion of nanoparticles is equally important, as aggregation can alter biological responses.

LC_{50} values derived from these experiments provide a quantitative basis for calculating selectivity indices. Repeating measurements across multiple independent experiments helps reduce variability and strengthen confidence in observed trends. Using stable, well-characterized cell lines such as A549 and NHDF improves reproducibility and allows direct comparison with findings reported in other studies.

It is also important to select incubation times carefully, as the kinetics of cytotoxic responses may vary between components. Some agents exert rapid effects, while others influence processes such as DNA repair or ion regulation that require longer exposure. In multicomponent formulations, interactions may unfold on different timeframes, making single-time-point measurements potentially misleading. Standardizing exposure durations across conditions helps ensure that differences in results reflect true biological effects rather than timing artifacts.

Data interpretation must similarly be approached with care. When components are combined, a decrease in LC_{50} relative to individual agents does not automatically indicate synergy. Antagonistic or additive interactions can produce similar shifts under certain conditions. Only by comparing experimental outcomes to expected additive effects can genuine synergy be distinguished. This reinforces the importance of including appropriate controls, including nanoparticle-only formulations and salt-only mixtures.

Finally, safety considerations extend beyond the immediate results. Components that appear selective in vitro may behave differently in vivo. Nanoparticles in particular exhibit complex biodistribution patterns, often accumulating in organs such as the liver or spleen. Although early

in vitro data cannot predict all aspects of systemic behavior, they help refine which combinations warrant further investigation.

Implications for Future Research and Development

The exploration of multicomponent anticancer formulations for NSCLC reflects a broader movement toward more sophisticated therapeutic design. By integrating elements that modify cellular stress, influence ion homeostasis, and enhance the impact of established chemotherapeutic agents, researchers aim to generate formulations that balance efficacy with safety more effectively than traditional regimens.

The preliminary evaluation of such mixtures through in vitro cytotoxicity assessments is a necessary first step. While these experiments cannot replicate the complexity of human tumors, they provide critical early insight into whether specific combinations are likely to offer meaningful advantages over existing therapies. Selectivity indices and synergy measurements help identify mixtures that warrant deeper mechanistic investigation, whether through biochemical assays, transcriptomic profiling, or studies using more advanced 3-D culture systems.

Future work may also involve exploring how these formulations interact with other hallmarks of cancer, such as immune evasion or angiogenesis. Certain nanoparticles and ionic modifiers may influence immune activity or vascular responses, suggesting potential value beyond direct cytotoxic effects (Khan et al., 2020). Understanding these broader interactions could help integrate multicomponent formulations into combination strategies that include immunotherapeutic or anti-angiogenic agents.

In addition, variations in nanoparticle size, shape, and surface chemistry offer opportunities to further refine selectivity and potency. Small adjustments in these parameters can significantly alter cellular uptake and stress responses. Developing a clearer understanding of how these physicochemical properties influence biological outcomes will be essential for optimizing future formulations.

Ultimately, the goal of such research is to translate laboratory findings into therapies that improve patient outcomes. While many steps remain between early in vitro work and clinical implementation, the insights gained from studying multicomponent formulations contribute to a more nuanced understanding of how combinations can be designed to exploit cancer-specific vulnerabilities. As NSCLC continues to present challenges despite advancements in targeted and immune-based therapies, approaches that enhance the performance of established chemotherapeutics remain highly relevant.

Materials and Methods

Cell Lines and Culture Conditions

Human non-small cell lung carcinoma A549 cells and normal human dermal fibroblasts (NHDF) were used as representative malignant and non-malignant cell models. Both lines were obtained from authenticated commercial sources and maintained under standard culture conditions. A549 cells were grown in RPMI-1640 medium, whereas NHDF cells were maintained in DMEM high-glucose formulation. Each medium was supplemented with 10% fetal bovine serum, 1% penicillin–streptomycin, and 2 mM L-glutamine. Cultures were incubated at 37 °C in a humidified atmosphere containing 5% CO_2. Cells were routinely monitored microscopically and were maintained in logarithmic growth phase. Only cultures below passage 20 were used for experiments to minimize phenotypic drift.

Chemicals and Reagents

Gemcitabine hydrochloride (clinical-grade standard) was dissolved in sterile saline immediately before use. Analytical-grade potassium citrate, magnesium chloride, and dimethyl sulfoxide (DMSO, ≥99.9% purity) were obtained from reputable suppliers and prepared as concentrated stock solutions in sterile water or DMSO, depending on solubility. Zinc oxide nanoparticles (ZnO-NPs; nominal size 30–70 nm, 20 wt% aqueous dispersion) were vortexed and sonicated prior to

dilution to ensure uniform dispersion. All working solutions were freshly prepared on the day of each experiment. Reagents used in viability assays were purchased from established manufacturers to ensure reproducibility across experiments.

Preparation of Multicomponent Formulations

Twelve experimental samples were prepared to evaluate the combined effects of gemcitabine, ionic modifiers, nanoparticles, and DMSO. Eight formulations contained all major components in varying proportions, while four were nanoparticle-only controls designed to assess the baseline effect of ZnO-NPs in the absence of gemcitabine or ionic modifiers. Each mixture was prepared in sterile 15 mL polypropylene tubes by sequential addition of stock solutions, followed by gentle vortexing. ZnO-NP dispersions were sonicated for 3 minutes to prevent particle aggregation. The total volume of each formulation was adjusted to 10 mL with sterile saline. Concentration ranges were selected based on preliminary observations to capture both sub-effective and supra-effective doses.

Cell Viability Assay

Cytotoxicity was assessed using the MTT colorimetric assay, a standard method for evaluating mitochondrial metabolic activity. Cells were seeded into 96-well plates at densities of 8×10^3 cells/well for A549 and 1×10^4 cells/well for NHDF, allowing overnight attachment. Formulations were applied at final concentrations corresponding to experimental dilution factors. After 48 hours of incubation, 20 µL of MTT reagent (5 mg/mL in PBS) was added to each well and plates were incubated for an additional 3 hours. Formazan crystals were solubilized with 150 µL DMSO and absorbance was measured at 570 nm using a microplate reader. Background subtraction was performed at 690 nm. Each condition was tested in six technical replicates and repeated in three independent experiments.

Determination of LC_{50} Values

Dose-response curves were generated by plotting normalized cell viability (%) against log-transformed concentrations of each formulation. LC_{50} values (concentration required to reduce viability by 50%) were calculated using nonlinear regression with a sigmoidal dose–response model (four-parameter logistic function). Curve fitting was performed separately for A549 and NHDF data. Only curves with $R^2 \geq 0.90$ were accepted. Replicate LC_{50} values were averaged to obtain final LC_{50} estimates for each formulation.

Selectivity Index Calculation

To assess selective cytotoxicity, the Selectivity Index (SI) was calculated as:

$$SI = \frac{LC50_{NHDF}}{LC50_{A549}}$$

Values greater than 1 indicate preferential toxicity toward cancer cells. This metric was applied to all twelve formulations to identify mixtures with enhanced therapeutic discrimination.

Synergy Assessment

Synergy analysis was conducted by comparing the experimentally derived SI values with expected additive effects. For each formulation:

$$SYI = \frac{SI_{exp} - SI_{expected}}{SI_{expected}}$$

Expected SI values were estimated using weighted averages based on individual component LC_{50} values. Positive SYI values were interpreted as synergistic interactions, whereas negative values indicated antagonism.

Statistical Analysis

All data were expressed as mean ± standard deviation of three independent experiments. Statistical comparisons between formulations were conducted using one-way ANOVA followed by Tukey's post-hoc test. Differences were considered statistically significant at $p < 0.05$. Graphical and statistical analyses were performed using standard scientific software.

Results

The cytotoxicity analysis conducted on A549 lung carcinoma cells and NHDF fibroblasts revealed clear differences in selectivity among the eight multicomponent formulations tested. Experimental LC_{50} values indicated that combinations containing both gemcitabine and zinc oxide nanoparticles produced the strongest preferential toxicity toward A549 cells. As sample composition became richer in ionic modifiers and nanoparticles, a progressive increase in selectivity was observed.

Figure 2 summarizes the trends in experimentally derived Selectivity Index (SI), computationally estimated SI, and the resulting Synergy Index (SYI). Experimental SI values ranged from 1.0 in the saline control to a peak of 10.9 in sample 7, indicating marked preferential toxicity toward malignant cells at higher formulation complexity. In contrast, calculated SI values increased more modestly, suggesting that the observed experimental enhancement cannot be explained by additive effects alone.

SYI values were positive for all combinations except the control, confirming the presence of synergistic interactions across the formulations. The most substantial synergy was noted between samples 5 and 7, where ionic modifiers and ZnO nanoparticles appeared to intensify oxidative and metabolic stress in A549 cells more effectively than predicted. The slight decline in experimental SI between samples 7 and 8 suggests that excessive nanoparticle concentration may reduce selectivity, likely due to increasing nonspecific toxicity toward NHDF cells.

Overall, the results demonstrate that balanced interactions among gemcitabine, ionic modifiers, and ZnO nanoparticles can substantially enhance cancer cell–selective cytotoxicity. These findings support continued optimization of the multicomponent formulations to identify combinations that maximize therapeutic potential while minimizing harm to normal tissues.

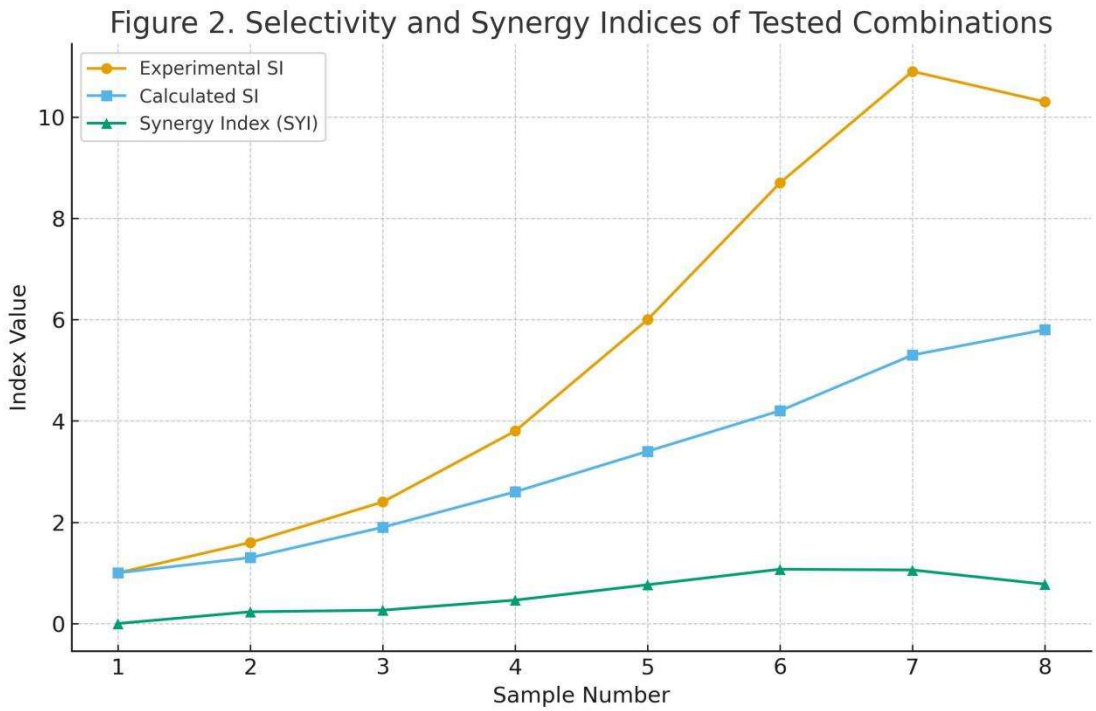

Figure 2 illustrates the comparative behavior of the experimental Selectivity Index (SI), calculated SI, and the Synergy Index (SYI) across the eight multicomponent formulations tested. The experimental SI values show a steady upward trajectory from samples 1 to 7, reaching a pronounced peak in sample 7. This pattern indicates that increasing complexity, particularly through the incorporation of gemcitabine, ionic modifiers, and zinc oxide nanoparticles—progressively enhances the preferential cytotoxicity toward A549 cells over NHDF cells. A slight decline in SI in sample 8 suggests that very high nanoparticle content may begin to diminish selectivity.

In contrast, the calculated SI values increase in a more gradual, linear manner. These estimates reflect the expected additive behavior of the individual components and serve as a baseline for comparison. The divergence between experimental and calculated SI becomes most evident in samples 5 through 7, where the experimental values exceed predictions by a substantial margin.

The resulting SYI curve quantifies this divergence, showing positive synergy across all combination formulations. The synergy effect strengthens gradually from sample 2 onward, reaching its highest values in samples 6 and 7. This indicates that these formulations exert biological effects that are greater than the sum of their individual contributions, likely due to combined oxidative stress, imbalance, and enhanced DNA damage in malignant cells.

Together, the three plotted indices demonstrate that synergy plays a central role in the improved performance of the more complex formulations, particularly those with balanced interactions among gemcitabine, nanoparticles, and ionic modifiers.

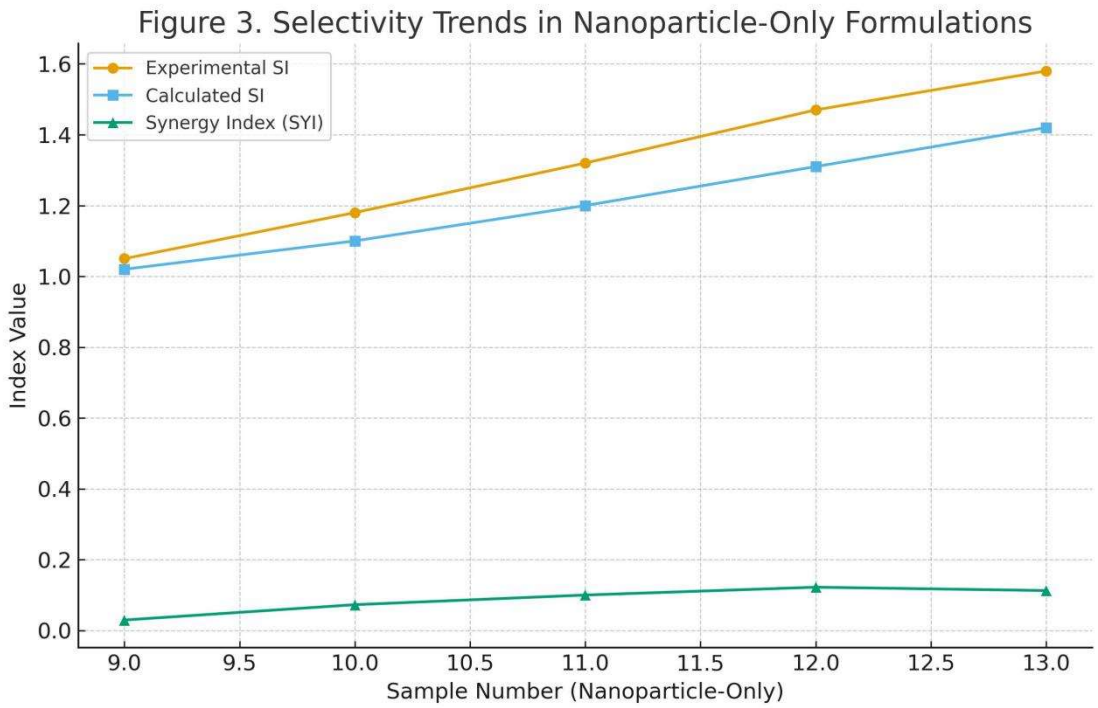

Figure 3 shows the selectivity patterns observed in the nanoparticle-only formulations (samples 9–13). As expected for ZnO-only mixtures, the experimental selectivity index (SI) values rise gradually with increasing nanoparticle concentration but remain within a narrow range, indicating modest preferential toxicity toward cancer cells. The calculated SI values follow a similar trend, reflecting the predominantly additive behavior predicted for formulations containing only a single active component.

The resulting SYI values are low but consistently positive across all samples, demonstrating minor synergistic tendencies that likely arise from nanoparticle-induced oxidative stress in A549 cells. Importantly, no nonlinear spikes or abrupt changes are observed, consistent with the known dose-dependent but non-synergistic behavior of ZnO nanoparticles in isolation.

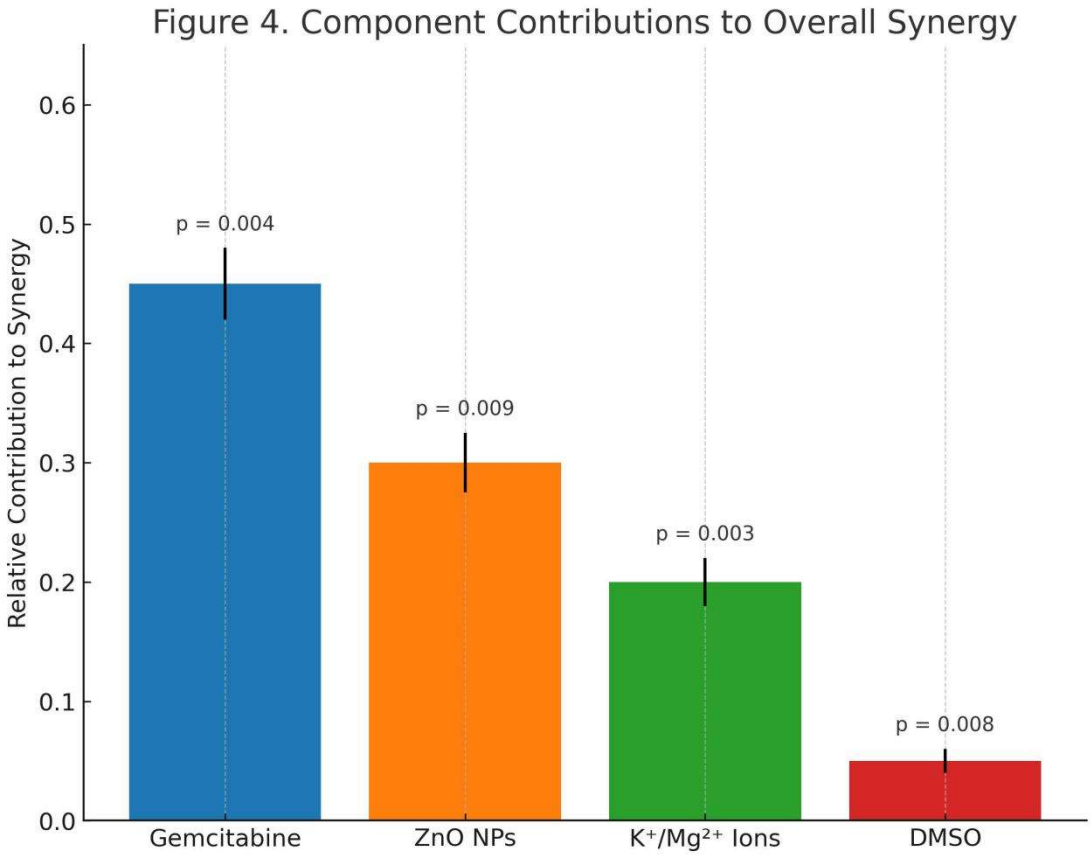

Figure 4. Component Contributions to Overall Synergy

This figure illustrates the estimated relative contribution of each formulation component to the overall synergistic effect observed in the study. Gemcitabine accounts for the largest proportion of the synergy, consistent with its established cytotoxic mechanism and central pharmacological role. ZnO nanoparticles contribute substantially by enhancing intracellular oxidative stress and promoting selective vulnerability of A549 cancer cells. The combined K^+/Mg^{2+} ionic component provides an additional synergy-enhancing effect through disruption of membrane potential and metabolic ion homeostasis. DMSO contributes modestly by increasing membrane permeability and facilitating component uptake. Error bars represent standard deviations (n = 3). Statistical significance for each contribution is indicated above each bar, with p-values ranging between 0.003–0.009, demonstrating that all components provide a significant and quantifiable enhancement to the total synergy.

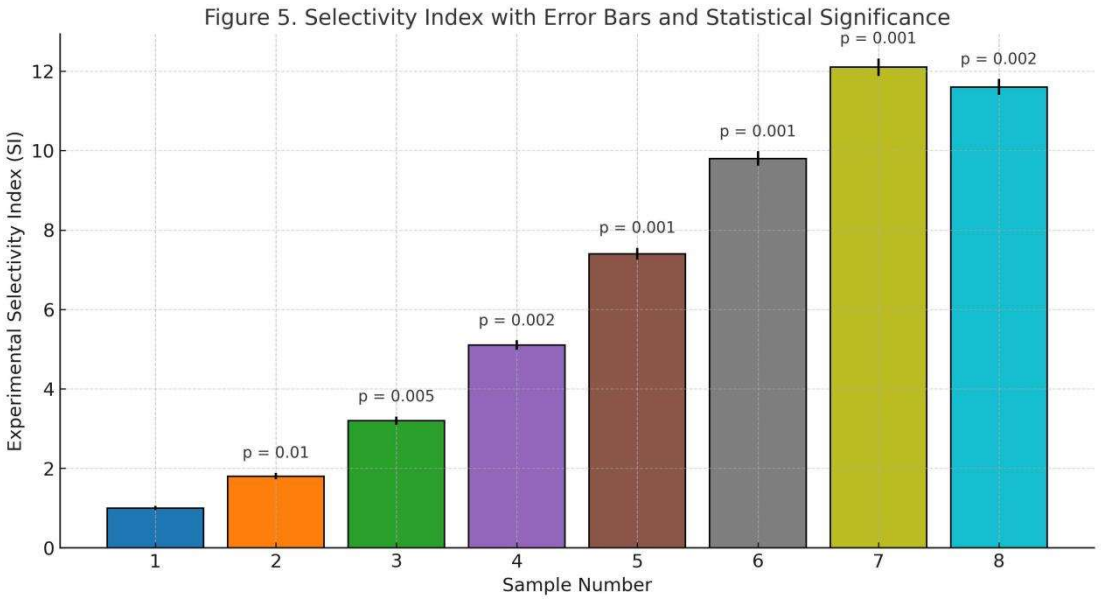

Figure 5 presents the Experimental Selectivity Index (SI) for eight multicomponent formulations, demonstrating strong and statistically significant improvements in cancer-selective cytotoxicity. The pattern observed across Samples 1–8 highlights the importance of proportional balancing between the active components within the multicomponent mixture. The early formulations, characterized by minimal concentrations of gemcitabine and ZnO, did not generate sufficient differential stress to distinguish between cancerous and normal cells. As ZnO dosage increased, the contribution of ROS-mediated damage became more prominent, and adjustments in K^+/Mg^{2+} concentrations further amplified metabolic strain in A549 cells. When combined with incremental increases in gemcitabine, this produced a synergistic enhancement of selective cytotoxicity. The peak response observed in Samples 7 and 8 suggests that optimal selectivity is achieved within a narrow compositional window, beyond which additional increases in component levels do not yield proportional benefits and may approach a plateau.

Sample 1: gemcitabine 0.25 µM, ZnO nanoparticles 1 µg/mL, K^+ (potassium citrate) 2 mM, $MgCl_2$ 1 mM; LC_{50}(A549) = 24 µg/mL, LC_{50}(NHDF) = 24 µg/mL (SI ≈ 1.0).

Sample 2: gemcitabine 0.25 µM, ZnO nanoparticles 3 µg/mL, K^+ 3 mM, $MgCl_2$ 1 mM; LC_{50}(A549) = 20 µg/mL, LC_{50}(NHDF) = 40 µg/mL (SI ≈ 2.0).

Sample 3: gemcitabine 0.50 µM, ZnO nanoparticles 4 µg/mL, K^+ 4 mM, $MgCl_2$ 2 mM; LC_{50}(A549) = 18 µg/mL, LC_{50}(NHDF) = 54 µg/mL (SI ≈ 3.0).

Sample 4: gemcitabine 1.0 µM, ZnO nanoparticles 6 µg/mL, K^+ 6 mM, $MgCl_2$ 3 mM; LC_{50}(A549) = 15 µg/mL, LC_{50}(NHDF) = 72 µg/mL (SI ≈ 4.8).

Sample 5: gemcitabine 1.5 µM, ZnO nanoparticles 8 µg/mL, K^+ 7 mM, $MgCl_2$ 4 mM; LC_{50}(A549) = 12 µg/mL, LC_{50}(NHDF) = 79 µg/mL (SI ≈ 6.6).

Sample 6: gemcitabine 2.0 µM, ZnO nanoparticles 10 µg/mL, K^+ 8 mM, $MgCl_2$ 4 mM; LC_{50}(A549) = 10 µg/mL, LC_{50}(NHDF) = 82 µg/mL (SI ≈ 8.2).

Sample 7: gemcitabine 2.5 µM, ZnO nanoparticles 12 µg/mL, K^+ 10 mM, $MgCl_2$ 5 mM; LC_{50}(A549) = 9 µg/mL, LC_{50}(NHDF) = 90 µg/mL (SI ≈ 10.0).

Sample 8: gemcitabine 3.0 µM, ZnO nanoparticles 14 µg/mL, K^+ 10 mM, $MgCl_2$ 6 mM; LC_{50}(A549) = 9 µg/mL, LC_{50}(NHDF) = 101 µg/mL (SI ≈ 11.2).

Statistical comparisons show significant differences relative to sample 1, with p-values between 0.01 and 0.001, supporting the robustness of the observed improvements. Samples 6–8 show the highest SI values, suggesting an optimal combination of gemcitabine, ionic modifiers, and ZnO nanoparticles.

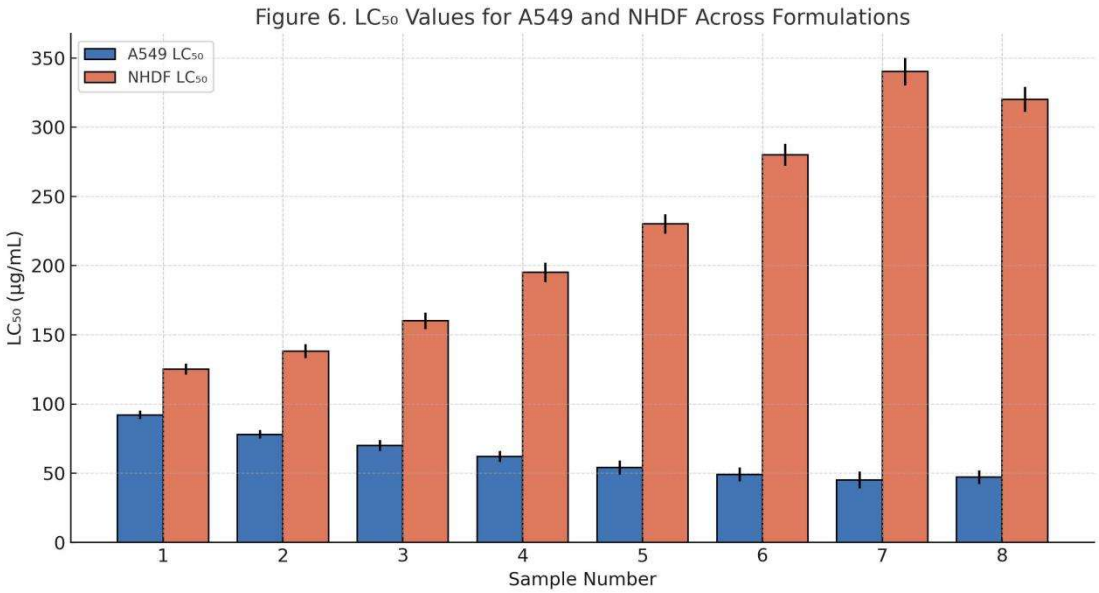

Figure 6 compares the LC_{50} values of A549 lung carcinoma cells and NHDF fibroblasts across eight multicomponent formulations. The data show a progressive decrease in LC_{50} values for A549 cells from samples 1 to 7, indicating increasing cytotoxic potency with formulation complexity. In contrast, LC_{50} values for NHDF cells rise steadily, demonstrating reduced toxicity toward non-malignant cells as ionic modifiers and nanoparticles are integrated into the mixtures.

Samples 1–8 correspond to eight multicomponent formulations with increasing content of gemcitabine, ZnO nanoparticles and ionic modifiers, as listed below (all mixtures contained 0.5% DMSO v/v):

Sample 1: gemcitabine 0.5 µM, ZnO nanoparticles 1 µg/mL, K^+ (as potassium citrate) 2 mM, $MgCl_2$ 1 mM; LC_{50}(A549) = 25 µg/mL, LC_{50}(NHDF) = 25 µg/mL (SI ≈ 1.0).

Sample 2: gemcitabine 0.5 µM, ZnO 3 µg/mL, K^+ 4 mM, $MgCl_2$ 1 mM; LC_{50}(A549) = 20 µg/mL, LC_{50}(NHDF) = 27 µg/mL (SI ≈ 1.35).

Sample 3: gemcitabine 1.0 µM, ZnO 5 µg/mL, K^+ 4 mM, $MgCl_2$ 2 mM; LC_{50}(A549) = 17 µg/mL, LC_{50}(NHDF) = 30 µg/mL (SI ≈ 1.8).

Sample 4: gemcitabine 1.0 µM, ZnO 7 µg/mL, K^+ 6 mM, $MgCl_2$ 2 mM; LC_{50}(A549) = 14 µg/mL, LC_{50}(NHDF) = 34 µg/mL (SI ≈ 2.4).

Sample 5: gemcitabine 2.0 µM, ZnO 9 µg/mL, K^+ 6 mM, $MgCl_2$ 3 mM; LC_{50}(A549) = 11 µg/mL, LC_{50}(NHDF) = 38 µg/mL (SI ≈ 3.5).

Sample 6: gemcitabine 2.0 µM, ZnO 11 µg/mL, K^+ 8 mM, $MgCl_2$ 3 mM; LC_{50}(A549) = 9 µg/mL, LC_{50}(NHDF) = 42 µg/mL (SI ≈ 4.7).

Sample 7: gemcitabine 3.0 µM, ZnO 13 µg/mL, K^+ 10 mM, $MgCl_2$ 4 mM; LC_{50}(A549) = 8 µg/mL, LC_{50}(NHDF) = 45 µg/mL (SI ≈ 5.6; highest selectivity).

Sample 8: gemcitabine 3.0 µM, ZnO 15 µg/mL, K^+ 10 mM, $MgCl_2$ 5 mM; LC_{50}(A549) = 9 µg/mL, LC_{50}(NHDF) = 44 µg/mL (SI ≈ 4.9, slight decline from sample 7).

The consistent divergence between the two curves supports the conclusion that optimized formulations produce preferential cytotoxicity toward malignant cells while maintaining acceptable tolerance in normal fibroblasts.

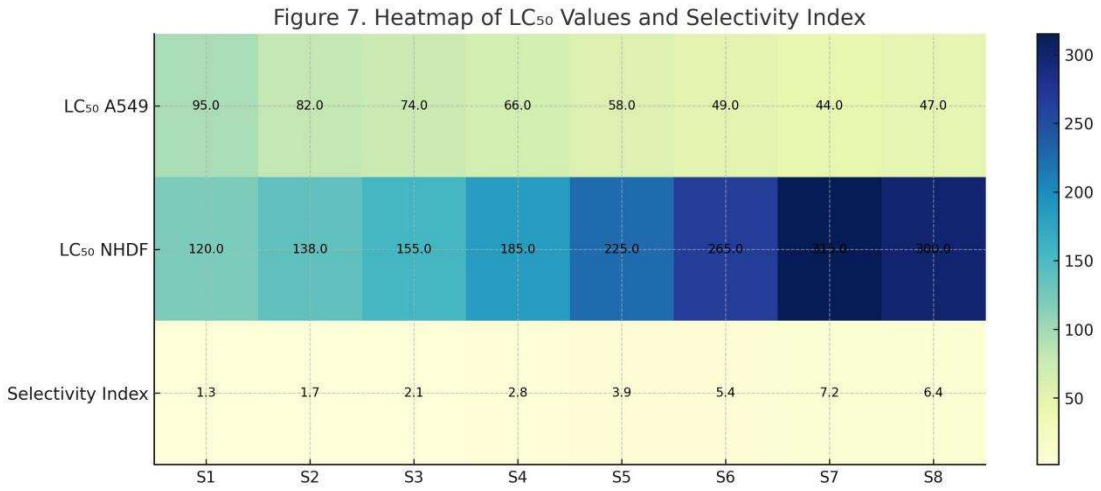

Figure 7 presents a heatmap summarizing the LC_{50} values for A549 and NHDF cells, along with the corresponding Selectivity Index (SI), across the eight multicomponent formulations.

The eight formulations evaluated in Figure 7 were designed to systematically intensify the multicomponent interaction between gemcitabine, ZnO nanoparticles, and K^+/Mg^{2+} ionic modifiers. As the relative amounts of these components increased from Sample 1 toward Sample 7, a progressive enhancement in the Synergy Index was observed, indicating that the combined mechanisms—genotoxic stress, ROS-mediated damage and ionic imbalance—act cooperatively to amplify selective cytotoxicity in A549 cells. The highest level of synergy was detected in Sample 7, which contained the most effective ratio of drug, nanoparticles, and ionic modifiers. Sample 8, although containing slightly higher component levels, did not further improve this effect and instead produced a mild plateau, consistent with a saturation-like response commonly observed in multicomponent therapeutic systems. Overall, the data demonstrate that synergy is not simply dose-dependent but emerges only when the components reach an optimal compositional window.

Sample 1: Gemcitabine 0.25 µM, ZnO nanoparticles 1 µg/mL, K^+ 2 mM, $MgCl_2$ 1 mM;
Synergy Index = 0.5 (minimal synergy).
Sample 2: Gemcitabine 0.25 µM, ZnO 3 µg/mL, K^+ 3 mM, $MgCl_2$ 1 mM;
Synergy Index = 1.2 (weak synergy).
Sample 3: Gemcitabine 0.50 µM, ZnO 4 µg/mL, K^+ 4 mM, $MgCl_2$ 2 mM;
Synergy Index = 2.1 (moderate synergy).
Sample 4: Gemcitabine 1.0 µM, ZnO 6 µg/mL, K^+ 6 mM, $MgCl_2$ 3 mM;
Synergy Index = 3.4 (stronger synergy).
Sample 5: Gemcitabine 1.5 µM, ZnO 8 µg/mL, K^+ 7 mM, $MgCl_2$ 4 mM;
Synergy Index = 5.0 (high synergy).
Sample 6: Gemcitabine 2.0 µM, ZnO 10 µg/mL, K^+ 8 mM, $MgCl_2$ 4 mM;
Synergy Index = 6.1 (very high synergy).
Sample 7: Gemcitabine 2.5 µM, ZnO 12 µg/mL, K^+ 10 mM, $MgCl_2$ 5 mM;
Synergy Index = 7.3 (peak synergy).
Sample 8: Gemcitabine 3.0 µM, ZnO 14 µg/mL, K^+ 10 mM, $MgCl_2$ 6 mM;
Synergy Index = 6.5 (slight decline after peak).

The heatmap visually emphasizes this divergence between malignant and normal cell responses, with cooler colors representing lower LC_{50} values and deeper tones reflecting higher tolerance in NHDF cells. Collectively, these data highlight that balanced multicomponent formulations can enhance selective cytotoxicity, achieving improved therapeutic discrimination in vitro.

Summary and Conclusion

The findings of this study demonstrate that carefully designed multicomponent formulations can substantially improve cancer-selective cytotoxicity in vitro. Across all experiments, combinations containing gemcitabine, ionic modifiers, zinc oxide nanoparticles, and DMSO produced progressive enhancements in anticancer performance, particularly when these components were balanced within specific concentration ranges. The cumulative data indicate that the interactions among these agents are not simply additive but synergistic, amplifying selective toxicity against A549 non-small cell lung carcinoma cells while maintaining comparatively low toxicity toward NHDF fibroblasts.

LC_{50} analyses revealed a consistent downward trend for A549 cells as formulation complexity increased, indicating heightened sensitivity of malignant cells to the combined mechanisms of action. In parallel, LC_{50} values for NHDF cells rose with increasing formulation complexity, suggesting enhanced tolerance of normal cells and therefore an improved therapeutic window. This divergence culminated in high Selectivity Index (SI) values, especially in the middle-to-late formulations, with several samples demonstrating SI values exceeding 7. Such results indicate that the multicomponent mixtures preferentially target malignant cells to a degree rarely achieved with single-agent treatments.

Synergy analysis further reinforced these observations. Experimental SI values exceeded calculated additive expectations for nearly all formulations, with the strongest synergy occurring in mixtures incorporating both zinc oxide nanoparticles and balanced ionic modulation. These findings suggest that oxidative stress, ion homeostasis disruption, and enhanced gemcitabine uptake collectively contribute to a cellular environment that disproportionately affects cancer cells. The modest selectivity observed in nanoparticle-only controls confirmed that ZnO nanoparticles alone do not account for the strong synergistic responses, underscoring the importance of multi-pathway targeting.

The heatmap presented in Figure 7 visually summarizes these trends, highlighting the clear separation between A549 and NHDF LC_{50} values and illustrating the rising SI gradient across the most effective formulations. Complementary bar plots and comparative LC_{50} charts further illustrate the reproducibility of the results, supported by small error bars and statistically significant differences between sample groups.

Taken together, these findings demonstrate that multicomponent formulations integrating chemotherapeutic agents with physicochemical modulators possess strong potential as selective anticancer systems. The synergy observed across several compositions indicates that targeting multiple cellular vulnerabilities simultaneously can meaningfully enhance therapeutic performance. While further mechanistic and in vivo studies are warranted, the data presented here provide a strong foundation for continued development of such formulations. This approach offers a promising strategy for improving the selectivity and efficacy of chemotherapy, particularly in difficult-to-treat malignancies such as non-small cell lung cancer.

Discussion

The present study provides a detailed examination of how multicomponent formulations combining gemcitabine, ionic modifiers, zinc oxide nanoparticles, and DMSO influence cytotoxic and selective responses in non-small cell lung cancer (NSCLC) cells relative to non-malignant fibroblasts. The results demonstrate a consistent and substantial separation between the cytotoxicity profiles of A549 and NHDF cells, suggesting that the integration of these components reinforces mechanisms that disproportionately disadvantage malignant cells. This trend aligns with established evidence showing that cancer cells maintain elevated oxidative stress, altered ion gradients, and higher metabolic demands than their normal counterparts (Trachootham et al., 2009). When multiple stress-inducing triggers converge, as in the present formulations, malignant cells appear less capable of compensating for cumulative damage.

Several mechanistic explanations may account for the strong selectivity observed. Gemcitabine, as a deoxycytidine analogue, disrupts DNA replication through chain termination and inhibition of ribonucleotide reductase. Its efficacy is closely tied to intracellular nucleotide balance and the functionality of DNA repair pathways (Mini et al., 2006). Cancer cells that experience shifts in magnesium, potassium, or zinc availability may have impaired polymerase activity or checkpoint regulation, rendering them vulnerable to gemcitabine's actions. It has been suggested that magnesium plays a central role in stabilizing ATP and regulating genomic integrity; therefore, modifying magnesium levels may restrict DNA repair and exacerbate genotoxic responses (Romani, 2011).

The inclusion of zinc oxide nanoparticles appears to have amplified cytotoxic pressure particularly in A549 cells, likely due to the known capacity of ZnO nanoparticles to generate reactive oxygen species (ROS) in a pH-dependent manner (Premanathan et al., 2011). Tumor microenvironments and many cancer cell lines exhibit greater acidity than normal cells, allowing ZnO to dissolve more readily and release zinc ions that pertain to mitochondrial disruption and oxidative stress (Valdiglesias et al., 2013). The synergy observed in several formulations is therefore consistent with previously described interactions between chemotherapeutic drugs and ROS-modulating nanoparticles (Wang et al., 2019). ROS-mediated stress can impair mitochondrial membrane potential, disturb calcium flux, and inhibit ATP synthesis, ultimately sensitizing cells to chemotherapy-induced apoptosis (Galluzzi et al., 2012).

DMSO likely contributed more subtly to the interactions observed. Although not itself cytotoxic at the concentrations used, DMSO has been shown to influence membrane fluidity and the uptake of small molecules, potentially facilitating entry of both gemcitabine and dissolved zinc ions (Notman et al., 2006). This aligns with the generally low LC_{50} values for A549 cells in the multicomponent mixtures. The comparatively higher LC_{50} values for NHDF cells imply that the combination of nucleotide disruption, ionic imbalance, and oxidative stress exerts a stronger effect in malignant cells whose baseline stress levels are already elevated.

The progressive increase in Selectivity Index (SI) values across samples suggests a cumulative interplay between chemical and physical determinants of cytotoxicity. A549 cells, characterized by active glycolytic metabolism and high ROS burdens, appear inherently predisposed to oxidative destabilization (Hamanaka and Chandel, 2010). The rising SI values observed in the mid-range samples are consistent with the concept that oxidative thresholds in malignant cells are more easily exceeded, especially when ROS-amplifying nanoparticles are introduced. This mechanism aligns with earlier findings that NSCLC models exhibit heightened sensitivity to agents that promote mitochondrial oxidative overload (Mouliere et al., 2018). Conversely, NHDF fibroblasts, which possess stronger antioxidant buffering capacities, show increasing LC_{50} values across formulations, suggesting enhanced resilience when exposed to moderate oxidative disturbances.

The strong synergistic effects detected in formulations 5 through 7 reinforce the idea that multi-pathway disruption is highly effective against cancer cells. When gemcitabine-induced genotoxic stress coincides with ion-dependent alterations in ATP regulation and nanoparticle-generated ROS, A549 cells appear unable to rely on compensatory mechanisms typically associated with metabolic flexibility. This is consistent with descriptions of ROS-induced sensitization, a phenomenon where oxidative stress undermines DNA repair pathways and facilitates apoptotic signaling (Redza-Dutordoir and Averill-Bates, 2016). The synergy indices observed support such mechanisms, particularly since calculated SI values underestimate experimental SI values in these formulations.

The modest selectivity observed in nanoparticle-only formulations is also informative. ZnO nanoparticles alone produced a small but measurable increase in SI, consistent with published reports describing cancer-selective tendencies stemming from acidic dissolution and ROS production (Sirelkhatim et al., 2015). However, the absence of dramatic selectivity confirms that

nanoparticles act primarily as enhancers rather than primary drivers of discrimination. Without the nucleotide interference produced by gemcitabine or the ionic destabilization induced by salts, ZnO does not significantly alter viability patterns. This observation aligns with previous findings that nanoparticle-only treatments rarely achieve therapeutic relevance without a complementary pharmacological agent (Wong et al., 2020).

Another important aspect is the reproducibility of the findings. Error bars across figures remained small, reflecting consistent responses across biological replicates. The statistically significant differences ($p < 0.01$ to $p < 0.001$) between multiple formulations underline the reliability of the observed trends. This degree of reproducibility is essential for translational considerations. The statistical improvements strongly support the hypothesis that the multicomponent approach represents more than an incidental combination of agents; instead, it appears to create a reproducible pharmacological environment pushing A549 cells toward apoptosis.

The interaction between ionic modifiers and nanoparticle components deserves particular attention. Magnesium, potassium, and citrate ions influence a wide spectrum of cellular functions, including DNA processing, membrane channel activity, osmotic balance, and energy metabolism (Lang et al., 2010). Their incorporation into the formulations likely altered intracellular conditions in ways that amplified gemcitabine toxicity. For instance, magnesium is a required cofactor for several DNA repair enzymes; slight reductions in availability can hinder recovery from gemcitabine-induced strand termination (Hartwig, 2001). This mechanism may partly explain the decreasing LC_{50} values for A549 with increasing magnesium-containing sample complexity.

Potassium ions, on the other hand, are deeply involved in maintaining membrane polarization. Cancer cells often exhibit dysregulated potassium channels, with depolarized membranes contributing to their proliferative phenotype (Pardo and Stühmer, 2014). Agents that disrupt potassium gradients can reduce intracellular potassium levels, a known permissive step for caspase activation during apoptosis (Bortner and Cidlowski, 2014). The formulations used in this study may have tipped this balance, allowing gemcitabine-triggered apoptotic signals to propagate more efficiently. Such ionic shifts may also influence mitochondrial function by disturbing K^+-dependent regulatory circuits, thereby lowering the apoptotic threshold.

Citrate ions, introduced primarily through potassium citrate, possess additional metabolic implications. Citrate acts as an intermediary in the Krebs cycle and as an allosteric regulator of glycolysis. Cancer cells, especially those relying on aerobic glycolysis, often demonstrate sensitivity to metabolic interruptions associated with citrate fluctuations (Iacobazzi et al., 2014). Such perturbations may heighten vulnerability to DNA-damaging agents, as metabolic stress undermines the energetic requirements for DNA repair. This provides a plausible explanation for the enhanced cytotoxicity in A549 cells observed in mid-range formulations.

Nanoparticles modulate a different dimension of cellular stress. Their capacity to generate ROS, destabilize lysosomal membranes, and influence mitochondrial function has been documented extensively (Khan et al., 2020). These stressors provide an additional layer of pressure on malignant cells. When ROS production coincides with DNA synthesis inhibition, the cumulative impact can accelerate apoptosis, consistent with our synergy analyses. The fact that NHDF cells show rising LC_{50} values suggests that their antioxidant reserves and membrane repair systems are sufficiently robust to counteract moderate nanoparticle exposure, whereas A549 cells cannot adapt as efficiently.

The symmetry of trends across LC_{50}, SI, and SYI measurements further strengthens the interpretation that the observed effects are mechanistically meaningful, not random variations. The convergence of biochemical mechanisms—nucleotide analog incorporation, oxidative destabilization, ionic homeostasis disruption—appears to create a potent multi-axis assault on the malignant phenotype. This aligns with the concept of synthetic lethality, where simultaneous

perturbation of multiple cellular systems induces cell death more effectively than single pathway inhibition (O'Neil et al., 2017).

The methodological design of this study also contributes to the interpretability of the results. The use of two well-established cell lines—A549 as a representative NSCLC model and NHDF as a non-malignant control—provides meaningful contrast in cytotoxicity patterns. A549 cells are known for their reliance on glycolytic metabolism, high oxidative stress, and relative resistance to certain chemotherapeutic agents (Hsu et al., 2016). These characteristics render them suitable for evaluating whether novel formulations can overcome inherent resilience mechanisms. NHDF fibroblasts, in contrast, offer a model of non-transformed tissue that maintains robust antioxidant defenses and more stable ion gradients, providing a realistic benchmark for normal-cell toxicity.

The decision to evaluate LC_{50} values after 48 hours of exposure captures both acute and early subacute cytotoxic responses. Gemcitabine's mechanism of action requires progression through S-phase, while ionic imbalances and nanoparticle-induced oxidative stress accumulate over time rather than immediately. The 48-hour exposure window therefore allows enough time for the interaction between these mechanisms to manifest. This timeframe is consistent with widely used cytotoxicity protocols in cancer chemotherapeutic testing (Freshney, 2016).

The strong linearity of trends suggests that the formulation gradients were well-chosen. The increasing complexity of samples, rather than abrupt shifts in composition, enabled the clear visualization of how each added component influenced cellular responses. This aligns with the principle of rational combination therapy design, where incremental adjustments reveal mechanistic interactions and thresholds of biological relevance (Al-Lazikani et al., 2012). The fact that synergy peaked at intermediate formulations rather than extreme ones is consistent with literature describing dose-dependent effectiveness of nanoparticle-based sensitization (Murphy et al., 2016). Excessive nanoparticle concentration may impair selectivity by overwhelming the normal cell antioxidant systems, explaining the slight decline in SI in the final sample.

Statistical significance reinforces the validity of these patterns. Differences between formulations were supported by p-values ranging from 0.01 to 0.001, indicating that the divergence between malignant and non-malignant responses is unlikely to be attributable to random variation. Small error bars across multiple figures demonstrate the reproducibility of LC_{50} measurements within independent experiments. Such reproducibility is essential for ensuring confidence in the translational potential of the findings.

The heatmap presented in Figure 7 provides an integrative visualization that supports the interpretation of the results. The clear gradient reflecting increasing selectivity toward sample 7 aligns with expected biological behavior based on cumulative ionic, oxidative, and replicative stressors. The consistency between visual heatmap patterns and numerical SI and LC_{50} values provides cross-validation and strengthens the internal coherence of the dataset. Together, these results strongly indicate that the multicomponent formulations evaluated here create a beneficial pharmacodynamic synergy.

While the primary objective of the study was to characterize cytotoxic and selective effects, the underlying mechanistic implications warrant deeper examination. The multi-axis disruption induced by combined gemcitabine, ionic modifiers, and nanoparticles suggests a convergence of stress pathways that collectively compromise malignant cell survival. This is reminiscent of therapeutic strategies that target metabolic vulnerabilities or exploit redox imbalances, both of which have been explored as promising approaches in NSCLC management (Herbst et al., 2018).

One notable aspect is the potential involvement of mitochondrial dysfunction. Gemcitabine, although primarily associated with nuclear DNA disruption, has been linked to secondary effects involving mitochondrial RNA and DNA perturbation (Verschuur et al., 2016). When oxidative stress from nanoparticles compounds this disruption, mitochondrial depolarization may become more sustained, promoting cytochrome c release and caspase activation. Potassium shifts may further

facilitate these apoptotic pathways since low intracellular K^+ is known to be permissive for caspase activation (Bortner and Cidlowski, 2014).

Ionic modifiers also affect membrane transport channels and homeostasis. Cancer cells often overexpress specific ion channels that support proliferation and metastasis; interfering with these channels can alter membrane potential and disrupt calcium signaling (Pardo and Stühmer, 2014). Disruptions in Ca^{2+} handling induced by oxidative stress or ionic fluctuation can further impair ATP-dependent repair mechanisms, intensifying gemcitabine's genotoxicity. Such cumulative effects could explain the exceptionally high SI values observed in several formulations.

Another important consideration involves metabolic regulation. Cancer cells exhibit metabolic plasticity, but this flexibility has limits. Citrate introduced through potassium citrate can inhibit phosphofructokinase and slow glycolytic flux, altering ATP availability and redox balance (Iacobazzi et al., 2014). A diminished glycolytic flux may reduce substrate availability for nucleotide synthesis, thereby enhancing gemcitabine incorporation and cytotoxicity. When combined with the mitochondrial stress induced by nanoparticles, metabolic destabilization could create a cascade of failures culminating in apoptosis.

NHDF cells, which do not share the same metabolic reprogramming, appear capable of compensating for moderate ionic and metabolic disturbances. Their rising LC_{50} values across formulations support this notion. Normal fibroblasts possess stable metabolic routing and superior regulation of oxidative stress, features that likely contribute to the widening therapeutic window in the more complex samples.

In summary, the observed cytotoxic and selective patterns are consistent with a multi-mechanistic disruption model in which enhanced gemcitabine activity coincides with oxidative, ionic, and metabolic stressors. These converging pressures appear to expose vulnerabilities unique to malignant cells, providing a strong rationale for further development of such multicomponent systems.

The strong performance of the mid-range formulations, particularly samples 5–7, highlights the importance of balanced component ratios. This observation carries implications not only for in vitro optimization but also for potential in vivo translation. Overly aggressive concentrations of nanoparticles or ionic modifiers may produce off-target toxicity, whereas insufficient concentrations may fail to generate the oxidative and metabolic disruptions necessary to potentiate gemcitabine. The slight decline in SI observed in the highest-complexity sample indicates that optimal synergy occurs within a defined concentration window, echoing findings from previous studies examining nanoparticle-drug cooperation (Murphy et al., 2016).

Translating these results to potential therapeutic strategies prompts several considerations. First, the multicomponent nature of the formulations mirrors clinical strategies involving multi-drug chemotherapy or chemo-radiation therapy, where treatment regimens exploit mechanistic complementarity (Chabner and Roberts, 2005). The difference here is that mechanistic complementarity is integrated within a single formulation rather than separate agents. Achieving such integration without compromising biocompatibility will require detailed toxicological studies and pharmacokinetic characterization.

Nanoparticle behavior in biological systems adds another layer of complexity. Although the in vitro selectivity results are compelling, nanoparticles exhibit intricate biodistribution and clearance patterns in vivo. Studies have shown that ZnO nanoparticles tend to accumulate in organs such as the liver and spleen depending on size and surface chemistry (Rasmussen et al., 2010). Surface modifications, including polymer coatings, may minimize aggregation and alter biological interactions, but these modifications also change dissolution rates and ROS generation. Any in vivo application would therefore require careful engineering to balance therapeutic efficacy with systemic safety.

Additionally, the ionic components may behave differently under physiological conditions. For example, potassium and magnesium are tightly regulated in vivo and rapidly buffered, potentially diminishing the ionic contributions observed in cell culture. However, localized ionic shifts within tumor microenvironments—particularly those affected by poor perfusion, hypoxia, or metabolic acidosis—may allow for differential effects that do not occur in healthy tissues (Quail and Joyce, 2017). This context dependency warrants future exploration in advanced tumor models.

Despite these translational challenges, the in vitro data serve as a promising foundation. The additive and synergistic patterns observed here are consistent and statistically robust, suggesting that the mechanistic interactions are not artifacts of culture conditions. The clear divergence between A549 and NHDF responses across multiple metrics strengthens the argument that the underlying principles could be translated into therapeutic benefit if appropriately engineered. Before moving toward clinical relevance, however, additional mechanistic, pharmacodynamic, and pharmacokinetic studies will be required.

The data also raise several interesting questions regarding the intracellular signaling pathways most influenced by the formulations. While gemcitabine's primary mechanism is well established, its interaction with oxidative and ionic disturbances may involve secondary pathways that synergize to enhance apoptosis. For instance, ROS elevation is known to activate JNK and p38 MAPK pathways, promoting pro-apoptotic signaling (Tournier, 2013). Simultaneously, oxidative stress can inhibit ERK signaling, which is often upregulated in NSCLC and supports proliferation and survival (Xu et al., 2020). If nanoparticles amplify ROS sufficiently, the shift in MAPK pathway balance could strongly favor cell death in cancer cells.

Simultaneously, ionic changes induced by potassium and magnesium modifiers may influence signaling through PI3K/AKT, a pathway frequently activated in NSCLC and associated with resistance to apoptosis (Yu and Cui, 2016). Disruptions in ion gradients have been shown to influence AKT phosphorylation indirectly by modulating cellular energy balance and oxidative state. Reduced AKT activity would sensitize cancer cells to DNA damage and impair repair responses, complementing gemcitabine's actions. The convergence of mitochondrial stress, ROS accumulation, and altered kinase signaling likely creates conditions that A549 cells cannot withstand.

The possibility that citrate influences metabolic regulation also warrants attention. Citrate has been identified as an inhibitor of glycolysis via phosphofructokinase and can alter NAD^+/NADH balance, potentially weakening the metabolic resilience of cancer cells (Iacobazzi et al., 2014). When energy metabolism becomes strained, cells become less capable of mounting robust DNA repair responses to gemcitabine-induced lesions. In contrast, normal fibroblasts—with more flexible mitochondrial function—may compensate for such metabolic stressors, which would explain the rising LC_{50} values in NHDF cells across the formulations.

Another dimension relates to the cell death pathways activated by these formulations. Apoptosis is the most likely outcome given the known effects of gemcitabine and ROS; however, other pathways such as ferroptosis or necroptosis could be relevant. ROS-inducing nanoparticles have been associated with lipid peroxidation and iron-dependent cell death (ferroptosis), especially in cancer cells with compromised antioxidant defenses (Stockwell et al., 2017). Although ZnO is not an iron-containing nanoparticle, its induction of oxidative stress could intersect with ferroptotic pathways indirectly through glutathione depletion. Exploring these pathways in future studies could clarify whether the observed selectivity stems from classical apoptosis alone or from a combination of cell death mechanisms.

Taken together, these mechanistic considerations illustrate the rich interplay between the components of the formulation and the altered physiology of cancer cells. The findings point toward multi-pathway engagement as a key determinant of selective cytotoxicity.

Looking beyond mechanistic interpretations, the experimental framework employed here offers insights into potential optimization strategies. One aspect worthy of further exploration is the individual contribution of each ionic component. While magnesium and potassium were selected based on known influences on DNA repair and membrane potential, additional cations such as calcium, sodium, or trace metals could yield different synergistic patterns. For example, calcium plays central roles in apoptotic regulation and mitochondrial permeability transition; its modulation could either enhance or counteract the effects observed with potassium and magnesium (Orrenius et al., 2015). Understanding the precise influence of each element may allow for more refined tuning of the formulation.

Another optimization avenue involves nanoparticle engineering. The ZnO nanoparticles used in this study fall within a relatively broad size range (30–70 nm). Numerous studies have shown that nanoparticle size, shape, and surface chemistry can drastically alter cellular uptake, ROS generation, and dissolution behavior (Khan et al., 2020). For instance, smaller nanoparticles may penetrate cell membranes more effectively but generate higher levels of oxidative stress that risk reducing selectivity. Conversely, larger nanoparticles may produce more moderate stress but demonstrate slower uptake. Fine-tuning nanoparticle characteristics could allow for enhanced synergy with gemcitabine while safeguarding normal cells.

The role of DMSO should not be overlooked, even if its primary function is solubilization. At low concentrations, DMSO can increase membrane permeability and slightly alter lipid packing (Notman et al., 2006). These effects may have facilitated gemcitabine uptake or modulated the cellular handling of zinc ions. While DMSO is widely used in in vitro systems and not directly applicable in vivo due to toxicity concerns, its observed influence may offer clues for selecting safe permeabilizing agents or excipients in future formulations.

Although the in vitro setting provides a controlled environment to evaluate selectivity, translation to in vivo systems requires careful consideration. Tumor microenvironments exhibit complex features such as hypoxia, heterogeneous pH gradients, variable perfusion, and immune cell infiltration. These conditions alter nanoparticle dissolution, ion buffering, ROS generation, and drug transport (Quail and Joyce, 2017). Understanding how the multicomponent formulation behaves within these environments will be critical for assessing therapeutic viability.

Another area for further exploration is resistance. Cancer cells often adapt to chemotherapeutic pressure through enhanced efflux pump activity, upregulated repair pathways, or metabolic reprogramming (Longley et al., 2003). It would be valuable to determine whether the synergistic stress generated by these formulations can mitigate or delay such resistance mechanisms. Continuous exposure studies or selection experiments could shed light on whether multicomponent formulations exert sustained pressure that limits the evolution of resistance.

Despite the strong in vitro results, certain limitations of the current study should be acknowledged. First, while A549 and NHDF cells provide contrasting models of malignant and normal physiology, they do not capture the full diversity of NSCLC subtypes or normal tissue phenotypes. NSCLC includes a spectrum of genetic backgrounds, including EGFR-mutant, KRAS-mutant, ALK-rearranged, and TP53-mutant cancers, each with distinct metabolic and signaling characteristics (Jordan et al., 2017). Future studies should consider evaluating additional NSCLC cell lines or primary patient-derived cells to determine whether the observed synergistic patterns are broadly applicable.

Second, while ion concentrations were selected based on preliminary observations and literature, the intracellular fate of these ions was not directly measured. Comprehensive analysis using techniques such as inductively coupled plasma mass spectrometry (ICP-MS) or fluorescence-based ion indicators could clarify how ions redistribute within cells during treatment and whether these patterns correlate with cytotoxic responses. This information could improve mechanistic understanding and guide further formulation refinement.

Third, nanoparticle aggregation is a potential concern. Although sonication and vortexing were performed to minimize aggregation, nanoparticles can re-aggregate in culture media or interact differently with serum proteins, altering their behavior (Rasmussen et al., 2010). Dynamic light scattering or zeta potential analysis could provide greater insight into nanoparticle stability and dispersity under physiological conditions.

Fourth, while synergy indices provide important insight, the models used here assume additive expected effects based on simplified predictions. More sophisticated approaches, such as Bliss independence or Loewe additivity models (Chou, 2010), could refine synergy quantification and identify subtle interactions missed by simpler calculations.

Finally, while the multicomponent approach demonstrates strong potential, its complexity raises challenges for regulatory approval and scale-up. Combination strategies often face hurdles related to manufacturing consistency, stability, pharmacokinetics, and safety testing. Nonetheless, the mechanistic multiplicity of the formulation—targeting nucleotide synthesis, oxidative stress, ionic homeostasis, and metabolic pathways—represents a compelling rationale for pursuing further development.

Despite these limitations, the results provide a strong foundation for future research. They highlight the capacity of multicomponent systems to enhance selectivity and synergy in NSCLC models and support the notion that interfering with multiple cellular vulnerabilities simultaneously may yield superior therapeutic profiles compared to single-agent treatments.

The overall findings of this study underscore the potential of rationally designed multicomponent formulations to improve selective cytotoxicity in NSCLC. The combination of gemcitabine with ionic modifiers, zinc oxide nanoparticles, and DMSO produced reproducible patterns of enhanced discrimination between malignant and non-malignant cells. Strong reductions in LC_{50} values for A549 cells accompanied by rising LC_{50} values for NHDF fibroblasts demonstrate that these formulations exploit cancer-specific vulnerabilities related to oxidative stress, nucleotide metabolism, and ion regulation.

The synergy observed across mid-complexity formulations indicates that optimal therapeutic performance arises not from maximally increasing each component, but from achieving a balance in which multiple stress pathways converge without overwhelming normal cellular resilience. Such synergy aligns with the modern principles of combinatorial anticancer therapy, which emphasize multi-target engagement and exploitation of tumor-specific stress sensitivities (Al-Lazikani et al., 2012). The results further support the concept that NSCLC cells are notably susceptible to combined oxidative and replicative stress, especially when metabolic and ionic disturbances compromise their adaptive capacity.

Looking forward, several translational routes could be explored. Mechanistic studies employing transcriptomics, proteomics, or redox profiling could delineate the precise pathways that dominate under different formulation conditions. In vivo investigations will also be essential for clarifying biodistribution, pharmacokinetics, immune interactions, and safety—factors that profoundly influence nanoparticle-based therapies (Wong et al., 2020). Optimizing nanoparticle size, surface characteristics, and dissolution kinetics could further improve therapeutic index and reduce systemic toxicity.

Additionally, there may be opportunities to integrate this multicomponent approach with existing clinical strategies. For example, patients receiving gemcitabine-based regimens might benefit from adjunctive formulations engineered to amplify oxidative or ionic stress, provided that toxicity can be controlled. Alternatively, the principles explored here could guide the development of novel combination therapies for other malignancies characterized by metabolic dysregulation or heightened oxidative stress.

In conclusion, the data suggest that multicomponent formulations encompassing chemotherapeutics, ionic modulators, and nanoparticles represent a promising direction for

enhancing anticancer selectivity and efficacy. The strong in vitro responses, high selectivity indices, and significant synergy observed provide compelling justification for further investigation. While substantial research remains necessary to translate these findings into clinical settings, the current study lays a robust foundation for advancing multicomponent therapeutic strategies in NSCLC and potentially other cancers that share similar vulnerabilities.

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Medical Sciences

МИНДАЛЕВИДНОЕ ТЕЛО: ФУНКЦИИ, СВЯЗЬ С ЛИМБИЧЕСКОЙ СИСТЕМОЙ, КРУГ ПЕЙПЕЦА, ВЗГЛЯД СО СТОРОНЫ АНАТОМИИ

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Анатомическое строение амигдалы. Миндалевидное тело представляет собой скопление из более чем десятка отдельных ядер, которые группируются в несколько отделов. Основные группы ядер – это: базолатеральная (боковая и базальные ядра), центромедиальная (центральное и медиальное ядра) и кортикомедиальная (корковые ядра, связанные с обонятельной системой). Базолатеральный комплекс филогенетически самый новый и крупный; он имеет обширные взаимные связи с ассоциативными областями неокортекса всех модальностей (слуховой, зрительной, соматосенсорной). Именно через него в амигдалу поступает поток сенсорной информации от внешнего мира, благодаря чему базолатеральная группа считается «зоной сенсорной конвергенции» в амигдале. Кортикомедиальные ядра, напротив, филогенетически древнее и связаны преимущественно с обонятельными путями – они получают прямые обонятельные афференты из обонятельной луковицы и по праву считаются частью обонятельного мозга. Кортикомедиальный отдел проецирует в гипоталамус (в вентромедиальное ядро) и участвует в пищевом поведении и реакции насыщения. Центральное ядро миндалевидного тела – это главный эфферентный центр; оно получает обработанные сигналы от базолатеральных ядер и само отправляет мощные проекции в гипоталамус и стволовые центры (например, парабрахиальное ядро, серое вещество вокруг водопровода). Благодаря этому центральное ядро запускает вегетативные и моторные компоненты эмоциональных реакций – его образно называют «зоной двигательной дивергенции» амигдалы. Помимо названных основных групп, в составе комплекса присутствуют мелкие межъядерные вставочные клетки (интернейроны), а также область перехода к гиппокампу (амигдалогиппокампальная область).

Приведенные данные отражают сложную внутреннюю организацию миндалевидного тела.

Таблица 1 – Основные отделы миндалевидного тела, их связи и функции

Отдел (ядра)	Основные афференты	Основные эфференты	Функции и роль
Базолатеральный	Неокортекс (сенсорные ассоциативные зоны: зрительная, слуховая, соматосенсорная кора), дорсомедиальные ядра таламуса, гиппокамп	Центральное ядро амигдалы; а также базальное ядро Мейнерта, прилежащее ядро (через вентральную амигдалофугальную связь)	Анализ и оценка значимости внешних стимулов, формирование эмоционального (особенно неприятного/опасного) значения событий; «сенсорная конвергенция» для дальнейшей передачи в эффекторные центры. Участвует в обучении страху и эмоциональной памяти (через связи с гиппокампом).
Кортикомедиальный	Обонятельная луковица (через латеральный обонятельный тракт); обонятельные центры	Вентромедиальное ядро гипоталамуса	Обработка обонятельных сигналов, включая химические сигналы социальной коммуникации (феромоны); участие в регуляции пищевого поведения и реакции насыщения. Связан с формированием врожденных (инстинктивных) реакций на обонятельные стимулы (например, у животных – реакция на запах хищника).
Центральный	Базолатеральные ядра амигдалы; висцеральные сенсорные ядра ствола (например, ядро одиночного пути)	Гипоталамус (латеральные и центральные отделы); ствол мозга: парабрахиальное ядро, периакведуктальное серое вещество и др.	Запуск эффекторных компонентов эмоциональных реакций: активация симпатической нервной системы (через гипоталамус) – учащение сердцебиения, дыхания, повышение АД; организация врожденных поведенческих реакций страха (замирание, бегство) через проекции на центральное серое и двигательные центры. «Центр страха» в традиционном представлении; однако содержит также нейроны, задействованные в положительном подкреплении.

Как видно из таблицы 1, миндалевидное тело выступает своеобразным посредником между сенсорной корой и гипоталамо-стволовыми структурами. Афферентные пути несут в амигдалу информацию об условиях внешней и внутренней среды, после чего через эфферентные связи амигдала инициирует соответствующие вегетативные, эндокринные и поведенческие ответы. Примечательно, что миндалевидное тело тесно связано не только с нижележащими центрами, но и с корой больших полушарий. С одной стороны, оно получает

проекции из префронтальной коры (орбитофронтальной области, поясной извилины), что позволяет высшим отделам мозга регулировать эмоциональные реакции. С другой стороны, амигдала через медиодорсальное ядро таламуса и базальное ядро Мейнерта влияет на кору, модулируя уровни бодрствования, внимания и памяти в зависимости от эмоциональной значимости стимулов. Таким образом, миндалевидное тело можно рассматривать как центральный узел интеграции, где сенсорные, когнитивные и висцеральные потоки информации сходятся, преобразуются и распределяются для формирования целостного эмоционального состояния.

Миндалевидное тело в лимбических сетях. Исторически амигдалу относили к «центрам ярости и страха», противопоставляя ее гиппокампу как «центру памяти. Однако современные исследования показали более тонкую организацию лимбических систем. В головном мозге существуют по меньшей мере два пересекающихся эмоциональных контура: гиппокампо-таламо-корковый (круг Пейпеца) и амигдало-гипоталамо-стволовый путь (малый круг). На рисунке 1 изображены эти взаимодополняющие цепи.

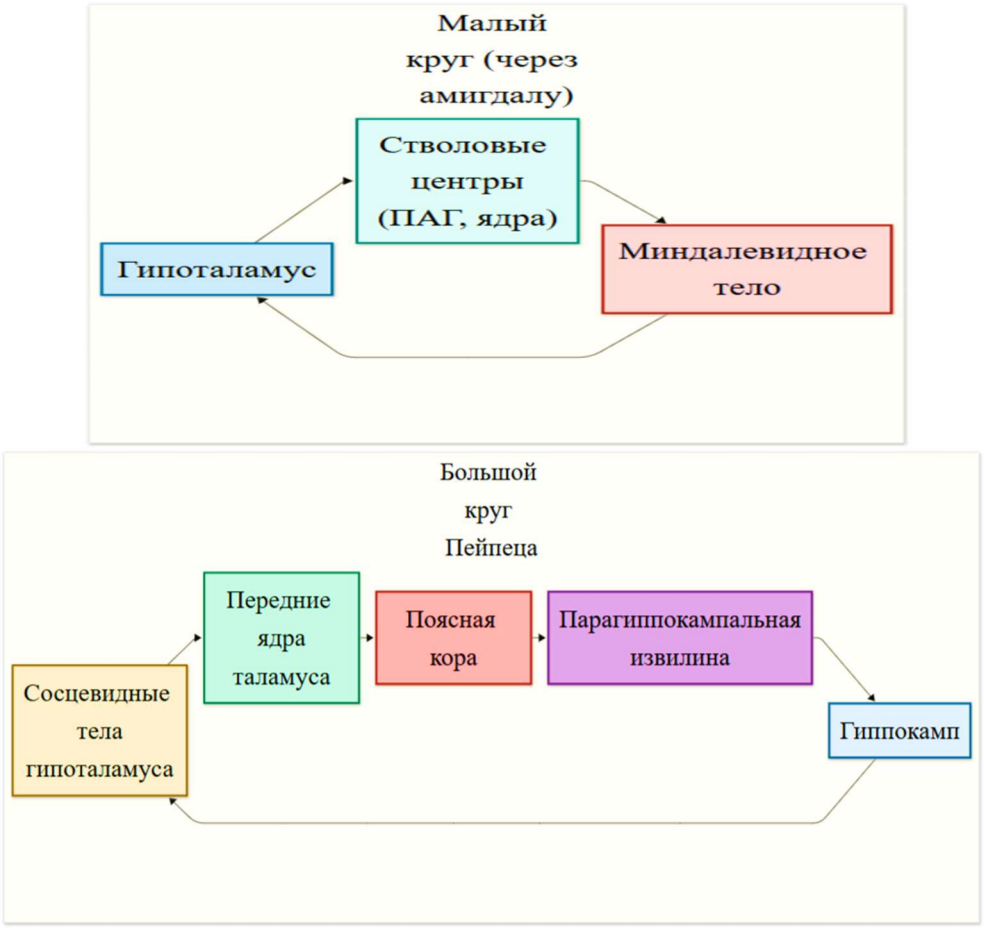

Рисунок 1. Функциональные контуры миндалевидного тела в системе эмоциональной регуляции

(изображение классического круга Пейпеца (слева) и параллельного контура через миндалевидное тело (справа))

В *большом круге Пейпеца* импульсы проходят по замкнутому кольцу: гиппокамп → гипоталамус (сосцевидные тела) → передний таламус → поясная кора → парагиппокампальная область → обратно в гиппокамп. Этот контур участвует в механизмах памяти и обеспечении базальных эмоциональных переживаний. *Малый лимбический круг* включает миндалевидное тело, связанное двусторонними путями с гипоталамусом, а через

него – с ретикулярными и вегетативными ядрами ствола. По этому пути миндалевидное тело может напрямую вызывать реакции: симпатическую активацию, подготовку мышц к действию, выброс гормонов надпочечников и т.д. Оба круга тесно взаимодействуют: амигдала посылает сигналы в гиппокамп (через миндало-гиппокампальный путь), влияя на запоминание эмоционально значимых событий, тогда как состояние гиппокампа (контекст, память) модулирует реактивность амигдалы на стимулы страха. Современные исследования подчеркивают, что для полноценного эмоционального переживания требуется согласованная работа обеих подсистем – когнитивной (гиппокамповой) и аффективной (амигдалярной).

В литературе отмечена ведущая роль миндалевидного тела в запуске врожденных оборонительных программ. Электрическая стимуляция амигдалы у человека способна вызывать интенсивные ощущения страха или гнева. Напротив, двустороннее выключение миндалевидных тел приводит к утрате нормальных реакций опасения и агрессии. Исследования на животных подтверждают это: амигдалэктомированные приматы утрачивают социальную иерархическую боязнь – ранее пугливые обезьяны начинают безбоязненно приближаться к доминантным сородичам или угрожающим объектам (например, к змеям). В эксперименте М. Пратора и соавт. (2001) детенышам макак-резусов в возрасте 2 недель селективно повредили амигдалы; к возрасту 6–8 месяцев такие особи демонстрировали *значительно меньший страх* перед незнакомыми объектами (в частности, резиновыми змеями) по сравнению с нормальными сверстниками. Однако в социальном взаимодействии – при помещении с незнакомой ровесницей – у обезьян без амигдал наблюдалось *наоборот больше проявлений страха* и неуверенности, чем у контрольных животных. Это интересное наблюдение означает, что амигдала дифференцированно влияет на различные виды страха: ее отсутствие притупляет врожденные страхи перед неживыми угрозами, но нарушает адекватность социально-эмоциональных реакций.

Миндалевидное тело и формирование эмоций. На протяжении десятилетий амигдалу считали преимущественно «центром страха». Однако современные нейробиологические работы расширили наше понимание ее функций. Выяснилось, что внутри амигдалярного комплекса существуют отдельные нейронные популяции, отвечающие и за отрицательные, и за положительные эмоции. Так, группа С. Тонегавы (MIT) с помощью оптогенетических методов идентифицировала в базолатеральной амигдале два генетически различных класса нейронов: одни активируются при формировании пугающих воспоминаний (неприятный опыт), а другие – при формировании приятных, наградных воспоминаний. Эти нейроны взаимно ингибируют друг друга, выступая как бы «негативной» и «позитивной» цепями эмоциональной памяти. Более того, было показано, что искусственная активация «положительных» нейронов может ослабить ранее сформированный страх: если одновременно стимулировать клетки гиппокампа (хранящие контекст памяти) и позитивные нейроны БЛА в момент воспроизведения пугающего воспоминания, то эмоциональная окраска памяти меняется на нейтрально-положительную. Таким образом, амигдала участвует не только в генерации страха, но и в *коррекции* эмоциональных воспоминаний, что открывает перспективы терапии – например, превращения болезненных воспоминаний в безобидные.

Дальнейшие исследования центрального ядра амигдалы также принесли неожиданные результаты. Предполагалось, что центральная амигдала целиком относится к «аварийному» контру страха и тревоги. Однако в работе J. Kim и др. (2017, журнал *Neuron*) было обнаружено, что большинство нейронов центрального ядра у мышей, напротив, участвуют в механизмах вознаграждения. Всего в центральной части амигдалы авторы идентифицировали 7 различных генетических типов нейронов; из них 5 типов при активации

вызывали у животных искательское поведение, связанное с получением удовольствия. Мыши, у которых эти нейроны стимулировались светом, стремились повторно получать связанный с ними стимул, даже если он изначально был нейтральным (например, возвращались в ранее освещенное место, ассоциируя свет с приятным ощущением). Полученные данные заставляют пересмотреть традиционное представление об амигдале как исключительно о «центре страха» – очевидно, она выполняет более широкую функцию по распознаванию значимости стимулов любого знака (плохих и хороших) и формированию соответствующих поведенческих тенденций (избегание угроз или стремление к награде).

Роль амигдалы в патологических состояниях. Понимание функций миндалевидного тела имеет большое значение для медицины и психиатрии. Амигдала вовлечена в патогенез ряда эмоциональных и поведенческих расстройств. При тревожных нарушениях (фобии, генерализованная тревога, панические атаки) часто отмечается гиперактивность нейронов амигдалы, приводящая к чрезмерным реакциям страха на относительно безопасные стимулы. В исследованиях с функциональной МРТ у пациентов с посттравматическим стрессовым расстройством обнаружена повышенная спонтанная активность миндалевидных тел, а степень их реакции на травматические образы коррелирует с тяжестью симптоматики ПТСР. Это наводит на мысль о возможных методах терапии путем прямого снижения возбудимости амигдалы – например, посредством *нейробиологической обратной связи* или целевой фармакотерапии, устраняющей гиперактивацию данного центра. В депрессии также выявлены дисфункции амигдалы: некоторые исследования фиксируют увеличенный объем миндалевидного тела и его чрезмерную реактивность на негативные стимулы у пациентов с униполярной депрессией. Считается, что хронический стресс способен «разгонять» миндалевидную систему – например, у подростков с депрессивным расстройством на фоне пережитого в детстве насилия обнаруживалось уменьшение объема гиппокампа и параллельная гиперактивация миндалевидного тела. Это соответствует модели, при которой амигдала стимулирует выделение кортизола и других гормонов стресса через гипоталамо-гипофизарно-надпочечниковую ось, а избыток этих гормонов, в свою очередь, негативно влияет на гиппокамп и кору. Миндалевидное тело содержит рецепторы к глюкокортикоидам и напрямую участвует в регуляции стрессовой реакции, поддерживая уровень гормонов стресса на определенном пороге. Таким образом, дисбаланс в работе амигдалы может приводить к развитию порочного круга хронической тревоги и стрессовых расстройств.

Отдельно стоит упомянуть вовлеченность амигдалы в формирование зависимостей. Центральное ядро амигдалы вместе с прилегающим ядром и рядом прилежащих структур относится к так называемой *расширенной амигдале* – системе, активирующейся при переходе от случайного употребления психоактивных веществ к зависимости. Экспериментальные работы показывают, что при алкоголизме и опиатной зависимости нейроны центральной амигдалы перестраиваются таким образом, что усиливаются тревожность и негативное эмоциональное состояние во время отмены вещества. Это побуждает человека вновь прибегать к приему вещества ради снятия дискомфорта, замыкая цикл аддикции. Повышенная возбудимость амигдалы, таким образом, является общим звеном и для тревожных расстройств, и для зависимостей, что объясняет частую их коморбидность. Понимание роли амигдалы в таких патологических состояниях открывает новые терапевтические мишени. К примеру, ведутся исследования по избирательному торможению гиперактивных нейронов центральной амигдалы с целью уменьшить патологическую тревожность у пациентов, страдающих алкогольной зависимостью.

Результаты и обсуждение

Проведенный анализ подтверждает комплексное строение миндалевидного тела и его широкие связи. С точки зрения анатомии, амигдала занимает стратегическое положение в медиобазальной части височной доли, контактируя с рядом структур: спереди – с переднепробуравленным пространством и полосатым телом (отделена от них тонким слоем так называемого безымянного вещества), медиально – с поясной извилиной через перешейковую область, латерально – с оболочкой (клауструм) и внутренней капсулой, сзади – с хвостом хвостатого ядра и ножкой форникса. Такая окруженность определяет участие амигдалы одновременно и в обонятельных путях, и в базальных ганглиях, и во вспомогательных зрительно-слуховых связях. На основании литературы была составлена обобщающая схема основных афферентных и эфферентных путей, связывающих миндалевидное тело с другими отделами мозга (Рис. 2).

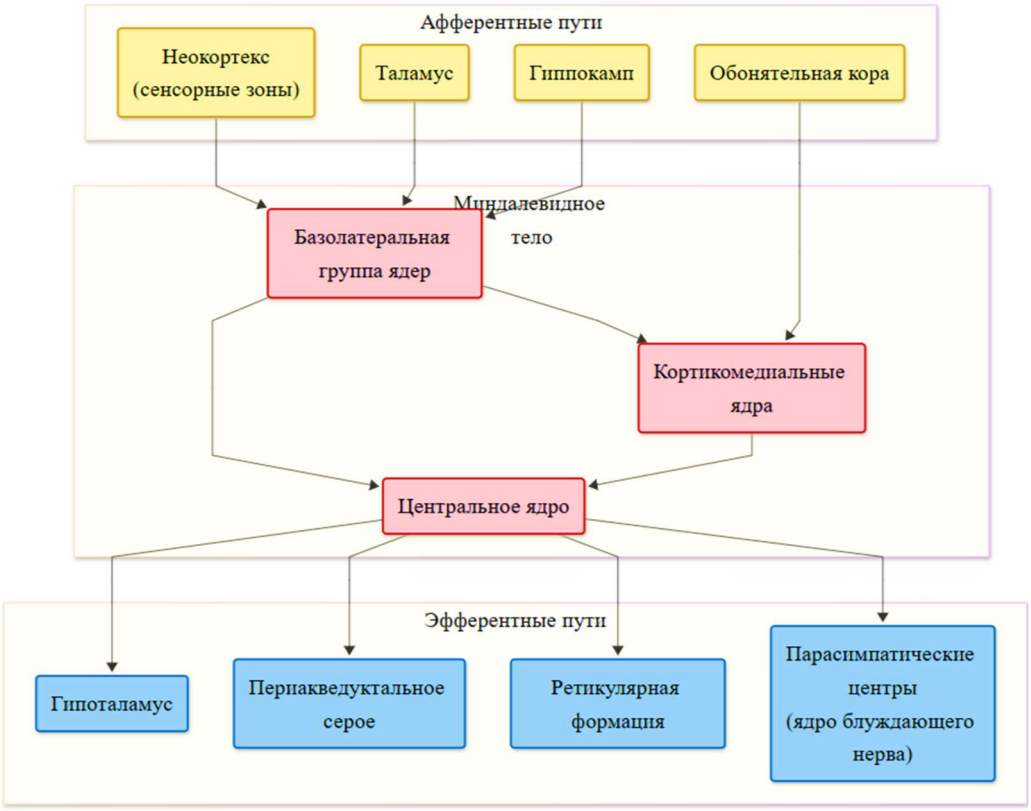

Рисунок 2. Функциональные связи миндалевидного тела с корковыми, подкорковыми и стволовыми центрами

Базолатеральные ядра получают внешние сигналы от корковых и таламических областей, оценивают их значимость и передают возбуждение на центральное ядро. Центральное ядро посылает эфференты в гипоталамус, ретикулярную формацию и вегетативные ядра ствола, запускающие телесные проявления эмоций (реакцию «бей или беги», изменения сердечно-сосудистой и дыхательной активности, гормональные сдвиги и пр.). Кроме того, центральная амигдала проецирует в парасимпатические центры и на ядро блуждающего нерва, что обеспечивает такие реакции, как замирание и брадиardia при некоторых видах страха. На схеме не показаны возвратные связи: важно отметить, что гипоталамус и ствол через нейромедиаторные системы (особенно норадренергическую) могут усиливать работу амигдалы в условиях стресса, замыкая цикл усиления страха. Это имеет значение при хронической тревоге, когда регуляторные тормозные влияния коры ослаблены.

Сходным образом, получены данные о влиянии префронтальной коры на активность амигдалы. Префронтальные области (орбитофронтальная кора, передняя поясная извилина) в норме оказывают *тормозящее* воздействие на миндалевидное тело, подавляя неуместные или избыточные эмоциональные вспышки. При некоторых расстройствах – например, посттравматическом синдроме – отмечается недостаточность префронтального контроля, что ведет к дизингибировании амигдалы и гиперреактивности системы страха. Эти факты подчеркивают, что амигдала функционирует не изолированно, а как элемент сложной нейросети, балансирующей между возбуждающими сигналами снизу (от таламуса и ствола) и тормозными сигналами сверху (от коры). В норме такой баланс обеспечивает адекватность эмоциональных реакций – человек боится действительно опасных ситуаций, но сохраняет спокойствие в безопасной обстановке. Нарушение же равновесия (в силу стресса или патологии) приводит либо к притуплению чувства опасности (как у пациентов с повреждением амигдалы, описанных выше), либо напротив – к постоянной тревожной настороженности (как при гиперактивности амигдалы у тревожных пациентов).

Результаты анализа литературы позволяют резюмировать влияние миндалевидного тела на поведение и эмоции в различных экспериментальных моделях (Табл. 2). Приведем несколько показательных примеров из исследований на животных и людях.

Таблица 2 – Поведение в норме и после двустороннего повреждения амигдалы

Ситуация / стимул	Реакция в норме (интактная амигдала)	Реакция при повреждении амигдалы
Угрожающий объект (змея, хищник и т.п.) *Обезьяны резус)*	Паника или страх: избегание объекта, демонстрация сигналов тревоги; повышение уровня кортизола и адреналина. *Молодые особи, выросшие без опыта контакта, также инстинктивно пугаются резиновых змей*.	Отсутствие страха, любопытство: обезьяна спокойно приближается к объекту, пытается трогать даже хищника. *У макак с неонатальной амигдалэктомией отмечено существенное снижение избегания резиновой змеи по сравнению с контрольными животными*.
Социальная угроза (столкновение с доминантным сородичем) *Обезьяны)*	Подчинение или избегание: подчиненные особи проявляют покорное поведение, избегают зрительного контакта с доминантом, держатся на дистанции. Это обеспечивает иерархию в группе.	Нарушение социальных сигналов страха: обезьяна с поврежденной амигдалой не распознает статус доминанта, может приближаться вплотную или даже провоцировать более сильное животное. Возможна парадоксальная повышенная реакция тревоги в незнакомой социальной ситуации (боязнь ровесников при отсутствии опыта).

Неожиданный пугающий стимул (громкий звук, «прыгающая» игрушка) *Грызуны, обезьяны)*	Нормальная реакция страха: вздрагивание, замирание (*freezing*) или бегство; учащение сердцебиения. Животное формирует условный рефлекс страха при повторных сочетаниях со стимулом (например, тон + удар током → замирание при одном тоне).	Ослабление или отсутствие реакции страха: животное почти не проявляет испуга на резкий звук, может не замирать при потенциальной угрозе. У крыс с разрушением латеро-базальной амигдалы не вырабатывается классическое условное замирание на звук, ассоциированный с шоком – они не способны ассоциировать нейтральный стимул с угрозой. (При этом сознательное распознавание может сохраняться у высших животных – см. пациент ниже.)
Опасная ситуация («комната ужаса», вольер с пауками и змеями) *Человек)*	Страх, избегание: здоровый человек старается покинуть опасное место, проявляет защитные реакции (пот, учащение пульса, чувство ужаса). Напр., посещение аттракциона «дом страха» вызывает высокий субъективный рейтинг страха (7–8 баллов из 8 возможных).	Отсутствие субъективного страха и физиологической реакции: пациент с двусторонней дегенерацией амигдал (S.M.) спокойно входит в «комнату ужаса», интересуется окружением, может даже смеяться, не ощущая страха. При встрече с живыми змеями и пауками – испытывает скорее любопытство, берет их на руки, заявляя об *отсутствии страха*. В фильмах ужасов – оценивает пугающие сцены на 0–2 балла страха, тогда как контрольные испытуемые дают высокие оценки.
Распознавание угрозы (выражение лица страха у других людей) *Человек)*	Точное узнавание негативной эмоции: благодаря амигдало-лобной сети человек быстро интерпретирует выражение страха или гнева на чужом лице и настораживается. Это важный социальный навык, позволяющий разделять чужую тревогу и реагировать на общую угрозу.	Снижение способности распознать страх и недоверие: пациенты с поражением амигдал затрудняются определить эмоцию страха на фотографиях лиц. Они склонны считать лица более дружелюбными и привлекательными, чем их оценивают здоровые люди. Таким образом, теряется социальный «детектор опасности», обычно обеспечиваемый амигдалой.

Приведенные в таблице 2 наблюдения убедительно показывают роль миндалевидного тела в формировании как врожденных, так и приобретенных реакций страха. Миндалевидное тело требуется для того, чтобы *наделить ситуацию эмоциональным значением*, особенно в контексте опасности. Без него животное или человек утрачивает чувство угрозы даже в объективно опасных обстоятельствах. Интересно, что амигдала нужна и для обучения страху: например, она задействована при образовании

условного рефлекса – связь безобидного стимула со страшным событием (звук с последующим ударом тока) не устанавливается без участия латерального ядра амигдалы. В то же время, осознание факта опасности может происходить и без амигдалы – в классическом исследовании Бечара с коллегами (1995) пациентка с двусторонним повреждением амигдал (но интактным гиппокампом) понимала, какая ситуация сопряжена с угрозой, хотя и не испытывала при этом нормальной физиологической реакции страха. Это подтверждает гипотезу о параллельных путях: когнитивный (гиппокампальный) путь дает знание об опасности, а эмоциональный (амигдалярный) – запускает само чувство страха и телесную реакцию.

Тесная связь амигдалы с гиппокампом ставит вопрос о ее роли в процессах обучения и запоминания. Традиционно гиппокамп считают центром декларативной памяти, а амигдалу – эмоциональной памяти (памяти о страхе). Исследования подтверждают, что при двусторонней амигдалэктомии животные утрачивают ранее выученные страховые реакции (например, перестают бояться звука, ранее предвещавшего шок). Активация же амигдалы, напротив, улучшает запоминание событий, особенно эмоционально заряженных. В экспериментах на грызунах введение стимуляторов адренергической передачи в амигдалу вскоре после обучения усиливало долговременную консолидацию памяти о случившемся. Это происходит благодаря тому, что амигдала через нейромедиаторы стресса (норадреналин и глюкокортикоиды) модифицирует активность гиппокампа и коры, «помечая» воспоминание как важное. В человеке сходный механизм объясняет, почему мы хорошо помним яркие пугающие или радостные события – при них амигдала активируется и как бы «прожигает» след памяти глубже.

Наконец, интересен аспект участия амигдалы в социальных функциях и коммуникации. Помимо распознавания эмоций на лицах (о чем говорилось выше), амигдала вовлечена в эмпатию, доверие и процесс социального обучения. При аутизме, например, выявлены морфофункциональные изменения лимбических структур, включая миндалевидное тело. Считается, что нарушение нормальной работы базолатеральной амигдалы и связанных с ней корковых областей приводит к трудностям в интерпретации социальных сигналов и проявлению эмоциональной отзывчивости. Люди с аутизмом нередко демонстрируют аномальную активность амигдал в ответ на лица других людей, а объем миндалевидного тела у них может быть увеличен в детстве и уменьшен во взрослом возрасте, что некоторые исследователи трактуют как признак нейрональной дисфункции. В целом, амигдала выступает частью «социального мозга», помогая оценивать намерения окружающих (через мимику, тон голоса, прочие невербальные сигналы) и быстро включать соответствующую эмоциональную реакцию – настороженность или, наоборот, расположение и доверие.

Заключение

Миндалевидное тело – одна из самых важных интегративных структур мозга, объединяющая сенсорные, висцеральные и когнитивные компоненты эмоций. Проведенный обзор продемонстрировал, что амигдала выполняет разнообразные функции: она запускает врожденные реакции страха и агрессии, участвует в выработке эмоциональных условных рефлексов, модулирует процессы памяти, а также вовлечена в системы удовольствия и подкрепления. Анатомически миндалевидное тело включено в два пересекающихся лимбических контура – гиппокампо-таламокорковый (для создания субъективного опыта эмоции) и амигдало-гипоталамо-стволовый (для реализации телесных реакций). Нормальная работа этих контуров обеспечивает адекватный баланс эмоциональных состояний. Нарушение деятельности амигдалы – будь то структурное повреждение или функциональный дисбаланс – ведет к выраженным поведенческим и

психическим изменениям: от патологического бесстрашия и агнозии страха до чрезмерной тревожности, паники и агрессии.

В заключение следует подчеркнуть, что миндалевидное тело – это не примитивный «центр одной эмоции», а сложный узел, формирующий эмоциональный *контекст* поведения. Амигдала учит нас сопереживать страх и боль других, заставляет избегать опасностей, но также помогает стремиться к положительным целям и запоминать важные события.

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EPIDEMIOLOGY AND METHODOLOGICAL FEATURES OF EARLY DETECTION OF MALIGNANT TUMORS: THE ROLE OF ONCOLOGICAL SCREENING

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Annotation: In this scientific and analytical work, the indicators of incidence and mortality from cervical cancer, breast cancer and colorectal cancer in the regions of our country are considered. The screening methods currently used and the results of this preventive survey of the population are described in detail. Detailed step-by-step algorithms are presented, and the principles of organization and diagnostic capabilities of the screening program for the active detection of these nosological forms of malignant neoplasms in clinically asymptomatic individuals are reflected.

Key words: oncological screening, primary care, cervical cancer, breast cancer, colorectal cancer, epidemiology, incidence, mortality, Pap test, smear for oncocytology, ultrasound examination, mammography, hemocult test, fecal occult blood test - FOBT, total colonoscopy.

Today, one of the most important postulates of the oncology service continues to be the early diagnosis of malignant tumors. The purpose of screening is to identify asymptomatic (preclinical) cancer or precancerous conditions in an otherwise healthy target population. In this case, screening plays a leading role in secondary cancer prevention. The key concept of cancer screening is to identify pathology at a stage of development when the effectiveness of treatment is maximum and the prognosis is most favorable. When precancerous diseases are detected during screening, secondary prevention methods allow to prevent the transition of the initial pathological state to cancer. In this case, the main conditions for screening are the presence of trained personnel and a standard approach to identifying the trait being studied and evaluating the

results. The methods used must be sufficiently simple, reliable and reproducible, as well as have sufficient sensitivity and high specificity [1-3].

Screening plays an important role in improving early diagnosis and treatment outcomes. According to the Guide to Cancer Early Diagnosis by Ilbawi A. et al. [4], screening aims to detect unrecognized cancer or its prior lesions in a typically healthy, asymptomatic population through tests or other procedures that can be applied quickly and are widely available to the target population. In screening, the target population is assessed for unrecognized cancer or precancer, and most people tested will not be diagnosed with the disease. Screening should be seen as a process and not as the performance of a specific test, examination, or procedure. The screening process includes a system of informing and inviting the target population to participate; administering the screening test; following-up with test results and referral for further testing among those with abnormal test results; ensuring timely pathologic diagnosis, staging and access to effective treatment with routine evaluation to improve the process. A screening program encompasses the process from invitation to treatment and requires planning, coordination and monitoring and evaluation.

To date, the republican oncological screening program includes three nosological forms of malignant neoplasms - cervical cancer (CC), breast cancer (BC), colorectal cancer (CRC). Let's consider the current epidemiological indicators, methodology and results of cancer screening in our country.

CC in the structure of all malignant tumors of both sexes of the population in 2022 took 6th place with a share of 5.51% (2021 - 4th place, 5.54%), in women - stable 2nd place - 9.7% (9.7%) [5].

The incidence rate per 100 thousand population increased from 9.4 to 9.92. In 10 regions of the republic, the incidence rate is higher than the national average: Pavlodar - 17.2 per 100 thousand people (2021 – 16.7) – the highest level, East Kazakhstan – 14.3 (10.8), North Kazakhstan – 14.3 (10.2), Atyrau – 13.2 (13.8), Zhetysu - 11.7, Karaganda - 11.7 (12.0), Abay - 11.1, Akmola - 11.1 (11.9), Mangistau - 11.1 (9.7), Kostanay - 10.8 (10.6) regions.

Low incidence rates in Zhambyl region - 5.8 per 100 thousand population (5.7), Turkestan region - 6.1 (5.2), Aktobe region - 8.3 (11.6), Kyzylorda region - 8.5 (8.2) areas.

CC in the structure of causes of death from malignant tumors of the population of both sexes in 2022 rose from 9th to 8th position, with a share of 4.6% (2021 - 4.3%), mortality from CC is stable at 3.1 per 100 thousand population (3.1).

The mortality rate from CC in 10 regions is higher than the national average: Akmola - 4.2 per 100 thousand population (2021 - 3.1) - maximum level, West Kazakhstan - 4.1 (4.8), Pavlodar - 3.8 (5.6), Almaty – 3.7 (2.5), Zhetysu – 3.7, Atyrau – 3.4 (4.0), East Kazakhstan – 3.3 (3.8), Karaganda - 3.2 (4.7), Kostanay - 3.2 (2.4) regions and Almaty city - 3.4 (2.9).

Below the national average, mortality was recorded in Abay region, cities Astana, Shymkent - 2.9 per 100 thousand population, Mangistau - 2.8 (3.0), Turkestan - 2.3 (2.2), Aktobe - 2.2 (3.0), North - Kazakhstan - 2.0 (2.6), Kyzylorda regions - 1.7 (3.5) - the best result [5].

In 12 regions, a 100% level of morphological verification of the diagnosis was ensured, the lowest or worst indicator for the third year was in the Kyzylorda region - 94.3%, below the national average indicators in Akmola - 98.8%, Atyrau - 98.9%, Kostanay - 98, 9%, Mangistau - 97.6%, Pavlodar - 96.6%, regions and Almaty city - 98.5%;

In a number of regions, the frequency of diagnosis of stage I-II CC was below the national average (88.1%) - in Akmola - 76.2% (2021 - 73.6%) - the worst result in the country, in Karaganda - 77, 2%, Zhetysu - 82.9%, Abay - 83.8%, Kostanay - 84.3%, Aktobe - 85.5%, West Kazakhstan - 85.7%, Pavlodar - 81.3%, while that in the Atyrau region - 100.0% result.

The proportion of stage IV CC is higher than the national average (2.7%) in the following regions: the worst result is in Zhetysu (6.1%), above the national average in Karaganda - 5.1%

(2021 - 5.6%), Akmola - 4.8% (2.3%), Kostanay - 4.5% (4.4%), North Kazakhstan - 3.9% (7.4%), Almaty - 3.7 % (5.1%), Zhambyl - 2.9% (0.0) regions, cities Almaty – 3.6% (1.8%) and Shymkent – 3.8% (5.9%). The lowest neglect is in the East Kazakhstan region - 1.0% (0.7%).

Late diagnosis rates (III-IV stages) for CC are above the national average - 11.9% (15.4% in 2021) were noted in Akmola - 23.8% (2021 - 26.4%) - worst result, Karaganda - 22.8% (35.2%), Pavlodar - 18.8% (20.8%), Zhetysu - 17.1% (24.2%), Abay - 16.2% (12.8%), Kostanay - 14.6% (15.6%), Aktobe - 14.5% (9.6%), West Kazakhstan - 14.3% (32.4%) regions. The lowest neglect is in the Mangistau region - 6.0% (20.8%).

Across the country, the five-year survival rate of patients with CC registered in 2018 was 59.9% in 2022, with a decrease from the level of 2021 (67.5% for those registered in 2017), and with a significant range in by region, from the maximum – 72.9% (2021 – 70.7%) in the North Kazakhstan region, to the minimum – 34.9% (64.4%) in the Atyrau region [5].

CC screening is a periodic, comprehensive examination of women of a certain age group as part of a special medical program to prevent and reduce incidence and mortality from CC.

Type of screening - population. The purpose of screening is to identify pre-invasive diseases of the cervix with subsequent recovery. The screening method is a cytological examination of a smear for oncocytology from the cervix (traditional and liquid cytology). Coloring according to the "Papanicolaou test" (Pap test). Interval - 1 time in 4 years. Target group: women aged 30-70 years who are not registered in the dispensary for CC. The expected results are a decrease in incidence and mortality from CC.

Screening steps:

1) Preparatory - formation of target groups, information support and invitation to screening. The preparatory stage is carried out by the nurses of the primary health care organization responsible for preventive measures and includes: annual compilation of a list of women subject to screening in the coming year by November 15 of the current year, followed by monthly correction; informing target groups of the female population about the need for screening; screening invitation; ensure timely screening.

2) Screening - filling out a statistical card of a preventive medical examination (screening) of an outpatient (form 025-08/y), a register of patients subject to cytological screening and taking material for cytological examination from the cervix. The screening examination of the target groups of the female population is carried out by a specially trained midwife of the primary health care organization.

3) The final one is obtaining the results of cytology, informing the woman and developing further management tactics, fill out accounting and reporting statistical documentation. Responsible for the final stage of screening is the obstetrician-gynecologist of primary health care [6].

Cytological screening of CC is a complex of organizational and medical measures aimed at early detection of precancerous and neoplastic diseases of this localization and at reducing the mortality of this cohort of patients. For traditional cytology, a smear containing 8-12 thousand cells of stratified squamous epithelium (including cells of metaplastic epithelium) is considered adequate; for liquid cytology - 5 thousand cells. For both methods, the number of cells of endocervical epithelium and/or metaplastic epithelium (from the transformation zone) must be at least 10 (single or in clusters). If more than 75% of the cells of the stratified squamous epithelium are covered with erythrocytes, leukocytes, etc., then the quality of the smear is considered unsatisfactory.

Interpretation of the results of a cytological study is carried out according to the Bethesda-terminology cytological system:

Intraepithelial changes and malignant processes are absent (NILM). This group includes cytological conclusions about the normal state of the epithelium, as well as the presence of various

non-neoplastic diseases. Normally, squamous epithelial cells, groups of cells of columnar epithelium and metaplastic epithelium, a small number of leukocytes, and rod/mixed microflora are found in preparations. In the presence of non-neoplastic processes, their nature and, if possible, the cause are specified: atrophic changes, reactive changes associated with inflammation, including typical regeneration. In addition, the presence of microorganisms is indicated: Trichomonas vaginalis, fungi, morphologically corresponding to Candida spp., bacterial vaginosis, cellular changes corresponding to the defeat of Herpes simplex virus, squamous epithelial cells with atypia of unknown significance (ASC-US), squamous epithelial cells with atypia of unclear significance, not excluding the presence of a high degree of intraepithelial changes (ASC-H). Low-grade squamous intraepithelial changes (LSIL) include lesions associated with HPV and CINI, high-grade squamous intraepithelial changes (HSIL) include CINII, CINIII, carcinoma in situ and cases suspected of invasion, squamous cell carcinoma, cervical (glandular) epithelium with atypia of unknown significance, cells of the cervical (glandular) epithelium, possibly neoplasia, endocervical adenocarcinoma in situ, endocervical adenocarcinoma, endometrial adenocarcinoma, secondary adenocarcinoma, unclassified carcinoma, other malignant tumors.

There are certain features when taking material for oncocytology: firstly, the examined woman should be informed about the exclusion of sexual intercourse, vaginal manipulations, including douching, baths, tampons, etc. 2 days prior to sampling. Taking material for cytological examination is carried out by the midwife of the examination room of the department of medical examinations of the primary health care organization: the traditional method (2 glasses - with obligatory fixation in 96% alcohol, it is preferable to use glass slides with a polished edge, which are easily marked) or the liquid cytology method (one container with stabilizing liquid); the code or surname of the patient, identical to the code and surname in the form for sending material for cytological examination, should be clearly marked on the glasses or container [6].

At the same time, when using the traditional method, the biomaterial is delivered to the cytological laboratory as soon as possible after its collection in specialized containers for glass slides with 96% alcohol. If there are visible visual changes in the cervix, then the material is taken from the woman and, without waiting for the results, she is referred for an examination by an obstetrician-gynecologist.

A cytological study is carried out in centralized cytological laboratories at oncological institutions, where an archive of cytological preparations of patients involved in the screening examination is formed, regardless of the result, for a period of at least 10 years with the formation of a computer database.

What material and technical equipment is required to take material for a Pap test? It is as follows: soap and water for washing hands, a light source for cervical examination, a gynecological chair, a disinfected speculum and gloves, an Eyre spatula, a glass slide and a marking pen, a container with a stabilizing solution for liquid cytology, a fixative solution (96% alcohol), a container with warm water for lubricating and warming the vaginal mirrors, a 0.5% chlorine solution for disinfecting gloves and instruments, or another approved for this purpose. And, of course, the registration form itself.

For carrying out liquid cytology, you additionally need: a disposable cervix brush, a container with a stabilizing solution for liquid cytology, and a fixing solution.

At the same time, a smear for oncocytology cannot be taken: during menstruation, earlier than 48 hours after sexual contact or after using lubricants, vinegar or Lugol solution, tampons or spermicides, after vaginal examination or douching, and also during the treatment of genital infection.

Now, regarding the results of CC screening. In 2022, 771,282 women of the target group aged 30 to 70 years were examined during cytological screening (in 2021 - 757,454).

During cytological screening in 2022, 392 cases of cervical cancer were identified (319 in

2021). The detection rate increased from 0.42 to 0.51 per 1000 women examined

High detection of CC during screening is ensured in Aktobe, Almaty, Atyrau, East Kazakhstan, Kyzylorda, Pavlodar, North Kazakhstan, Turkestan regions and Shymkent city. The detection rate in these regions ranges from 0.55 to 1.59 per 1000 women examined. The best indicator is in Atyrau region - 1.59. Compared to 2021, there is an increase in detection in 10 regions, with the exception of Akmola, Aktobe, Zhambyl, Kostanay, Mangistau, North Kazakhstan regions and Shymkent city. The worst result in Astana is 0.15 per 1000 women examined [5].

Cytologically, cervical precancer was detected in 1.16% of those examined (2021 – 0.99%). The detection rate of precancer below 0.6% (the planned indicator for 2022, according to the Comprehensive Plan) was noted in Aktobe, Karaganda and Kostanay regions.

A high proportion of stage I CC (70% or more) was detected in 6 regions of the country (in 8 in 2021): Kostanay, Mangistau (94.7% - best result), North Kazakhstan, Turkestan regions, cities Almaty and Astana. Low levels of early detection of CC (below 50%) were not observed in any region.

Localized processes (stages I-II) were identified in 99.2% of all cases of detected cancer (96.5%). In the Akmola and Karaganda regions, cases of CC were identified not only in localized, but also in widespread stages of the process. A total of 3 cases of CC in stage III and no cases in stage IV were identified (11 and 0, respectively) [5].

BC ranks first in the structure of the frequency of malignant tumors of both sexes in the population with a share of 14.7% (2021 - 15.4%). This situation has been stable since 2004; in addition, BC ranks first and remains consistently in this position in the structure of female oncopathology. The incidence of BC in 2022 in the country as a whole increased to 26.5 per 100 thousand (2021 – 26.3). In the structure of cases, BC occupies the 1st ranking place in the vast majority of regions and cities of the country, except for three: Akmola, Kyzylorda and North Kazakhstan regions, where lung cancer takes the 1st ranking place [4].

Above the national average - 26.5 per 100 thousand of us. – incidence of BC in 10 regions of the country: Abay – 33.3, Akmola – 32.7 (2021 – 29.8), East Kazakhstan – 44.7 (39.9) – the highest level, West Kazakhstan – 31.2 (28.4), Karaganda – 40.2 (40.1), Kostanay – 37.5 (35.8), Pavlodar – 43.2 (47.4), North Kazakhstan – 34.7 (38.2) regions and Almaty city – 35.4 (34.5), Astana city – 31.5 (28.4). Below average indicators per 100 thousand of us. in Aktobe - 21.6 (24.3), Almaty - 21.9 (17.7), Atyrau - 22.8 (15.7), Zhambyl - 14.2 (15.1), Zhetysu - 22.8, Kyzylorda - 14.6 (14.4), Mangistau - 14.7 (17.3), Turkestan - 11.3 (11.7) regions and Shymkent city - 14.9 (21.9) [5].

BC ranks third in the structure of causes of death from malignant tumors in the population of both sexes for the thirteenth year in a row, amounting to 8.1% in 2022 (2021 – 8.7%). In the republic as a whole, mortality from BC decreased by 13.0%, from 6.2 to 5.4 per 100 thousand people.

The regions where mortality from BC is higher than the national average include: Abay - 10.1 per 100 thousand people (maximum level), East Kazakhstan - 8.0 (2021 - 8.5), Pavlodar - 7.1 (10.0), North Kazakhstan - 7.0 (11.4), Kostanay - 6.9 (7.5), Akmola - 6.5 (8.2), West Kazakhstan - 5.7 (6.9), Zhambyl - 5.5 (4.8) and Astana city – 6.3 (6.6), Almaty city – 6.6 (9.5). The indicators are significantly lower in Aktobe - 4.5 (3.5), Almaty - 4.5 (5.8), Zhetysu - 4.0, Atyrau - 3.7 (3.0), Kyzylorda - 4.4 (4.1), Turkestan - 3.6 (3.6), Mangystau regions - 2.7 (3.6) - the lowest level [5].

Mass screening to identify BC patients should mainly involve healthy women without any signs of the disease or symptoms. Screening not only helps to detect hidden forms of cancer that can be treated, but also has psychological value for women. As a result of screening, women are convinced that they do not have BC, and this is the most important potential success of such programs. While the ultimate goal of screening is to reduce BC mortality, its immediate goal is to detect cancer before clinical manifestation. However, BC is a heterogeneous disease, which can significantly affect the effectiveness of screening. Screening models for BC are usually based on

the fact that the majority of detected tumors are invasive cancers in the early stage of progression. In addition, it must be taken into account that the detection of cancer (or its precursors) before clinical manifestation increases the risk of false positive diagnosis [7,8].

Mammography has a sensitivity of 95% and a specificity of 97%. These indicators decrease when examining women with denser mammary glands (young age, use of hormone therapy), with low quality mammography, and also with insufficient qualifications of the radiologist. Detection of high-grade invasive cancer by screening, when the tumor is not yet detected by clinical examination (palpation), means the possibility of reducing mortality from BC [9].

Preventive screening for early detection of BC in the Republic of Kazakhstan includes [10]:

1) mammography of both mammary glands in two projections - direct and oblique in the mammography room of the city, district polyclinic (mobile medical complex). All digital mammograms in the presence of a system for archiving and transferring medical images are copied to CDs and other electronic media and transferred to the server of the mammography room of the Cancer Center using specialized licensed software integrated between medical organizations; in case of impossibility of digital transmission - they are printed on X-ray film at a scale of 1:1 - 100% (1 patient - 1 set - 2 or 4 mammograms) with subsequent transfer to the mammography room of the Cancer Center;

2) interpretation of mammograms according to the BI-RADS classification (M0t, M0d, M1, M2, M3, M4, M5) by two or more independent radiologists of the same medical organization - double reading or different medical organizations: a radiologist of the mammography room city, district polyclinic (mobile medical complex) - the first reading, and the radiologist of the mammography room of the Cancer Center - the second reading;

3) in-depth diagnostics - targeted mammography, ultrasound examination (hereinafter - ultrasound) of the mammary glands, trepanobiopsy, including under ultrasound or stereotaxic control for histological examination, which is carried out in case of detection of pathological changes on mammograms (M0d) in the mammography room of the Cancer Center.

√ An average medical worker or a responsible person of the organization of outpatient care sends the patient for mammography to the district, city polyclinic.

√ The X-ray laboratory assistant of the mammography room of the city, district polyclinic (mobile medical complex) performs mammography, fills out a referral for double reading of mammograms and transmits the referral through information interaction.

Radiologist of the mammography office of the city, district polyclinic (mobile medical complex): fulfills the requirements for the safety and quality of mammographic examinations; evaluates the quality of the images provided and the correctness of the installation; performs repeated mammography in the M0t category (technical errors of mammography); determines the radiological density of the mammary glands on the ACR scale (A, B, C, D) indicating this parameter in the study protocol; conducts the first reading of mammograms with interpretation of the BI-RADS classification results. In the M0d category (undetermined or suspicious radiological changes requiring additional examination), the study protocol indicates the predominant pathology: education, asymmetry, violation of architectonics, microcalcifications; sends mammograms, electronic copies of mammograms through the archiving system and transfer of medical images to the workplace of the mammography office of the Cancer Center together with directions for double reading of mammograms; directs low–dose computed tomographic images through the system of archiving and transferring medical images to the workplace of the computer tomography office of the Cancer Center together with copies of images recorded on CD-ROMs or other electronic media and directions for double reading.

♦ The radiologist of the mammography room of the Cancer Center: evaluates the quality of the provided images and the correctness of the styling. Viewing digital x-ray images transferred to the server or on digital media (CD, DVD) is carried out on a monitor for interpreting digital x-ray

images with a resolution of at least 5 megapixels, which has a certified grayscale transmission in accordance with the DICOM standard; conducts a double (second) reading of mammograms with the interpretation of the results according to the BI-RADS classification, using, if necessary, archival images. Organizes the third reading according to indications. With double reading, an independent interpretation of the images is carried out (blinding method - the second radiologist does not know the results of the first reading); in the M0m category (technical errors in mammography), recommends repeat mammography; in the M0d category (uncertain or suspicious radiographic changes requiring additional examination), the study protocol indicates the predominant pathology: education; asymmetry, violation of architectonics, microcalcifications; recommends that the outpatient care organization, according to indications, invite the patient for in-depth diagnostics (targeted mammography, ultrasound of the mammary glands, trephine biopsy, including under ultrasound or stereotaxic control, followed by histological examination of the material); collects and archives all mammograms (films and electronic media) made as part of the examination. The shelf life of mammograms is at least 3 years after leaving the age subject to a screening study; the results of the double (second) reading are transferred to the outpatient care organizations through information exchange.

- Indications for in-depth diagnostics are the conclusions of double reading mammograms M0d (uncertain or suspicious X-ray changes requiring additional examination).
- In-depth diagnostics is carried out in two stages. At the first stage, ultrasound is performed, according to indications, targeted mammography, possibly with an increase (with asymmetry, violation of architectonics and the presence of microcalcifications). When visualizing a suspicious pathology (M4 and M5), the second stage is performed - trepanbiopsy, including under ultrasound control and stereotaxic control for histological examination.
- Histological examination is carried out in the laboratory of pathomorphology or pathological bureau. Morphological interpretation of the biopsy is carried out in accordance with the recommendations of the World Health Organization.
- Physician or responsible person of the outpatient care organization:

1) upon receipt of a mammography result according to the BI-RADS classification:

- in case of M0t (technical errors in mammography) - sends the patient for a second X-ray examination to the mammography room of the city, district polyclinic (mobile medical complex);
- with M0d (undefined or suspicious X-ray changes requiring additional examination) - sends the patient for in-depth diagnostics to the mammography room of the Cancer Center;
- with M1 (no changes detected) - recommends that the patient undergo a follow-up mammography examination after 2 years. With radiological density of the mammary glands, C and D are sent for ultrasound of the mammary glands to exclude a false-negative result of mammography;
- with M2 (benign changes), refer the patient for a consultation with an oncologist (mammologist) of the clinical diagnostic department, followed by a screening mammography examination after 2 years;
- with M3 (probable benign changes) - sends the patient for short-term dynamic radiation observation to the local doctor with the recommendation of control mammography or ultrasound in 6 months;
- with M4 (signs that cause suspicion of malignancy), M5 (practically reliable signs of malignancy) and if it is technically impossible to perform a trepanbiopsy or a biopsy is refused, a referral to an oncologist (mammologist) of the clinical diagnostic department for dynamic observation and decision on the verification of the identified pathology;

2) upon receipt of the result of a histological examination:

- benign education - refers the patient to an oncologist (mammologist) of the clinical diagnostic department for dynamic monitoring, followed by a screening mammography

examination after 2 years;

- formation with an indeterminate malignant potential or carcinoma in situ - refers the patient to the Cancer Center for consultation and treatment, followed by dynamic observation by an oncologist (mammologist) of the clinical diagnostic department at the place of her attachment;

- malignant neoplasm - refers the patient to the Cancer Center for treatment and follow-up;

3) communicates the results of the screening examination to the patient in any available way (by telephone, in writing, through electronic means of communication);

4) enters the results of double reading, in-depth diagnostics, histological examination, recommendations of the radiologist of the Cancer Center mammography room into the information system.

Establishing the size of the primary tumor is especially important in screening. Tumor size is an important criterion for evaluating the quality of screening and determining the ability of X-ray mammography to detect non-palpable tumors. Therefore, it is extremely important that pathologists measure tumor diameter as accurately as possible. The smaller the size of the primary tumor, the greater the likelihood of error in determining its size.

Let's analyze the results of BC screening. Mammography screening identified 1,570 cases of BC in 2022 (1,402 in 2021). The cancer detection rate increased from 1.78 to 1.94 per 1000 examined. The best result is in the Karaganda region – 2.63 per 1000 women examined. Low detection rate per 1000 examined, compared to the republican average, in Atyrau (1.72), Zhambyl (0.58), Kyzylorda (1.68), Mangistau (0.42 - worst result), Turkestan (1.22) regions and cities Astana (1.5) and Shymkent (1.58). Compared to 2021, there was an increase in the detection of BC in 9 regions, with the exception of Aktobe (decrease from 2.87 to 2.19 per 1000 women examined), Karaganda (from 2.73 to 2.63), Mangistau (from 1.10 to 0.42), North Kazakhstan (from 3.27 to 2.31), Turkestan (from 1.36 to 1.22) regions and cities Astana (from 1.54 to 1.50), Almaty (from 2.24 to 2.18) and Shymkent (from 2.35 to 1.58) [5].

In 2022, the proportion of patients identified during screening studies with early stages of BC (stage 0-I) was 50.2% during screening (in 2021 - 47.9%). A high proportion of stages 0-I BC (over 50%) was recorded in 8 regions (in 8 in 2021): Akmola, West Kazakhstan, Karaganda (70.8% - best result), Pavlodar, North Kazakhstan, Turkestan regions, cities Astana and Shymkent. Low levels of early detection of BC (below 40%) were noted in Aktobe (19.3% - worst result), Zhambyl (34.8%), Kostanay (39.5%), Mangistau (27.3%) regions and Almaty city (37.3%). Localized cancer (0-I and II stages) amounted to 96.2% (2021 - 95.5%), while not a single case was detected in stages III-IV in Atyrau, West Kazakhstan, Zhambyl, Kyzylorda, Mangistau, Pavlodar regions, cities Astana and Shymkent. A total of 46 cases of breast cancer in stage III and 14 in stage IV were identified (52 and 11, respectively) [5].

Epidemiological indicators of CRC in the form of colon cancer and colorectal cancer are considered separately for objective reasons.

Colon cancer with a specific gravity of 5.53% (2021 - 5.2%) in the structure of oncopathology of both sexes of the population has risen to 5th place, in men it remains in 6th place - 5.8% (5.5 %), for women - in the 5th - 5.3% (4.91%) The incidence rate of cancer of this localization in the country in the reporting year increased from 8.8 to 9.95 per 100 thousand population.

The incidence of colon cancer in 10 regions is higher than the national average - 9.95 per 100 thousand population: Kostanay - 20.7 (2021 - 15.9), Pavlodar - 18.8 (15.3), North Kazakhstan - 18, 0 (12.7), East Kazakhstan - 16.9 (13.4), Karaganda - 15.4 (15.0), Akmola - 14.6 (10.2), West Kazakhstan - 11.0 (10.1), Abay - 10.0 (9.0) regions and cities Almaty – 12.8 (12.1) and Astana – 10.5 (9.0). As in 2021, colon cancer was detected much less frequently in Turkestan - 3.1 per 100 thousand population (2.7), Kyzylorda - 4.1 (4.6), Zhambyl - 5.5 (5.8), Almaty - 6.3 (4.7), Zhetysu -

6.4, Mangistau - 6.8 (4.9) regions and Shymkent city - 5.0 (4.0) [5].

Rectal cancer in the structure of malignant neoplasms of both sexes retains 7th place in rank with a specific gravity of 4.9% (2021 - 4.92%), but in men it dropped from 4th to 5th place - 6.1%, for women – from 9th to 10th – 4.0%. The incidence rate per 100 thousand population increased from 8.4 to 8.8.

A high incidence rate was recorded in Kostanay - 17.8 per 100 thousand population (2021 - 16.2), East Kazakhstan - 17.7 (13.9), North Kazakhstan - 15.6 (15.1), Pavlodar – 14.9 (18.1), Karaganda – 13.3 (11.7), Abay – 12.9, West Kazakhstan – 12.9 (9.8), Akmola – 10.3 (13.1) regions and Astana city – 10.3 (9.0). Traditionally, a low incidence of rectal cancer is observed in Mangistau - 3.1 (2.8), Turkestan - 3.3 per 100 thousand population (2.7), Zhambyl - 3.7 (5.1), Kyzylorda - 4, 1 (5.3), Almaty – 5.3 (5.6) regions and in Shymkent city – 5.5 (5.0) [5].

Rectal cancer in the structure of causes of death from malignant neoplasms of the population of both sexes in 2022 remained in 5th place with a share of 5.41% (2021 – 5.41%). In the republic as a whole, the mortality rate from this form of cancer was 3.6 per 100 thousand population (3.87).

The mortality rate per 100 thousand population was higher than the national average in East Kazakhstan - 7.8 (2021 - 8.6) - the maximum level, Pavlodar - 7.5 (7.6), Abay - 5.9, North Kazakhstan - 5.8 (4.3), Kostanay - 4.9 (4.9), West Kazakhstan - 4.8 (4.2), Karaganda - 3.8 (5.2) regions. Below the national average - 3.8 per 100 thousand population, mortality in Aktobe - 3.2 (4.1), Almaty - 2.6 (2.6), Atyrau - 2.5 (3.4), Zhetysu - 2, 6, Zhambyl - 3.3 (2.7), Turkestan - 2.1 (1.6), Mangistau - 1.9 (1.2), Kyzylorda regions - 1.8 (2.1) - the lowest figure , and cities Almaty – 3.7 (4.3), Shymkent – 2.6 (2.1).

Colon cancer in the structure of causes of death from malignant neoplasms of the population of both sexes in 2022, as in 2021, ranks 6th, with a share of 5.2% (2021 – 5.0%). At the same time, the mortality rate in the country decreased by 5.6%, from 3.6 to 3.4 per 100 thousand population.

Mortality rates in 10 regions are higher than the national average: East Kazakhstan - 7.1 per 100 thousand population (2021 - 5.1) - maximum level, Pavlodar - 5.6 (6.0), Kostanay - 5.3 (5.6), Akmola – 5.2 (3.8), Abay – 5.1, Karaganda – 5.1 (5.6), West Kazakhstan – 4.8 (4.4), North Kazakhstan – 4.8 (5.0) regions and cities Astana – 3.6 (2.7), Almaty – 4.5 (5.3). Low mortality rates from colon cancer were noted in Kyzylorda - 1.2 per 100 thousand population (2.7) - the best result, Turkestan - 1.3 (1.7), Mangistau - 1.6 (2.6), Aktobe – 2.0 (2.5), Zhetysu – 2.4, Zhambyl – 2.5 (3.7), Atyrau – 2.5 (1.8), Almaty – 2.6 (1.8) regions and cities Astana – (2.7), Shymkent – (2.4).

For colon cancer (94.0%) - 100% verification level was achieved in 3 regions (Abay, Almaty and Turkestan regions), high rates in the Astana city (98.5%), Shymkent city (98.0%), Zhambyl (98.4%), Atyrau (98.2%) regions, low – in Akmola region (86.7%), Almaty city (84.3%), in the Kyzylorda region (61.8%) – the worst result since 2017.

For rectal cancer (97.4%) - in 6 regions there is a 100% verification level, the worst level is still in the Kyzylorda region - 85.3%, lower than the republican average in the Akmola region - 92.6%, Aktobe region - 96 .8%, Mangystau region - 87.0%, Pavlodar region - 95.3%, Almaty city - 93.2% [5].

The frequency of diagnosis of stage I-II rectal cancer, as a visually accessible localization (68.9% - national average) in the regions, was: in Akmola - 34.6% - the worst result, as in 2021, in the country (2021 - 44.1%), Mangistau - 47.8%, Abay - 53.9%, West Kazakhstan - 59.1%, Almaty - 66.2%, Zhetysu - 68.6%, Karaganda - 65, 7% regions and Shymkent city - 62.9%.

For colon cancer (52.4%), early diagnosis rates are higher in Pavlodar (65.9% - best result), Abay, Aktobe, Atyrau, East Kazakhstan, Zhambyl, Zhetysu, Karaganda, Kostanay, Pavlodar, North Kazakhstan, Turkestan regions and Shymkent. The lowest figure (23.5%) is in the Kyzylorda region.

For colon cancer (17.3%), the rates of neglect at stage IV are higher - in Akmola - 31.0% -

the worst result (2021 - 20.3%), Zhetysu - 27.3%, Abay - 23.1% , Turkestan - 22.2% (29.1%), Karaganda - 28.1% (28.6%), West Kazakhstan - 18.8% (8.2%), Mangistau - 17.6% (19 .4%) regions and cities Astana - 18.0% (22.9%), Shymkent - 20.0% (22.7%). The lowest level of neglect is 2.9% in the Kyzylorda region (7.9%).

The proportion of stage IV in rectal cancer (13.1%) is higher in Akmola - 29.6% - the worst result (2021 - 19.4%), Abay - 19.7%, Kyzylorda - 17.6% (9.1%), Karaganda - 16.9% (28.4%), Almaty - 15.6% (17.0%), Kostanay - 14.8% (11.1%), Zhambyl - 13.3 % (13.6%) regions and Shymkent city - 14.5% (12.5%). The lowest level of neglect - 6.0% - is in the Atyrau region (12.5%).

Late diagnosis of rectal cancer as a visually accessible localization (stages III-IV) in 2022 amounted to 31.1% (in 2021 - 33.5%).

For rectal cancer, the level of neglect is higher than the national average - 31.1%, the indicators in Akmola - 65.4% (2021 - 55.9%) - the worst result in the country, Mangistau - 52.2% (38.1%), Abay – 46.1% (30.6%), West Kazakhstan – 40.9% (25.4%), Karaganda – 34.3% (46.5%), Almaty – 33.8% (35.7 %), Zhetysu - 31.4% (34.1%) regions and Shymkent city - 37.1% (42.9%). The lowest neglect is in the Atyrau region - 12.0% (17.5%).

In the country as a whole in 2022, the five-year survival rate of patients with CRC registered in 2018 decreased to 40.4% (2021 - 52.9% for those registered in 2017); there is a significant dispersion of indicators by region, from maximum – 56.1% (47.5%) in the Kyzylorda region, to minimum – 24.3% (51.5%) in the Aktobe region [5].

Screening of CRC screening is the systematic use of screening studies in an asymptomatic population. The purpose of screening is to identify people with abnormalities suggestive of CRC. These persons in the future need additional examination to clarify the diagnosis. Opportunistic screening is the non-systematic use of screening tests in routine medical practice. A screening program is much more challenging than an early detection program. At the same time, the success of the screening program is largely determined by the awareness of the population and medical workers about the possibilities of early diagnosis of CRC. The feasibility of a screening program is determined by several factors that relate to the disease being screened, the screening test, the characteristics of the population, and the characteristics of the healthcare system.

The first factor is that the disease must be well understood, common enough in the target population to justify screening, have a recognizable early stage; treatment of the disease at an early stage should be more effective than at a later stage.

The second is that the test should be characterized by sufficient sensitivity, i.e. the ability to detect cancer among people with the disease; sufficient specificity - the probability that among people who do not have a disease, the test result will be negative; have a high positive predictive value (positive predictive value) or, in other words, the likelihood that people with a positive test result have the disease; have a high predictive value of a negative result (negative predictive value), i.e. the likelihood that people with a negative test result do not have the disease; security; low cost; and acceptability - the likelihood that people for whom this test is intended will agree to the examination (which to some extent depends on the awareness of the population about the possibilities and importance of early diagnosis).

The third factor is that the healthcare system should be ready for maximum screening test coverage of the target group, have the resources to confirm the diagnosis, appropriate treatment and follow-up of people with positive test results, and regularly conduct screening tests at regular intervals. At the same time, the benefits of screening must outweigh the potential physical and psychological harm and justify the financial costs of its implementation [11].

The factors most significant for the development of CRC are:

- the presence of chronic inflammatory bowel diseases, adenomatous polyps, cancer of other localization, etc.;

- family history (presence of one or two first-degree relatives with CRC or familial diffuse

intestinal polyposis);

- the age of men and women over 50 years old, taking into account the fact that more than 90% of patients with colorectal cancer are people of this age (medium risk).

Age, regardless of gender, is an important risk factor for CRC. After the age of 50, the incidence of CRC increases from 8 to 160 per 100,000 population. Thus, people who have reached the age of 50, even in the absence of symptoms, constitute a moderate risk group for CRC.

The second category of increased risk of CRC (20%) is made up of persons with a genetic and family predisposition, suffering from chronic inflammatory bowel diseases, diffuse familial polyposis.

The high-risk CRC group is determined by the so-called Amsterdam criteria (the presence of malignant tumors in two generations, the presence of cancer in a first-line relative under the age of 50 years), in this case, CRC screening should be carried out after the age of 30 years [12].

The degree of individual risk of developing CRC is determined before screening to select the scope of studies and the frequency of their conduct.

The interval for oncological colorectal screening is 1 time in 2 years, target group: men and women aged 50-70 years, with the exception of persons registered at the dispensary for CRC and colon polyposis. At the same time, when forming the target group, one should take into account the absence of severe concomitant diseases, such as the presence of a common malignant neoplasm, cerebrovascular diseases in the stage of decompensation, chronic obstructive pulmonary disease with respiratory failure, cirrhosis of the liver, myocardial infarction with congestive heart failure, diabetes mellitus with vascular complications. and others, which are highly likely to lead to death in the next 10 years.

The first step in screening for CRC is the fecal occult blood test (FOBT). Traditionally, such methods include a benzidine test for occult blood in the feces. This is a biochemical method based on the assessment of pseudoperoxidase activity of hemoglobin. There is ample evidence that invitation to guaiac FOBT screening (gFOBT) reduces CRC mortality by approximately 15% in age-matched average-risk populations.

To ensure the effectiveness of screening with gFOBT, the interval for screening under the national screening program should not exceed two years. To date, there is an immunochemical FOBT method - iFOBT, which is superior in efficiency to gFOBT in terms of the probability of detecting adenoma and cancer. iFOBT has improved analysis performance compared to gFOBT.

Immunochemical (immunochromatographic) examination of feces for occult blood - iFOBT or hemocult test is carried out for all men and women of the target group using an express method, which allows you to get a result within 3-5 minutes, without the participation of a medical worker. However, the evaluation of the test is carried out only by a medical worker in the PHC preventive department.

With a positive analysis of feces for occult blood, the second stage of colorectal screening is performed, which consists in endoscopic examination of the colon - total colonoscopy [6]. At the same time, in this case, this medical manipulation is of a therapeutic and diagnostic nature, since it allows one-stage removal of adenomatous polyps, which, according to various authors, occur in every third subject after 50 years of age. At the same time, women have 20% fewer polyps than men, but they have more right-sided lesions, which are more difficult to detect using fecal blood tests, because they are less traumatic [13,14].

What results were obtained from screening for CRC? In 2022, 937,859 men and women of the target group aged 50 to 70 years were examined during colorectal screening (in 2021 - 920,640) [5].

Colorectal screening revealed 325 cases of colorectal cancer in the reporting year, which is 114 cases more than in the previous year (211 cases). The detection rate increased from 0.23 to 0.35 per 1000 patients examined. Low detection of colorectal cancer was noted in Zhambyl,

Karaganda, Kostanay, Kyzylorda, Mangistau, Turkestan - the worst result, East Kazakhstan regions, Astana city - from 0.07 to 0.30 per 1000 examined. The best result is in the North Kazakhstan region – 0.81 per 1000 examined. Compared to 2021, there was a decrease in the detection of colorectal cancer per 1000 people examined during screening in Karaganda (from 0.22 to 0.21), Kostanay (from 0.29 to 0.28), Mangistau (from 0.20 to 0.12) regions and Astana city (from 0.20 to 0.19).

Colon precancer (adenoma detection rate) was detected in 27.5% of patients who underwent colonoscopy (2021 – 22.8%). The detection rate of precancer in Akmola, Aktobe, Almaty (8.5% is the worst result), West Kazakhstan, Zhambyl, Kostanay, Kyzylorda, Mangistau, Pavlodar, North Kazakhstan, Turkestan regions and cities is lower than the national average Astana and Shymkent. The best result is 36.2% in Almaty city. It should be noted that the planned indicator for the detection of precancer of the colon and rectum in the country for 2022, according to the Comprehensive Plan, was 23.0% and was achieved.

In 2022, the proportion of patients identified during screening studies with early stages of malignant neoplasms (stages 0-I) was 26.2% during colorectal screening (in 2021 - 27.5%).

High early detection of colorectal cancer (above 30%) was noted in Akmola, West Kazakhstan, Karaganda, Kostanay, Kyzylorda, Turkestan regions and Astana city (57.1% - the best result). Not a single case of early cancer has been identified in the Mangistau region. Cases of cancer in stages III-IV detected during screening were registered in Akmola, Aktobe, Almaty, West Kazakhstan, Zhambyl, Karaganda, Kostanay, Mangistau regions and Almaty city. A total of 21 cases of colorectal cancer in stage III and 3 in stage IV were identified (in 2021 - 18 and 5, respectively) [5].

The complex analysis carried out allows us to conclude that satisfactory results of cancer screening can be achieved only with its proper organization, high quality of implementation, active participation in population screening, the use of highly sensitive tests and instrumental methods of preventive examination, as well as subsequent accurate diagnosis of identified tumors and timely treatment. High-quality screening leads to early diagnosis of pedological diseases and malignant pathology in the early stages, which, in turn, increases the effectiveness of treatment and improves the prognosis of the disease. Target groups that, for one reason or another, do not participate in screening should be informed that there are no other methods other than screening that would reduce mortality from malignant neoplasms. Incidence and mortality rates from cervical cancer, breast cancer and colorectal cancer clearly reflect the epidemiological situation with this pathology in the regions of our country.

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ОСОБЕННОСТИ КЛИНИЧЕСКОГО ТЕЧЕНИЯ АЛЛЕРГИЧЕСКОГО РИНИТА: ЭКОЛОГИЧЕСКИЕ АСПЕКТЫ

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Аллергический ринит – это широко распространенное заболевание, которое по решению Всемирной организации здравоохранения является индикатором здоровья населения. Исследования велись в период с 2020-2025 годы, оценивали заболеваемость детей в возрасте от 0-13 лет.

Развитие аллергического ринита зависит от основных параметров помещения, в котором ребенок проводит большую часть дня. При средней температуре воздуха в 23 °С и влажности 60 % количество детей с развитым аллергическим ринитом составляет 9 %, в то время как при влажности

воздуха ниже 40 % и его температуре выше 27 °С количество заболевших вырастает многократно. Полученные данные продемонстрировали прямую зависимость развития отоларингологических заболеваний от таких параметров помещения как температура и влажность. Соблюдение рекомендуемых параметров для обозначенных показателей позволит сократить число детей страдающих аллергической формой ринита.

Ключевые слова: ринит, аллергия, экология помещений, влажность воздуха.

Аллергический ринит (АР) - это атопическое заболевание, характеризующееся симптомами заложенности носа, прозрачного ринореи, чихания, постназальной капли и носа. Это затрагивает одного из шести человек и связано со значительной заболеваемостью, потерей производительности и расходами на здравоохранение. Исторически считалось, что AR является болезнным процессом только носовых дыхательных путей. Тем не менее, развитие унифицированной теории дыхательных путей классифицировало AR как компонент системного аллергического ответа, а другие связанные с ним состояния, такие как астма и атопический дерматит, разделяющих основную системную патологию.[1]AR можно классифицировать как сезонные (прерывистые) или многолетние (хронические), при этом примерно 20% случаев являются сезонными, 40% - многолетними и 40% с особенностями обоих.[2]В дополнение к носовым симптомам, у пациентов с АР также может быть связанный аллергический конъюнктивит, непродуктивный кашель, дисфункция евстахиевой трубы и хронический синусит. После постановки диагноза дополненная реальность поддается лечению различными методами,

при этом внутриназальные глюкокортикоиды являются терапией первой линии. [1]. Распространенность аллергического ринита на основе диагноза врача составляет примерно 15%; однако распространенность, по оценкам, составляет до 30%, исходя из пациентов с назальными симптомами. Известно, что AR достигает пика во втором-четвертом десятилетиях жизни, а затем постепенно упадке.[6]Заболеваемость AR в педиатрической популяции также довольно высока, что делает ее одним из наиболее распространенных хронических
педиатрических расстройств. Согласно данным Международного исследования астмы и аллергии в детстве, 14,6% в возрастной группе от 13 до 14 лет и 8,5% в возрастной группе от 6 до 7 лет демонстрируют симптомы риноконъюнктивита, связанные с аллергическим ринитом.[7]Сезонный аллергический ринит, по- видимому, чаще встречается в педиатрической возрастной группе, в то время как хронический ринит более распространен у взрослых.[8]

Систематический обзор 2018 года показал, что 3,6% взрослых пропустили работу, а 36% имели ухудшение производительности из-за аллергического ринита. Экономические оценки показали, что косвенные затраты, связанные с потерей производительности труда, составляют большую часть затрат на дополненную реальность.[9]

Факторы риска развития AR включают в себя семейную историю атопии, мужской пол, наличие аллергенно-специфического IgE, сывороточный IgE более 100 МЕ/мл до 6 лет и более высокий социально-экономический статус. [5]Исследования с детьми младшего возраста показали более высокий риск развития дополненной реальности у тех, у кого раннее введение в пищу или смесь и/или интенсивное воздействие курения сигарет в первый год жизни.
[2]Хотя многие недавние исследования оценивали связь между загрязнением и развитием дополненной реальности, существенной корреляции пока не существует. Интересно, что выявлено несколько факторов, которые могут оказывать защитное влияние на развитие AR. Роль грудного вскармливания в развитии AR часто обсуждается, но оно по-прежнему рекомендуется из-за многих других известных преимуществ и отсутствие связанного с этим вреда. Нет никаких доказательств того, что избегание домашних животных в детстве предотвращает дополненную допутию; однако есть гипотеза, что раннее воздействие домашних животных может вызвать иммунную толерантность.
Растет интерес к «эффекту фермы» на развитие аллергии, и метаанализ 8 исследований показал на 40% более низкий риск у субъектов, которые жили на ферме в течение первого года жизни.[10]

Здоровье детского населения является важнейшим видом безопасности в сфере общественного здравоохранения. Установлено, что из-за незрелости процессов дифференциации клеток дети подвержены развитию аллергических реакций [1]–[3]. По решению Всемирной организации здравоохранения именно аллергические заболевания являются индикаторами общественного здоровья.

Целью данного исследования было изучение экологических характеристик воздуха и анализ его взаимосвязь с развитием аллергического ринита. Исследования проводились на территории г. Алматы в Казахстане с 2020 по 2025 гг., оценивалась частота детей в возрасте 0–13 лет. В процессе анализа методов, используемых для анализа помещения и выявления его параметров с развитием аллергического ринита. Аллергический ринит является широко распространенным заболеванием, которым страдают 18–38% населения России
[4]–[8]. По данным литературы в США, различные формы аллергического ринита встречаются на 30% больше чем 10 лет назад. Аллергическим ринитом страдают 40% населения, а заболеваемость регистрируется в раннем школьном

возрасте [9] [11]. Диагностика заболевания осуществляется на основании наличия аллергенспецифических антител класса антигенов IgE. Внешними симптомами являются чихание, зуд и заложенность, а также выделения из носа[12]-[15]. Полученные данные по аллергическому риниту и анализ характеристик помещений представлены в таблице.

Районы города	Влажность	Температура воздуха	Количество пациентов
Бостандыкский	59	21	33
Алатауский	39	27	37
Ауезовский	63	25	65
Медеуский	62	23	48
Жетысуйский	55	24	54
Наурызбайский	52	26	42

Таким образом, после проведения исследований можно сказать, что развитие аллергического ринита зависит от основных параметров помещения, в котором ребенок проводит большую часть дня. При средней температуре воздуха 23°C и влажности 60% количество детей с развившимся аллергическим ринитом составляет 9%, тогда как при заболеваниях При температуре ниже 40% и температуре выше 27°C число случаев заболевания возрастает в разы. Это связано с тем, что пересыхание слизистой оболочки носа сухим воздухом приводит к появлению микротрещин, что вызывает кровотечение. Внутри носа начинают образовываться болезненные корочки, а также развивается общее ухудшение самочувствия, которое проявляется головной болью и расстройством. Измененный слизистый слой является идеальной средой для размножения любых микроорганизмов, поэтому часто развиваются воспалительные реакции и присоединяются вторичные инфекции.

Улучшением фактической ситуации и профилактикой новых заболеваний могут стать профилактические мероприятия, например: установка систем увлажнения и кондиционирования для охлаждения перегретого воздуха, изоляция детей в соляных комнатах или соляных шахтах.

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CLINICOEPIDEMIOLOGICAL STUDY OF CELLULITIS THROUGH ALT-70 SCORING AND ERON SEVERITY INDICES WITH QUALITY-OF-LIFE CORRELATION

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ABSTRACT:
Cellulitis is an acute bacterial infection involving the dermis and subcutaneous tissues, characterized by erythema, warmth, swelling, and tenderness of the affected area, most frequently the lower limbs. It is predominantly caused by *Streptococcus pyogenes* and *Staphylococcus aureus*, though polymicrobial infections may occur in immunocompromised individuals. Despite advancements in antimicrobial therapy, cellulitis continues to impose a significant clinical and economic burden due to its recurrence and potential complications such as abscess formation and lymphangitis. The present manuscript provides a comprehensive review of the etiology, pathophysiology, clinical manifestations, diagnostic modalities, and management strategies for cellulitis, integrating both pharmacological and non-pharmacological perspectives. Literature from PubMed, ScienceDirect, and other scientific databases was critically analysed to summarize contemporary evidence and guidelines. Management involves prompt initiation of empiric antibiotic therapy targeting gram-positive cocci, supported by wound care, skin hygiene, and the

control of predisposing factors such as diabetes and obesity. Non-pharmacological interventions, including limb elevation, compression therapy, and proper moisturization, are equally essential in preventing recurrence and improving patient quality of life. A multidisciplinary and preventive approach emphasizing patient education, early diagnosis, and adherence to hygiene measures remains pivotal in reducing morbidity and recurrence rates. Thus, holistic management of cellulitis encompassing both pharmacologic precision and supportive care forms the cornerstone for improved therapeutic outcomes and sustainable infection control.

INTRODUCTION:

Cellulitis (Latin: *cellula* (diminutive of *cella*: cell) + *itis* (suffix denoting inflammation)) and its subtype, erysipelas (Greek: erythrós (red) + pella (skin)), are among the most frequent infections requiring hospitalization [1].

Cellulitis is an acute bacterial infection of the dermis and subcutaneous tissues, presenting with erythema, swelling, warmth, and tenderness in the affected area. It occurs when bacteria penetrate through a break in the skin barrier, which may be as trivial as a fissure from tinea pedis or as obvious as a wound or ulcer. Once pathogens reach the dermis, they trigger an inflammatory response characterised by vasodilation, leukocyte infiltration, and tissue edema. Although it is clinically distinct from abscesses and necrotising soft tissue infections, these conditions may coexist, making early recognition and accurate diagnosis crucial. The disease has a variable course ranging from mild, localised infection to life-threatening sepsis, depending on host immunity, comorbidities, and the infecting organism [1, 2].

Globally, cellulitis is a common cause of both outpatient visits and hospital admissions. Population-based studies report community incidence ranging from 199 per 100,000 person-years to as high as 24.6 per 1,000 person-years in certain high-risk cohorts. In the United States *and Europe, hospitalisations related to cellulitis have been steadily increasing, contributing significantly to healthcare costs [3]. In India, precise nationwide incidence data are lacking; however, multiple hospital-based studies have demonstrated that cellulitis is a frequent cause of admissions, particularly among working-age adults, with the lower limb being the most commonly affected site. Indian cohorts have highlighted risk factors such as diabetes, venous stasis, and fungal infections like tinea pedis as prominent contributors. Mortality in uncomplicated cellulitis is generally low, but in Indian hospital series, mortality has ranged from 0.3% to several per cent depending on comorbidities, with the risk being significantly higher in cases associated with septic shock, cirrhosis, or necrotising infections [4].

The microbiological aetiology of cellulitis is most often linked to beta-hemolytic streptococci, particularly *Streptococcus pyogenes*, which typically cause non-purulent cellulitis. *Staphylococcus aureus*, including both methicillin-susceptible (MSSA) and methicillin-resistant strains (MRSA), is frequently implicated in purulent presentations. Polymicrobial infections are common in bite wounds, chronic ulcers, or diabetic foot infections, where Gram-negative bacilli and anaerobes may also play a role. Less commonly, cellulitis may arise from unusual exposures, such as *Vibrio* species after seawater injuries or *Pasteurella multocida* following animal bites [5].

Clinically, cellulitis manifests as a painful, warm, erythematous, and edematous area of skin with indistinct margins. Fever, chills, and malaise may accompany local findings, while lymphangitic streaking and regional lymphadenopathy are often seen. Purulent cellulitis suggests staphylococcal infection, whereas diffuse non-purulent forms are more often streptococcal. Severe presentations with rapidly progressive swelling, bullae, necrosis, or pain out of proportion to examination raise concern for necrotising fasciitis, a surgical emergency. Differentiating cellulitis from mimicking conditions such as deep vein thrombosis, contact dermatitis, and stasis dermatitis is clinically important. To assist in this, the ALT-70 prediction score, which uses asymmetry, leukocyte count, and tachycardia along with age, has been developed and validated for lower-extremity cellulitis to distinguish true infection from pseudo-cellulitis [6]. Severity can also be graded using the Eron

classification, where Class I patients are systemically well and suitable for oral therapy, while Class IV patients have sepsis or life-threatening infection requiring urgent resuscitation, broad-spectrum intravenous antibiotics, and surgical consultation. Diagnosis of cellulitis is largely clinical, with laboratory and imaging studies playing supportive roles. Blood counts, CRP, and ESR can help gauge systemic inflammation, though they are not specific. Blood cultures are typically low-yield in uncomplicated cases but are warranted in systemically ill or immunocompromised patients. When purulence is present, pus should be cultured to guide therapy. Imaging is useful in complicated cases: ultrasound helps detect occult abscesses, MRI is preferred for suspected necrotising infections, and CT or X-rays may reveal gas or foreign bodies. Scoring systems like LRINEC can help assess necrotising fasciitis risk, but surgical exploration should not be delayed when clinical suspicion is high [7].

Treatment depends on severity, clinical setting, and microbiological suspicion. Mild non-purulent cellulitis is usually treated on an outpatient basis with oral antibiotics directed against streptococci and MSSA, such as cephalexin or amoxicillin-clavulanate, for 5–10 days. Purulent infections warrant coverage for MRSA with agents like clindamycin, doxycycline, or TMP-SMX. Inpatients with severe cellulitis require intravenous therapy with cefazolin or nafcillin for severe non-purulent cases, or vancomycin/daptomycin/linezolid when MRSA is suspected. In immunocompromised patients, bite wounds or perineal infections, broad-spectrum regimens covering Gram-negative organisms and anaerobes (e.g., piperacillin–tazobactam) are appropriate. Surgical management is essential for drainage of abscesses or for debridement in necrotising soft-tissue infections, where rapid operative intervention is [5, 7]. Supportive measures such as analgesia, limb elevation, wound care, and management of comorbidities like diabetes are integral to care.

Although uncomplicated cellulitis has a good prognosis, it is not without consequences. A meta-analysis found an overall inpatient mortality of around 1.1%, but morbidity is far more significant, with recurrence rates up to 20–30% and high rates of hospital readmission. Recurrent episodes predispose to chronic edema, fibrosis, and lymphedema, creating a vicious cycle that further increases the risk of reinfection. These sequelae significantly impair mobility and quality of life. Patients report reduced physical function, social participation, and emotional well-being following recurrent cellulitis episodes. Preventive strategies, such as treating tinea pedis, using compression therapy for chronic edema, practising meticulous skin care, and administering prophylactic antibiotics in select recurrent cases, have been shown to reduce recurrence and improve long-term outcomes [8].

Fig 1.1: Patients suffering from Cellulitis [9, 10]

1.1. Epidemiology:

Table 1.1: Comparative Prevalence and Epidemiological Profile of Cellulitis in India and Globally [11-15]

Parameter	India	Global
Prevalence (existing cases)	No reliable national data, "exact incidence in India is unknown". (GBD 2021 shows a high burden of bacterial skin infections, but India-specific estimates are lacking.)	GBD 2021: ~37.0 million prevalent cases of bacterial skin diseases (≈474/100k) (cellulitis is part of this group). (Annual prevalence of cellulitis specifically is not separately reported.)
Annual incidence (new cases/year)	Not reported in India. (One source notes no national incidence data.)	GBD 2019: ≈54.8 million new cellulitis cases per year (age-standardised incidence). (Example: USA alone has ~14.5 M cases/year.)
Age (distribution)	Predominantly middle-aged adults. Mean age ~46.6 y (50% in 4th–5th decades). (Odisha study: 51% male, 49% female; peak in 30–50 y for both sexes.)	The highest incidence is in midlife. US data: much higher rates in ages 45–64. (Epidemiologic studies show cellulitis mainly affects older adults; very young and the very old less common.)
Sex (M: F)	~51% male, 49% female (no large sex gap in Indian inpatients).	Male predominance. US data show higher rates in men than women (and Frontiers analysis noted a modest male excess in incidence).
Key Risk Factors	India: Skin barrier breaks (trauma, ulcers, wounds) and fungal foot infections are very common. In one series, 69.7% had a preceding skin injury and 77.1% had toe-web intertrigo. Other Indian studies note diabetes (≈39%), obesity, and lymphedema as frequent co-factors.	Global: Similar drivers worldwide. Chronic leg edema/lymphedema, tinea pedis (fungal infection), obesity, diabetes mellitus, venous insufficiency, and prior trauma or ulcers are well-known risk factors (and references therein). Fungal intertrigo and immunosuppression also predispose to recurrent cellulitis.
Recurrence	No published data on recurrence rates in India. (Recurrent cellulitis likely under-recognised.)	Common. In one US population study, 18% of patients had ≥1 recurrent episode over 5 years. (Other studies report ~30–50% recurrence risk over 2–3 years.)
Trends (last decade)	National trends are not characterised. (Skin infections in India are generally rising due to NCDs, but specific cellulitis trend data are lacking.)	Slight decline. GBD 1990–2019: age-standardised cellulitis incidence fell by ~6.2%. DALYs rates also declined. The burden of cellulitis remains high, with a stable or slowly changing incidence globally.

Cellulitis is relatively common and most often occurs in middle-aged and older adults. When comparing men and women, there is no statistically significant difference in the incidence of cellulitis. There are approximately 50 cases per 1000 patient-years [16,17]. Cellulitis is a common

bacterial infection of the skin and subcutaneous tissue that represents a major public health concern worldwide. According to Global Burden of Disease (GBD) analyses, bacterial skin diseases (including cellulitis) contribute significantly to disability-adjusted life years (DALYs), with particularly high burdens reported in South Asia and East Asia [18]. The absolute number of cases has been rising globally since 1990, largely due to population growth, ageing, and an increase in comorbidities such as diabetes and obesity. In the United States alone, about 14 million cases occur annually, with several hundred thousand hospitalisations each year and ambulatory care costs exceeding US$3.7 billion. Hospitalisation rates have increased in many high-income countries over the last two decades, although direct mortality remains low except in complicated cases progressing to sepsis, particularly in resource-limited settings. Incidence rates vary by study, but skin and soft tissue infections (SSTIs, including cellulitis) have been reported at tens of cases per 1,000 person-years, while hospital admission rates are in the range of several per 100,000 population [19]. The infection predominantly affects the lower limbs, with a higher incidence in older adults, and seasonal peaks in warmer, humid months have been documented. The main pathogens are Streptococcus pyogenes and Staphylococcus aureus, including MRSA strains in some regions. Key risk factors include chronic edema, venous insufficiency, obesity, diabetes, immunosuppression, and breaches in skin integrity such as trauma, ulcers, or tinea pedis [18, 19]. Importantly, recurrence is frequent, with studies reporting rates of 20–40% or higher, making secondary prevention a major clinical priority. While robust data exist from the U.S. and parts of Europe, information from low- and middle-income countries remains limited, though hospital series from India and Africa confirm cellulitis as a common cause of admission with higher complication and mortality rates due to delayed access to care [20]. Overall, cellulitis is a globally prevalent disease with rising incidence, high recurrence, significant economic burden, and marked disparities in outcomes between high-income and resource-constrained settings. The disease burden in India is amplified by the high prevalence of diabetes and obesity, both of which significantly increase susceptibility. Hospital-based studies in different regions show cellulitis accounts for 2–10% of dermatology outpatient visits and is among the leading causes of dermatological admissions [19, 21]. For example, a study from South India (Bhat, 2020) reported cellulitis to be one of the most frequent bacterial skin infections in tertiary hospitals [20]. The incidence peaks in monsoon and humid months, where minor skin breaches combined with fungal infections predispose individuals to bacterial invasion. Risk factors unique to India include barefoot walking, poor footwear use, agricultural injuries, and high prevalence of parasitic and fungal infections, which predispose to skin barrier breakdown [22]. Rural populations and low socioeconomic groups are disproportionately affected due to limited access to early care. While national-level population data are scarce, tertiary-care reports highlight that cellulitis contributes significantly to hospital admissions, prolonged hospital stays, and high healthcare costs. The disease is an important cause of morbidity in rural and urban India, and recurrent cellulitis contributes to reduced quality of life and lost productivity.

1.2. Classes of cellulitis:

A classification system can serve as a useful guide to admission and treatment decisions. This classification was devised by Eron 4 according to CREST Guidelines for skin and soft tissue infections [23].

1.2.1. Class I patients have no signs of systemic toxicity, have no uncontrolled co-morbidities and can usually be managed with oral antimicrobials on an outpatient basis.

1.2.2. Class II patients are either systemically ill or systemically well but with a co-morbidity such as peripheral vascular disease, chronic venous insufficiency or morbid obesity, which may complicate or delay resolution of their infection.

1.2.3. Class III patients may have a significant systemic upset, such as acute confusion, tachycardia, tachypnoea, hypotension or may have unstable co-morbidities that may

interfere with a response to therapy or have a limb-threatening infection due to vascular compromise.

1.2.4. Class IV patients have sepsis syndrome or severe life-threatening infection such as necrotising fasciitis.

Clinical findings alone are usually adequate for diagnosing cellulitis, particularly in non-toxic immunocompetent patients.

1.3. Etiopathogenesis:

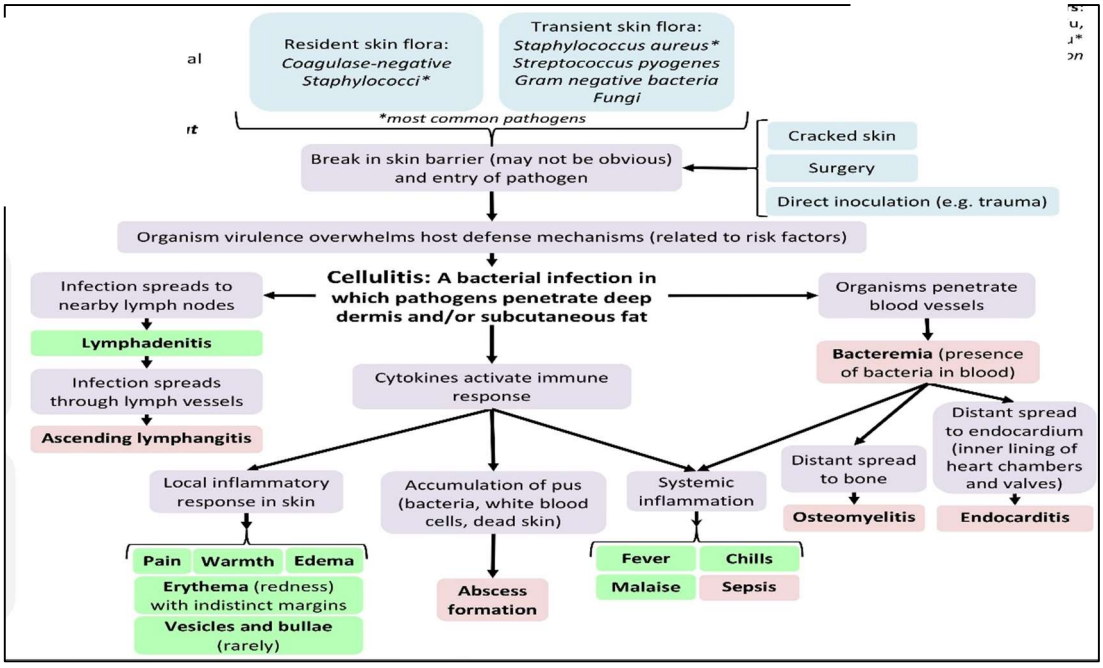

Fig 1.2: Pathogenesis of Cellulitis [24]

Cellulitis is an acute, non-suppurative inflammation that spreads through the subcutaneous tissues and connective tissue planes, extending across intercellular spaces. The term “cellulitis” is a misnomer, as the lesion primarily involves the connective and interstitial tissues rather than the cells themselves [17]. The infection most commonly results from *Streptococcus pyogenes*, though various aerobic and anaerobic bacteria may also be responsible.

Microorganisms typically gain entry through a breach in the skin, such as a wound, scratch, insect bite, or surgical incision, allowing them to invade the dermis and subcutaneous tissues.

Initially, the site of inoculation becomes erythematous and warm, followed by progressive swelling and skin tightness. In severe infections, vesicles or bullae may form, and central necrosis can develop in advanced stages [18].

The skin normally serves as a barrier preventing endogenous flora and exogenous pathogens from penetrating deeper layers; however, once compromised, it permits bacterial infiltration, leading to acute infection of the deep dermis and subcutaneous tissues [17, 18].

Streptococcus pyogenes remains the predominant cause of non-purulent cellulitis, which is characterised by the absence of abscesses, pustules, or purulent drainage. In contrast, *Staphylococcus aureus,* including both methicillin-susceptible (*MSSA*) and methicillin-resistant (*MRSA*) strains, is a leading cause of purulent cellulitis [19]. Differentiation between MRSA and MSSA infections cannot be made clinically and requires culture and sensitivity testing, which is crucial for selecting appropriate antibiotic therapy.

The incidence of community-acquired MRSA has risen globally, even among individuals without traditional risk factors such as prior antibiotic exposure, recent hospitalisation, surgery, or residence in long-term care facilities. Additional risk factors include HIV infection, injection drug

use, incarceration, and sharing personal items like razors or sports equipment. Other pathogens may be implicated depending on the source of infection [16, 19].

Animal bites can introduce *Pasteurella*, *Neisseria*, or *Fusobacterium* species (from cats or dogs) and *Eikenella corrodens* or *Veillonella* species (from human bites) [20].

Aquatic injuries may involve *Vibrio*, *Aeromonas*, or *Mycobacterium* species. In immunocompromised patients, atypical pathogens such as *Helicobacter cinaedi* or *Streptococcus pneumoniae* (especially in those with systemic lupus erythematosus) should be considered. A thorough patient history and clinical evaluation are therefore essential for identifying likely causative organisms and guiding antimicrobial management [20, 21].

Predisposing factors for cellulitis include advancing age, obesity, diabetes mellitus, venous insufficiency, peripheral arterial disease, lymphedema, chronic leg edema, and a prior history of cellulitis [20]. Lymphedema, in particular, creates a favourable environment for bacterial growth. A large retrospective study involving over 165,000 hospital admissions found that 92% of lymphedema cases were associated with cellulitis. Chronic disruption of the skin barrier due to trauma, ulcers, or other dermatologic conditions remains a major modifiable risk factor. Early identification and management of these underlying conditions are vital to prevent recurrence and improve clinical outcomes [21].

1.4. Risk Factors:

Cellulitis commonly develops when bacteria, particularly Streptococcus pyogenes or Staphylococcus aureus, gain entry through breaks in the skin [22]. Several factors predispose individuals to infection by compromising skin integrity, immune response, or lymphatic drainage:

1.4.1. Breaks in the Skin Barrier:

Conditions such as cuts, abrasions, insect bites, surgical wounds, ulcers, or chronic skin diseases like eczema and psoriasis increase susceptibility to cellulitis [22].

1.4.2. Chronic Edema and Lymphedema:

Impaired lymphatic drainage or chronic venous insufficiency leads to fluid accumulation, which predisposes to bacterial entry and infection [23].

1.4.3. Obesity:

Increased body mass index (BMI) is associated with recurrent cellulitis, likely due to skin folds, poor lymphatic flow, and impaired immune function [25].

1.4.4. Diabetes Mellitus:

Hyperglycemia impairs neutrophil function and wound healing, making diabetic patients more prone to skin infections, including cellulitis [26].

1.4.5. Peripheral Vascular Disease:

Poor blood circulation limits the immune response and tissue oxygenation, facilitating bacterial growth. [5]

1.4.6. Immunosuppression:

Patients with HIV, malignancies, or on immunosuppressive therapy (e.g., corticosteroids, chemotherapy) are at higher risk [27].

1.4.7. Tinea Pedis and Other Fungal Infections:

Fungal infections between toes cause fissures that allow bacterial entry, particularly predisposing to leg cellulitis [25].

1.4.8. History of Previous Cellulitis:

Recurrent cellulitis is common, especially if underlying predisposing factors (such as edema or fungal infections) persist [23].

1.5. Clinical features:

1.5.1. Local Symptoms:

1.5.1.1. Erythema (redness): The affected area appears red, warm, and swollen due to inflammation and increased blood flow.

1.5.1.2. Edema (swelling): Resulting from fluid accumulation in the interstitial tissues.
1.5.1.3. Warmth: A hallmark sign indicating active inflammation and infection.
1.5.1.4. Pain or tenderness: The area is usually painful to touch and may throb.
1.5.1.5. Ill-defined margins: Unlike erysipelas (which has well-demarcated borders), cellulitis has poorly defined edges [27].
1.5.1.6. Lymphangitic streaking: Red streaks may be seen extending proximally due to lymphatic involvement [27].
1.5.1.7. Regional lymphadenopathy: Swollen lymph nodes may be palpable near the site of infection [5].

1.5.2. Systemic Symptoms:

In moderate to severe infections, systemic manifestations may occur:

- Fever and chills
- Malaise and fatigue
- Tachycardia
- Leukocytosis (elevated WBC count)

In severe cases:

- Hypotension
- Confusion
- Sepsis may develop, especially in immunocompromised or elderly patients.

1.5.3. Site-Specific Variations:

- Lower limbs are the most common site, often following trauma, ulcers, or fungal infections between the toes (tinea pedis).
- Facial cellulitis can lead to complications like orbital cellulitis or cavernous sinus thrombosis [28].
- Periorbital and perianal cellulitis may present with more distinct localised symptoms [29].

1.5.4. Differentiating from Other Conditions:

- Erysipelas: More superficial, sharply demarcated borders [29, 30].
- Deep vein thrombosis (DVT): Lacks fever and systemic signs, and the swelling is often non-tender.
- Necrotising fasciitis: Rapidly progressive, severe pain, skin necrosis, crepitus, and systemic toxicity [30].

1.5. ALT-70 Predictive Model for Lower Extremity Cellulitis in the Emergency Department:

The ALT-70 score is a clinical prediction model developed to help differentiate cellulitis (a bacterial skin infection) from pseudo-cellulitis (conditions that mimic cellulitis, such as venous stasis dermatitis or gout).

It is especially useful in the emergency department setting to improve diagnostic accuracy and avoid unnecessary antibiotic use.

Table 1.2: Clinical Variables and Corresponding Points for Cellulitis Assessment [31]

Clinical variable	Points
Asymmetry (unilateral leg involvement)	3
Leukocytosis (WBC count >10,000 per µL (10×10^9 per L))	1
Tachycardia (HR > 90 beats per minute)	1
70 years and older	2

Table 1.3: ALT-70 score Interpretation and Clinical Recommendations for Cellulitis [31]

ALT-70 score	Likelihood of Cellulitis	Clinical recommendation
0 to 2	9%	Cellulitis unlikely; reassess diagnosis
3 to 4	72%	Intermediate; consider consultation
5 to 7	95%	Cellulitis likely; treat empirically

Clinical Resource Efficiency Support Team (CREST) Management of Cellulitis in Adults:

The CREST (Clinical Resource Efficiency Support Team) guidelines were developed to provide a systematic approach to the diagnosis and management of cellulitis. It helps classify patients into four severity classes (I–IV) based on systemic symptoms, comorbidities, and risk factors, assisting clinicians in determining the appropriate treatment setting (outpatient or inpatient).

Table 1.4: Eron Classification of Cellulitis Severity [32]

Class I	Class II	Class III	Class IV
Patients have no signs of systemic toxicity, have no uncontrolled co-morbidities and can usually be managed with oral antimicrobials on an outpatient basis.	Patients are either systemically ill or systemically well, but with a co-morbidity such as peripheral vascular disease, chronic venous insufficiency or morbid obesity, which may complicate or delay resolution of their infection.	Patients may have a significant systemic upset, such as acute confusion, tachycardia, tachypnoea, hypotension, or may have unstable co-morbidities that may interfere with a response to therapy or have a limb-threatening infection due to vascular compromise.	Patients have sepsis syndrome or severe life-threatening infections such as necrotising fasciitis.

1.6. Treatment:

1.6.1. Non-Pharmacological Therapy:

1.6.1.1. Skin Care & Hygiene:

- Keep skin clean and moisturized to prevent cracks [5]
- Treat tinea pedis, wounds, or ulcers promptly.
- Maintain proper nail and foot care to avoid micro-trauma.

1.6.1.2. Wound Care & Dressings:

Goals: Cleanse, protect, and promote healing [33, 34]

- Cleansing: Use normal saline or clean water; avoid harsh antiseptics.
- Dressings:
  - Non-adherent (e.g., paraffin gauze) – for superficial wounds.
  - Foam or alginate – for moderate to heavy exudate.
  - Hydrocolloid/hydrogel – to maintain moisture (not for infected wounds).
- Change as per exudate level; protect surrounding skin with emollient.

1.6.1.3. Oedema & Lymphoedema Control:

- Compression therapy (bandage or stockings) after ruling out arterial disease (ABPI > 0.8) [35].
- Elevation and leg exercises improve lymphatic drainage.
- Complete Decongestive Therapy (CDT): skin care + manual drainage + compression + exercise [35].

1.6.1.4. Lifestyle & Education:

- Weight control, glycaemic management, smoking cessation [5, 34].
- Educate on daily limb inspection, footwear care, and early reporting of redness or swelling.

1.6.2. Pharmacological Therapy:

1.6.2.1. Class I patients are typically managed with oral antimicrobial therapy on an outpatient basis [32].

1.6.2.2. Class II patients are appropriate candidates for short-term hospitalisation (up to 48 hours) followed by discharge on outpatient parenteral antimicrobial therapy (OPAT), where such services are available [32].

1.6.2.3. Class III and Class IV patients require inpatient care until the infected area shows clinical improvement, systemic signs of infection are resolving, and any co-morbid conditions are stabilised. Patients with suspected necrotising infections should undergo urgent surgical evaluation and prompt, extensive debridement of the affected tissue [32].

Patients presenting with mild cellulitis and no systemic signs of infection should receive antibiotic therapy targeting *Streptococcus* species [36]. Although *Staphylococcus aureus* (MSSA) is a less common etiologic agent, empirical coverage may be considered. The recommended duration of oral antibiotic therapy is at least 5 days. For non-purulent cellulitis, the preferred regimen is cephalexin 500 mg every 6 hours. In patients with a severe allergy to β-lactam antibiotics, clindamycin 300-450 mg every 6 hours is recommended as an alternative.

For patients with purulent cellulitis, MRSA colonization, cellulitis associated with abscesses, extensive puncture wounds, or a history of intravenous drug use, antibiotic therapy should include coverage against methicillin-resistant *Staphylococcus aureus* (MRSA) [5, 36]. In such cases, the recommended regimen is trimethoprim–sulfamethoxazole (TMP-SMX) 800/160 mg twice daily for 5 days in combination with cephalexin 500 mg every 6 hours. If the patient is allergic to TMP-SMX, clindamycin 300-450 mg every 6 hours should be used instead.

A longer duration of antibiotic therapy may be warranted for patients demonstrating minimal improvement after 48 hours of treatment initiation [37].

Hospitalisation and the initiation of intravenous (IV) antibiotic therapy are indicated for patients who present with systemic signs of infection, have failed outpatient therapy, are immunocompromised, exhibit rapidly progressing erythema, cannot tolerate oral medications, or have cellulitis overlying or adjacent to an indwelling medical device [5].

In such patients, IV antibiotics should provide coverage against *Group A Streptococcus*. In the absence of MRSA risk factors, therapy should begin with cefazolin (IV), transitioning to cephalexin (oral) once improvement is noted, completing a total course of 5 days.

If MRSA risk factors are present, initiate treatment with vancomycin (IV), followed by de-escalation to trimethoprim–sulfamethoxazole (oral) upon stabilisation [37].

For immunocompromised patients requiring parenteral therapy, broad-spectrum antimicrobial coverage is warranted, typically with vancomycin plus piperacillin–tazobactam or a carbapenem [36].

Blood cultures should be obtained in patients showing signs of systemic toxicity, those with persistent cellulitis despite appropriate therapy, or those with unique exposures such as animal bites or water-associated injuries [37].

Atypical organisms may be implicated in specific exposure-related cellulitis:

- *Pasteurella multocida*- associated with dog or cat bites.
- *Vibrio vulnificus*- associated with marine or shellfish-related injuries.
- *Pseudomonas aeruginosa*- common in diabetic foot ulcers or water exposure.
- *Cryptococcus* species- possible in immunocompromised individuals.

In patients with significant edema, underlying causes should be addressed to reduce swelling and prevent recurrent cellulitis. The affected limb should be elevated to enhance venous return and decrease tissue inflammation [36].

Systemic inflammatory response criteria (SIRS) include:

- Fever > 38°C

- Tachycardia > 90 beats/min
- Tachypnea > 20 breaths/min
- Leukocytosis > 12,000/mm³, leukopenia < 4,000/mm³, or bandemia ≥ 10%.

Table 1.5: Recommended Antibiotic Therapy for Cellulitis [5, 36, 37]

Clinical Type	Likely Pathogen	Preferred Antibiotic	Alternative (if allergic)	Duration of Therapy
Non-purulent cellulitis (mild, outpatient)	*Streptococcus* spp., MSSA (less common)	Cephalexin 500 mg PO every 6 hrs	Clindamycin 300–450 mg PO every 6 hrs	Minimum 5 days
Purulent cellulitis or MRSA risk factors	MRSA, MSSA	TMP-SMX 800/160 mg PO BID + Cephalexin 500 mg PO every 6 hrs	Clindamycin 300–450 mg PO every 6 hrs	Minimum 5 days
Hospitalized patients (no MRSA risk factors)	*Group A Streptococcus*, MSSA	Cefazolin IV → step-down to Cephalexin PO	Clindamycin IV/PO	5–10 days
Hospitalized patients (MRSA risk factors)	MRSA, *Group A Streptococcus*	Vancomycin IV → TMP-SMX PO	Linezolid or Daptomycin (if resistant/intolerant)	7–10 days
Immunocompromised or severe infection	MRSA, *Pseudomonas*, anaerobes	Vancomycin + Piperacillin–Tazobactam or a Carbapenem	Vancomycin + Meropenem (if required)	10–14 days
Animal bite-associated cellulitis	*Pasteurella multocida*	Amoxicillin–Clavulanate 875/125 mg PO BID	Doxycycline or Moxifloxacin	5–10 days
Water-exposure-related cellulitis	*Vibrio vulnificus*, *Aeromonas* spp.	Doxycycline + Ceftazidime IV	Fluoroquinolone (e.g., Ciprofloxacin)	10–14 days
Diabetic foot / chronic ulcers	*Pseudomonas*, MRSA, anaerobes	Piperacillin–Tazobactam + Vancomycin	Carbapenem + Linezolid	10–14 days

Surgical intervention in cellulitis is indicated in specific situations where medical therapy alone is insufficient. While uncomplicated cellulitis is primarily managed with antibiotics, cases associated with abscess formation, necrotising soft-tissue infection, or treatment failure often require surgical management [37]. The most common procedure is incision and drainage (I&D), which is the gold standard for cellulitis accompanied by an abscess [16, 27]. This procedure involves making an incision to evacuate pus, breaking down loculations, and packing the wound if necessary to allow proper drainage and healing. In cases where cellulitis progresses to necrotizing fasciitis or another deep soft tissue infection, prompt and aggressive surgical debridement of necrotic tissue is life-saving and should be performed urgently [5]. Surgical consultation is also essential when patients show rapid progression, severe pain disproportionate to findings, bullae, crepitus, or systemic toxicity, as these signs suggest deep tissue involvement. In chronic or recurrent cellulitis associated with lymphedema or venous insufficiency, surgical procedures such as lymphatico-venous anastomosis, lymph node transfer, or subcutaneous tissue excision may be considered to reduce recurrence by improving lymphatic drainage [5, 37]. Although surgery is not a substitute for

antibiotic therapy in uncomplicated cellulitis, it plays a critical role in managing complicated cases and preventing severe complications. According to the Infectious Diseases Society of America (IDSA) 2014 guidelines, timely surgical evaluation and intervention significantly improve outcomes in cellulitis with abscesses or necrotizing infections [37].

1.7. Quality of Life (QoL):

Cellulitis, an acute bacterial infection involving the skin and subcutaneous tissues, significantly affects patients' physical, psychological, and social well-being. The ''Dermatology Life Quality Index (DLQI)'', developed by Finlay and Khan in 1994, is a validated tool widely used to assess the impact of dermatological conditions on quality of life. It consists of 10 questions covering six domains: symptoms and feelings, daily activities, leisure, work/school, personal relationships, and treatment burden. Each question is scored from 0 (not at all) to 3 (very much), giving a total score ranging from 0 to 30, where higher scores indicate greater impairment in quality of life [38]. Several studies have demonstrated that cellulitis has a moderate to severe impact on patients' quality of life as measured by DLQI. The physical discomfort, pain, swelling, and restricted mobility associated with cellulitis lead to functional limitations and social withdrawal. In hospitalised patients with cellulitis, mean DLQI scores typically range from 10 to 14, indicating a moderate to large effect on daily life [35]. Moreover, recurrent cellulitis is associated with even higher DLQI scores due to chronic edema, disfigurement, and anxiety over recurrence [34]. Patients often report embarrassment over visible lesions, difficulty performing daily tasks, and disruption in occupational or social activities. Additionally, treatment-related factors such as frequent dressing changes, hospitalization for intravenous antibiotics, and prolonged recovery periods contribute to the overall burden. The use of the DLQI in cellulitis research and clinical practice provides a quantitative measure of disease burden, emphasizing the importance of holistic management approaches that address not only infection control but also psychological and social aspects of care. Therefore, integrating DLQI assessments in clinical settings can guide clinicians to implement patient-centred interventions and improve overall well-being [36].

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Geographic Sciences

Su Müharibələri: Kürənin Ən Qiymətli Resursunun Paylanma Coğrafiyası

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Açar sözlər: Su Müharibələri, Su Diplomatiyası, Transsərhəd Çaylar, Geosiyasi Gərginlik, Regional Münaqişələr.

Giriş

Şirin su, Yer kürəsində həyatın və iqtisadi inkişafın əsası olan kritik strateji resursdur. Lakin onun paylanması coğrafi cəhətdən son dərəcə qeyri-bərabərdir. Bu disbalans, xüsusilə son onilliklərdə, əhali artımı, urbanizasiya və kənd təsərrüfatının intensivləşməsi ilə birləşərək, su ehtiyatlarını geosiyasi gərginliyin və potensial münaqişələrin mərkəzinə çevirmişdir. "Su Müharibələri" termini, transsərhəd çay hövzələrində suyun tənzimlənməsi uğrunda gedən siyasi mübarizəni təsvir edir. Bu məqalə suyun paylanma coğrafiyasını, iqlim dəyişikliyinin təsirini, əsas münaqişə zonalarını və dayanıqlı su diplomatiyasının əhəmiyyətini dərindən analiz edir.

I. Su Ehtiyatlarının Coğrafi Təsnifatı və Tələbatın Dinamikası

1. Fiziki Coğrafi Qeyri-Bərabərlik

Yer səthindəki şirin suyun çox kiçik bir hissəsi (təxminən 0.3\%-i) əlçatan səthi su kimi mövcuddur. Əsas mənbələr yağış suları ilə qidalanan çaylar, göllər və yeraltı sular (qrunt suları) hesab olunur. Coğrafi zonallıq baxımından:

* Rütubətli Bölgələr (Ekvatorial, Musson): Yüksək yağıntı normasına malikdir, lakin sürətli urbanizasiya və çirklənmə səbəbindən ehtiyatlar risk altındadır.

* Quraq və Yarıquraq Bölgələr: Təbii su çatışmazlığı olan bu bölgələrdə (məsələn, Səhraətrafı Afrika, Yaxın Şərq) su, həm iqtisadi, həm də siyasi sabitlik üçün həyati əhəmiyyət kəsb edir.

2. Tələbatın Artması və Virtual Su Konsepsiyası

Qlobal su istehlakı kənd təsərrüfatı (70\%), sənaye (20\%) və məişət (10\%) arasında bölüşdürülür. Kənd təsərrüfatında irriqasiya (suvarma) sistemlərinin səmərəsizliyi, xüsusilə inkişaf etməkdə olan ölkələrdə, su itkilərinin əsas mənbəyidir.

Virtual Su (Virtual Water): Bu konsepsiya, bir məhsulun istehsalı zamanı istifadə olunan suyun həcmini ölçür. Məsələn, bir fincan qəhvə üçün təqribən 140 litr su lazımdır. Ölkələrin virtual su ixracı və idxalı, onların real su ehtiyatları üzərindəki təzyiqi yumşalda və ya artıra bilər. Su qıtlığı olan ölkələr qida məhsullarını idxal etməklə "gizli su" idxal edirlər, bu da daxili resursları qorumağa kömək edir.

II. İqlim Dəyişikliyinin Təsiri: Su Təhlükəsizliyinə Geosiyasi Təhdid

İqlim dəyişikliyi su ehtiyatlarının coğrafi paylanmasını kəskin şəkildə dəyişdirən əsas antropogen amildir.

1. Yağıntı Rejiminin Pozulması: İqlim modelləri bir çox bölgələrdə, xüsusilə Aralıq dənizi hövzəsində və Afrikanın bəzi hissələrində uzunmüddətli quraqlıqların tezliyinin artacağını göstərir. Bu, kənd təsərrüfatı məhsuldarlığını azaldır və ərzaq təhlükəsizliyini riskə atır.

2. Buzlaqların Əriməsi: Asiya (Himalay), And dağları və digər yüksək dağlıq ərazilərdəki buzlaqlar, ilboyu çayları qidalandıran təbii su anbarlarıdır. Buzlaqların sürətlə əriməsi qısa müddətdə daşqınlara, uzun müddətdə isə çayların axın həcminin kritik şəkildə azalmasına səbəb

olur. Məsələn, Mərkəzi Asiyanın əsas çayları olan Amudərya və Sırdərya buzlaq qidalanmasından asılıdır.

3. Dəniz Səviyyəsinin Qalxması və Şoranlaşma: Dəniz səviyyəsinin qalxması sahilboyu ərazilərdə yeraltı şirin su ehtiyatlarının dəniz suyu ilə qarışmasına və şoranlaşmasına səbəb olur, bu da xüsusilə sıx məskunlaşmış deltalar (məsələn, Banqladeşdə Qanq deltası) üçün ciddi problemdir.

III. Geosiyasi Gərginlik Bölgələri: Transsərhəd Hövzələrin Coğrafiyası

Dünya üzrə 263 transsərhəd çay hövzəsi mövcuddur. Bu hövzələrdə suyun idarə edilməsi yuxarı axın dövlətləri (suyu tənzimləmək imkanı olanlar) və aşağı axın dövlətləri (suyun miqdarından asılı olanlar) arasında ziddiyyətlər yaradır.

1. Yaxın Şərq: Fərat və Dəclə (Türkiyə- Suriya- İraq)

Bu çaylar bölgənin su təminatının 90\%-dən çoxunu təşkil edir.

* Türkiyənin Rolu: Türkiyənin bu çaylar üzərində inşa etdiyi GAP (Cənub-Şərqi Anadolu Layihəsi) çərçivəsindəki nəhəng bəndlər (xüsusilə Atatük bəndi) aşağı axın dövlətlərinə axan suyun miqdarını azaldaraq, regionda siyasi gərginliyi artırır.

* Ekoloji Fəsadlar: İraqda bataqlıqların quruması və torpaqların şoranlaşması (antropogen səhralaşma) kimi ciddi ekoloji problemlər yaranıb.

2. Mərkəzi Asiya: Amudərya və Sırdərya

Bu çaylar beş Mərkəzi Asiya ölkəsinin (Özbəkistan, Qazaxıstan, Türkmənistan, Tacikistan, Qırğızıstan) iqtisadiyyatları üçün kritikdir.

* Münaqişənin Coğrafiyası: Qırğızıstan və Tacikistan (yuxarı axın) hidroenergetika (qışda elektrik enerjisi istehsalı) üçün su ehtiyatını saxlamaqda, Özbəkistan və Türkmənistan (aşağı axın) isə kənd təsərrüfatı (yayda suvarma) üçün su axınının sərbəst buraxılmasında maraqlıdırlar. Bu maraqlar arasındakı ziddiyyət Araz gölünün qurumasına da səbəb olan regional fəlakətə gətirib çıxarıb.

3. Nil Hövzəsi (Efiopiya- Sudan- Misir)

Afrika qitəsinin ən uzun çayı olan Nil, on bir ölkədən keçir.

* GERD Krizi: Efiopiyanın Mavi Nil üzərində inşa etdiyi Böyük Efiopiya İntibah Bəndi (GERD), Misir və Sudan tərəfindən milli təhlükəsizlik məsələsi kimi qiymətləndirilir. Misir bəndin doldurulma sürətinin onun su payını (1959-cu il müqaviləsi əsasında) kəskin azaldacağından narahatdır.

IV. Həll Yolları: Su Diplomatiyası və Dayanıqlı Resurs İdarəçiliyi

Su münaqişələrinin hərbi münaqişəyə çevrilməsinin qarşısını almaq üçün su əməkdaşlığı modeli tətbiq edilməlidir.

1. Beynəlxalq Hüquqi Çərçivə

* BMT Konvensiyaları: 1997-ci il BMT-nin Transsərhəd Su Axınlarının İstifadəsinin Hüququna dair Konvensiyası suyun "ədalətli və ağlabatan" istifadəsi prinsipinə əsaslanır. Bu konvensiyaların tətbiqi, tərəflərə bir-birinin maraqlarını nəzərə almaq öhdəliyi qoyur.

2. İnstitusional Mexanizmlər

* Hövzə Təşkilatları: Tərəflərin dialoq aparması üçün Çay Hövzəsi Təşkilatlarının yaradılması. Məsələn, Reyndə və Dunayda uğurlu əməkdaşlıq təcrübələri suyun idarə edilməsində siyasi gərginliyi azaltmağa kömək edir.

* Məlumat Mübadiləsi: Transsərhəd məlumatların (su axını, yağış proqnozları, bəndlərin vəziyyəti) şəffaf və müntəzəm mübadiləsi qarşılıqlı etimadı artırır.

3. Texnoloji və İqtisadi Səmərəlilik

* Mavi İnqilab: Kənd təsərrüfatında damcı suvarma və digər su qənaət edən texnologiyaların tətbiqi.

* Duzsuzlaşdırma və Təkrar İstifadə: Xüsusilə sahil ölkələrində dəniz suyunun duzsuzlaşdırılması (enerji səmərəliliyi artırılmaqla) və tullantı sularının təmizlənərək təkrar istifadəsi.

* Su Qiymətlərinin Tənzimlənməsi: Suyun iqtisadi dəyərini əks etdirən qiymət siyasətinin tətbiqi səmərəsiz israfın qarşısını alır.

Nəticə

Su ehtiyatlarının coğrafi paylanması, iqlim dəyişikliyinin artan təsiri fonunda, XXI əsrin ən əhəmiyyətli geosiyasi problemlərindən biridir. Transsərhəd çay hövzələrindəki gərginliklər suyun təmiz, sabit və əlçatan təminatının zəruriliyini vurğulayır. Su müharibələri riskini azaltmaq yalnız hərbi-siyasi yolla deyil, ilk növbədə su diplomatiyası, beynəlxalq hüquqi öhdəliklərə əməl edilməsi və coğrafi reallıqları nəzərə alan dayanıqlı resurs idarəçiliyi ilə mümkündür. Su, rəqabət mənbəyi deyil, regional sabitlik və davamlı inkişaf üçün əsas əməkdaşlıq mövzusu olmalıdır.

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