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Germany

October, 2026
№ 14



Berlin, Germany
8-9.10.2026

International
Scientific
Conference

Foundations and Trends in Modern Learning

UDC 001.1
P 97

Publisher.agency: Proceedings of the 14th International Scientific Conference «Foundations and Trends in Modern Learning» (October 8-9, 2026). Berlin, Germany, 2026. 285p

ISBN 978-4-4248-8400-2
DOI 10.5281/zenodo.23564694

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Pedagogical Sciences

ARTIFICIAL INTELLIGENCE AND EDUCATIONAL TECHNOLOGY IN ELT

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ABSTRACT

The rapid advancement of technology in the Industrial 4.0 era has transformed many aspects of life, including English language education (1, pg. 1). The landscape of English Language Teaching (ELT) is currently undergoing a profound metamorphosis, driven by the convergence of **Artificial Intelligence (AI)** and broader **educational technology**. While digital tools have long provided the infrastructure for modern classrooms, the integration of AI introduces a cognitive dimension previously reserved for human instructors: the ability to simulate reasoning, problem-solving, and linguistic understanding.

In the context of language acquisition, the synergy between AI and educational technology creates a dynamic, student-centered environment. AI-created software includes programs that gather knowledge and perform other autonomous tasks, such as computation and student search (2, pg. 5). AI serves as the analytical engine, capable of identifying patterns in learner errors and behavior to provide real-time, personalized interventions. Meanwhile, educational technology provides interactive platforms ranging from multimedia tools to digital assessments that deliver these insights to the student. Together, these innovations allow educators to move beyond a "one-size-fits-all" curriculum toward **adaptive learning systems** that priorities individual needs, fostering higher levels of engagement and motivation. This article explores how this technological partnership is redefining the efficiency of language skills acquisition in the 21st century.

KEYWORDS: Artificial Intelligence, adaptive learning, skills, advantages,

INTRODUCTION

The words "artificial" and "intelligence" form the term "artificial intelligence". The word "artificial" refers to something fabricated or unreal, but it is not entirely deceptive, according to Ahmed (3, pg. 10). With the development of technology and digital platforms, learning English has also become easier (4, pg. 2). Artificial Intelligence and technology play an important role in modern English Language Teaching. Now, there are opportunities to enhance your English skills. This means that if we have tools that can teach English, we might not need English teachers in the classroom or English education (5, pg. 3)

They bring many advantages, but also some disadvantages, while their overall importance continues to grow. Artificial Intelligence (AI) in English Language Teaching (ELT) offers significant opportunities for personalized learning and efficiency, but it also brings challenges regarding dependency, equity, and the human element of teaching.

Advantages of AI in ELT

Personalized Learning & Tutoring: AI platforms provide customized learning experiences, adapting to individual student needs, learning styles, and paces.

- **24/7 Support:** AI-powered catboats and virtual tutors offer instant feedback and tutoring at any time, allowing students to practice speaking, reading, and writing outside of classroom hours.
- **Content Creation & Efficiency:** AI enables educators quickly to create tailored teaching materials, lesson plans, and assessments, reducing administrative burdens.
- **Enhanced Skill Practice:** AI tools help students improve specific skills, such as pronunciation, vocabulary acquisition, and understanding colloquialisms through interactive practice.
- **Increased Accessibility:** AI tools can break down language barriers, making learning materials more accessible to learners with diverse needs.

Disadvantages of AI in ELT

- **Over-reliance and Reduced Critical Thinking:** Excessive dependence on AI for writing and problem solving may hinder the development of students' own critical thinking and creative skills.
- **Lack of Human Emotion and Nuance:** AI cannot replicate the emotional intelligence, creativity, and empathy of human teachers, which are crucial for motivation and understanding complex cultural nuances.
- **Data Privacy and Ethics:** The use of AI involves collecting large amounts of student data, raising concerns about privacy, security, and potential misuse.
- **Algorithmic Bias:** AI systems may unintentionally reinforce biases present in the data used to train them, leading to unfair treatment or inaccurate, standardized language modeling.
- **Technology Gaps and Costs:** The high cost of implementing AI solutions can create inequalities, and technology failures can disrupt the learning process.

Enhancing Specific Language skills

Mukhallafi (6, pg 40) states that AI research is characterized by the use of artificial intelligence systems for English language teaching and learning to improve the process of organizing, structuring, and selecting content. It increases the variety of teaching sources and schooling flow based on students' levels and through the individualization of independent learning procedures, as well as intelligent systems and simulation of teaching and assessment methods.

Integrating AI into English Language Teaching (ELT) has evolved from simple grammar checking to sophisticated, multimodal support that targets the four foundational skills (Listening, Speaking, Reading, and Writing) with high precision. Here is an overview of how AI can enhance each skill in a 2026 classroom context:

Skill	Primary Goal	Recommended Tools
Speaking	Fluency & Confidence	Gliglish, ELSA Speak, Speakpal
Listening	Comprehension & Accents	Speechify, Natural Reader, YouTube AI Captions
Reading	Differentiation & Vocabulary	Diffit, Twee, SciSpace
Writing	Structure & Register	Grammarly, Paperpal, Wordtune

Automated Essay Scoring

One instructive example is Automated Essay Scoring (AES). To become strong writers, which is a valuable life skill, students need regular and specific feedback. However, reviewing and providing feedback on essays is very time-consuming for humans. Hence, Ellis Page provided a first vision for computer programs that could review and provide feedback on student essays in 1966 (7, pg 47). Some of today's applications of AES technologies will be familiar to readers, such as Grammarly, Turnitin, and the various essay analysis engines used by publishers and assessment companies. Also note that while the traditional AES functionality emphasises scoring or rating essays, newer AI-enabled products focus more on providing students with constructive criticism and on developing their writing skills. Writing is a life skill that is important to the pursuit of college and career ambitions, and developing writers requires comprehensive feedback. If developers could inexpensively augment human feedback to developing writers with AI feedback, it's possible that support for learning to write could become more equitable (8, pg 40). And yet, AES is an instructive example because researchers have analysed limitations, too (9, pg 243).

Miguel A. Cardona, Roberto J. Rodríguez , Kristina Ishmael, further note that while human and AI judgements of essays may correlate, people and computers are not noticing the same things in student writing. Due to these limitations, we must continue to emphasise a human-in-the-loop foundation for AI-enhanced formative assessment. AI may support but not replace high-quality, human-led processes and practices of formative assessment in schools (10, pg 40).

Key AI Tools Used in ELT

Several AI-powered tools have been successfully applied in ELT. Examples include:

Content Generation Tools: AI tools such as **ChatGPT** and **QuillBot** help generate texts, exercises, and paraphrased content for learning.

Gamified Learning Tools: Applications such as **Kahoot!, Quizlet**, and **Wordwall** make learning more engaging and fun.

Speech Recognition Applications: Applications like **ELSA Speak** analyze pronunciation and offer corrective guidance.

Adaptive Learning Platforms: Systems like **Duolingo** and **Lingvist** adjust content based on learner progress, ensuring optimal challenge and reinforcement. These tools not only support individualized learning but also facilitate self-paced study, promote engagement, and provide valuable data for teachers to monitor progress.

Future of AI in ELT

The future of Artificial Intelligence in English Language Teaching is expected to bring even more advanced and innovative changes to education. AI technologies will continue to develop and become more intelligent, offering highly personalised and interactive learning experiences for students.

In the future, AI systems are likely to become more human-like in communication. Advanced virtual tutors will be able to understand emotions, tone of voice, and learning difficulties, providing more natural and supportive interaction for learners. This will make language learning more similar to real-life communication.

Another expected development is the use of fully adaptive learning environments. These systems will automatically adjust not only the level of tasks but also teaching methods based on student behavior and progress. This will make learning more efficient and faster.

In addition, virtual reality (VR) and augmented reality (AR) combined with AI may create immersive language learning environments. Students will be able to practice English in realistic situations such as airports, classrooms, or workplaces without leaving their homes.

However, even in the future, the role of teachers will remain important. AI will support education, but human guidance, motivation, and emotional connection cannot be replaced.

Therefore, the future of ELT will likely be a combination of human teaching and advanced AI technologies.

Conclusion

In conclusion, Artificial Intelligence and technology have become an important part of modern English Language Teaching. They have changed the traditional way of learning by making it more interactive, flexible, and personalized. AI-based tools help students improve their language skills faster by giving instant feedback and providing practice opportunities in different forms.

At the same time, these technologies support teachers by saving time and making lesson planning and assessment easier. However, it is also important to use technology in a balanced way, because human interaction and teacher guidance are still essential in language learning.

Overall, I believe that AI and technology will continue to play a major role in ELT, and when used effectively, they can greatly improve the quality of English education and make learning more effective for all students.

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READINESS OF PRIMARY SCHOOLS FOR THE INCLUSION OF PUPILS WITH DISABILITIES IN SLOVAKIA

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Abstract:
This paper presents a research project designed to analyse the current conditions provided to pupils with special educational needs who, after meeting the statutory criteria, are educated in mainstream primary schools in the Slovak Republic. It outlines the proposed methodology for assessing the conditions that support successful inclusion and for formulating concrete recommendations for schools. The project focuses on external and internal conditions, differences between regions and school sectors, and the experiences of headteachers, teachers and parents.

Keywords:
inclusive education; pupils with special educational needs; disabilities; mainstream primary school; school readiness

Introduction

The education of pupils with disabilities in mainstream primary schools is becoming a regular part of an inclusive society. The quality of this process, however, varies considerably and depends on the school's philosophy, staffing, professional capacity and organisational conditions. These factors influence not only the educational opportunities of pupils with disabilities, but also their participation in everyday school life and the experience of classmates, teachers and other members of the school community. Inclusion therefore involves more than the placement of a pupil with a disability in a mainstream classroom. It also requires appropriate conditions, professional support and a school environment that is able to respond to different educational needs.

The importance of creating such conditions can also be seen in other educational and cultural environments. Kováčová (2024), in examining the space of museums and galleries from the perspective of visitors with disabilities, points to the importance of accessibility, responsiveness to individual needs and opportunities for participation. Similar principles are relevant to the school environment, where the quality of inclusion is closely connected with the conditions created for pupils with disabilities and the people who work with them.

Against this background, it is important to examine how prepared primary schools are to educate pupils with different types of disability. It is also necessary to identify and analyse the opportunities and limits of school integration within mainstream primary education. Attention should be given to the professional preparedness of teachers, organisational conditions, available support and cooperation among those involved in the education of pupils with disabilities. Examining these aspects may help to identify areas in which mainstream primary schools in Slovakia are well prepared for inclusion, as well as areas where further support and development are needed.

Rationale for the research topic

Inclusive education is recognised as an important objective by several international bodies and policy documents, including the European Agency for Special Needs and Inclusive Education (2017), the United Nations Convention on the Rights of Persons with Disabilities (2006), the Salamanca Statement (UNESCO, 1994) and the Global Education Monitoring Report on inclusion (UNESCO, 2020). These sources emphasise that support for children with diverse needs should maximise their academic and social development in line with the goal of full inclusion. According to statistics published by the Slovak Centre of Scientific and Technical Information in 2023, 46,324 school-age children with special educational needs were educated in mainstream state, private and church primary schools. Slovakia also reported one of the highest proportions in the European comparison presented by Ramberg, Lénárt and Watkins (2018).

There is still limited knowledge about the extent to which pupils, regardless of their abilities, can develop their potential and genuinely experience inclusion in primary school. This project therefore examines both the conditions for inclusion and the relationships surrounding pupils with special educational needs. The desired standard is a school that can respond appropriately to different disabilities, provide high-quality school integration and create the conditions for meaningful inclusive education. The central question is whether inclusive education in Slovakia functions as an established reality or remains largely aspirational.

For the purpose of assessing school readiness, the conditions for integration are divided into external and internal conditions. External conditions include legislation and standards, technical requirements, the financial capacity of schools, staffing arrangements, specialist guidance from counselling and support services, and the legal framework for educating pupils with disabilities in mainstream classes. These conditions strongly influence what schools can provide internally. Internal conditions include the attitudes and professional preparedness of school staff, the class community's understanding of inclusion, organisational arrangements, previous experience and cooperation with families. The attitudes of the wider parent community and its willingness to accept pupils with diverse needs are also important.

Aim and tasks of the planned research

From a theoretical perspective, the project aims to define the key concepts, conditions and possibilities of educating pupils with special educational needs in mainstream primary schools in accordance with current legislation. From an empirical perspective, it aims to monitor and analyse the external and internal conditions for integration in primary schools across the regions of the Slovak Republic and to compare the findings.

The project seeks to answer the following **research questions** *(Table 1).*

Table 1: Research Questions

Research Questions	Specification of the Research Questions
1.	To what extent are mainstream primary schools prepared to integrate pupils with disabilities?
2.	Which groups of pupils with disabilities are most frequently integrated into mainstream primary schools?
3.	What specific risks of inclusive education do teachers, parents and other stakeholders identify in primary schools?
4.	What specific opportunities does inclusive education offer in primary schools?

Source: Author's own elaboration

The research tasks are organised into two linked phases and include the following **activities** *(Table 2).*

Table 2: Research Activities

1.	Define the theoretical foundations of the research topic.
2.	Determine how many primary schools in each region educate pupils through school integration, identify the types of disability most frequently represented, and establish which professionals schools know and cooperate with in practice.
3.	Recruit selected primary schools from every region, with equal representation planned for state, church and private schools.
4.	Monitor and analyse the internal and external conditions for integration in primary schools by means of SWOT analysis.
5.	Evaluate, interpret and compare the findings obtained through the SWOT analysis.
6.	Conduct interviews with teachers, headteachers and other respondents to gain a deeper understanding of the issue.
7.	Analyse the interviews and formulate conclusions.
8.	Develop an assessment battery for evaluating the conditions under which pupils with diverse needs are included in mainstream primary schools and test it experimentally.
9.	Formulate recommendations for educational practice.

Source: Author's own elaboration

Research setting and research sample

The research will be conducted in primary schools in all regions of the Slovak Republic. The sample will include state, private and church schools. Equal representation of these school sectors will be sought in each region, subject to school availability and consent to participate.

The questionnaire sample will consist primarily of primary school teachers and headteachers. A smaller interview sample will include teachers, headteachers and, where appropriate, parents of pupils educated through school integration. Participants will be selected purposively from among people who have direct experience of the issue. The sample will reflect variation in length of professional experience, sex, educational attainment, school size, region and school sector.

The assessors participating in the SWOT analysis will be teachers, members of school support teams, special education professionals or headteachers who have direct knowledge of the conditions for educating pupils with special educational needs at their school. They must have practical experience of planning, providing or managing support for at least one integrated pupil and sufficient knowledge of the school's staffing, material, organisational and cooperation arrangements to assess both internal and external factors. The final sample will be a convenience sample because participation depends on the availability and willingness of schools and respondents.

Research methods

The project will use a theoretical and empirical mixed-method design with a predominantly qualitative orientation. The combination of document analysis, a questionnaire, SWOT analysis, an adapted Index for Inclusion and semi-structured interviews will make it possible to examine formal conditions as well as the experiences of the people involved.

a) *Document and content analysis with SWOT analysis:* The theoretical part will use document analysis, critical analysis of professional literature and content analysis of relevant materials. Current legislation, policy documents and professional publications will be examined to define the external and internal conditions of school integration. The empirical mapping phase will include a pilot survey, monitoring of pupils with special educational needs in mainstream primary schools, a non-standardised questionnaire, SWOT analysis and an adapted Index for Inclusion.The SWOT analysis will classify identified factors as strengths, weaknesses, opportunities and threats. Results will be compared across regions and school sectors. The synthesis of these findings will support the development of assessment cards for evaluating conditions in primary schools, followed by their experimental testing (Kováčová, 2010).

b) *Questionnaire:* The questionnaire is suitable for collecting information in writing from a larger group of respondents and lies at the boundary between quantitative and qualitative methods. Its structure and wording must be planned carefully. Rochovská et al. (2007) emphasise the importance of an appropriate question structure, while Turek (1996) recommends that a questionnaire should not exceed approximately 30 items so that respondents are not overburdened. The planned questionnaire will therefore be concise and will combine closed and open-ended items focused on staffing, material, organisational and cooperation conditions. Closed-item responses will be summarised descriptively, while open-ended responses will be grouped into thematic categories.

c) *Semi structured interview*: Individual semi-structured interviews will be used to obtain respondents' personal views and experiences. Participants will be selected purposively from groups directly affected by the issue: teachers, headteachers and parents of pupils integrated into mainstream primary schools. A common interview framework will make responses comparable, while follow-up questions will allow relevant topics to be explored in greater depth. The interviews will include open and, where useful, closed questions. With the participants' consent, responses will be transcribed and analysed thematically (Gavora et al., 2010).

This sequence of methods is intended to answer the research questions and fulfil the project aims. It will connect the theoretical description of school integration with an analysis of actual conditions, compare findings by region and school sector, and provide the basis for an assessment battery for mainstream primary schools.

Organisation of the research

The research will proceed through linked phases so that each stage informs the next. The schedule will cover the period from preparation and recruitment of schools to the final report and recommendations.

1. Review professional literature, current legislation and policy documents; refine the research problem, questions and instruments.
2. Conduct a preliminary study and pilot the questionnaire, interview framework and SWOT assessment procedure.
3. Recruit state, church and private primary schools in the individual regions of the Slovak Republic.
4. Collect questionnaire, interview and SWOT data and document the relevant internal and external conditions.
5. Analyse and compare findings across regions and school sectors.
6. Develop and experimentally test the assessment battery, then prepare the final report and recommendations for practice.

Research methodology

The research will examine the conditions under which pupils with special educational needs are educated in mainstream primary schools in accordance with current legislation. At the beginning of the preliminary phase, several practical variables remain uncertain, especially school recruitment and data collection. A preliminary study was therefore used to refine the research idea and assess whether the planned procedures are feasible in the selected schools.

The methodology corresponds to the aims of the project. It includes the collection and study of theoretical sources, current legislation, restrictions affecting school integration and professional views in the field. These findings provide the basis for defining the research problem, research questions and aims. The pilot mapping focuses on the current extent of school integration and on the internal and external conditions identified through the questionnaire, interviews, the adapted Index for Inclusion and SWOT analysis.

Participation may be limited by respondents' lack of time or willingness to express their views and experiences. The schedule will therefore allow additional time to recruit replacement schools or participants when necessary. This limitation will be considered when interpreting the results, particularly because a convenience sample cannot be treated as fully representative of all primary schools in Slovakia.

Interviews with teachers, headteachers and other respondents will provide a deeper understanding of the findings. The combined analysis of actual school conditions will be used to create an assessment battery that schools can use to evaluate their readiness. The battery will then be tested experimentally and revised on the basis of the results.

Conclusion

The proposed research will provide a structured account of how external and internal conditions influence the education of pupils with special educational needs in mainstream primary schools in Slovakia. Combining document analysis, a questionnaire, SWOT analysis, an adapted Index for Inclusion and semi-structured interviews will make it possible to compare formal requirements with the everyday experiences of schools, teachers, headteachers and parents.

The expected output is an experimentally tested assessment battery accompanied by practical recommendations for schools and professionals involved in inclusive education. The findings should identify recurring barriers, existing strengths and practices that may be transferable between schools and regions. Attention will also be given to differences in the conditions under which inclusive education is implemented, as these may influence how individual measures are applied in practice. The study may therefore contribute not only to the assessment of current conditions, but also to a better understanding of what schools need in order to implement inclusive approaches more consistently. Because the study uses a convenience sample, its conclusions will need to be interpreted with appropriate caution. Nevertheless, the planned comparison across regions and school sectors can provide useful evidence for improving the conditions of inclusion and for planning support that responds to the needs of both pupils and schools. The results may also serve as a basis for further research focused on the effectiveness of specific forms of support and on differences between schools with different levels of experience with inclusive education.

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MUSIC–SPEECH INTERACTION IN LANGUAGE EDUCATION FROM NEUROCOGNITIVE AND LINGUISTIC PERSPECTIVES

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Abstract

This article examines music–speech interaction as a multilevel neurocognitive, linguistic, and educational phenomenon in the context of a creative university. It analyzes the shared characteristics of musical and speech signals associated with pitch, duration, intensity, tempo, and rhythmic organization, as well as the specific ways in which these characteristics are functionally realized within different sign systems. The article explores music–speech interaction at the phonological, prosodic, intonational, rhythmic, syntactic, lexico-semantic, and discourse levels in relation to auditory perception, attention, memory, prediction, and structural integration. Particular attention is given to the educational potential of students' musical experience in language-related disciplines, including the development of auditory sensitivity, prosodic perception, rhythmic organization of speech, verbal memory, interpretive skills, and communicative competence. The article substantiates a functional approach in which musical material is incorporated into the educational process in accordance with a specific linguistic or speech-related objective, while its effectiveness is determined by the nature of the learning activity and the individual characteristics of learners. The article also identifies prospects for experimental research into music–speech relationships and considers the potential of digital technologies and artificial intelligence tools for analyzing the acoustic characteristics of music and speech and for developing adaptive learning tasks. The integration of music and language-related disciplines in a creative university is presented as an interdisciplinary educational approach that brings together auditory, cognitive, linguistic, and communicative activities.

Keywords: *music, speech, music–speech interaction, neurocognitive processes, phonology, prosody, intonation, rhythm, language education, creative university, speech production, interdisciplinary learning, digital technologies.*

Introduction

Music and speech are fundamental forms of human communication, both realized through temporally organized acoustic signals in which pitch, duration, intensity, tempo, and rhythmic organization play an important role. Despite the functional differences between these systems, similarities in certain characteristics of the acoustic signal have contributed to the development of an interdisciplinary field bringing together linguistics, neuroscience, cognitive psychology, musicology, and pedagogy.

One basis for comparing music and language is their hierarchical organization. Patel considers musical and linguistic sequences as systems of discrete elements combined into larger structural units and relates their comparison primarily to processes of syntactic processing and structural integration. At the same time, speech and music are not identical systems, since linguistic syntax is associated with grammatical relations and propositional content, whereas musical structure organizes sound material according to different principles [1].

Neurocognitive research complements this structural comparison by examining the mechanisms of auditory perception, attention, memory, prediction, and emotional evaluation. Peretz considers musical ability a complex cognitive system with a specific organization that simultaneously interacts with other mechanisms involved in the processing of auditory information [2]. Koelsch associates the perception of musical structure with distributed neural systems involved in the processing of acoustic features, short-term auditory memory, musical syntax, and meaning [3]. Prosodic organization of speech is of particular interest because changes in fundamental frequency, duration, intensity, tempo, and pausing contribute to the structuring of the speech stream and the expression of communicative meanings. Contemporary research on prosody demonstrates the complex organization of tonal and intonational characteristics of speech [4]. An important area of research has been the investigation of the possible transfer of specific auditory-processing mechanisms between music and speech. Experimental evidence suggests that musical training may be associated with differences in the processing of temporal, frequency, and spectral characteristics of auditory signals, including speech materials [5]. At the same time, such findings do not support treating musical experience as a universal factor that automatically enhances language proficiency, since the nature of this relationship depends on the type of musical activity, duration of training, characteristics of the task, and individual characteristics of learners.

In the educational environment of a creative university, this issue is of particular importance because musical and speech activities are integrated into a common professional context. Students simultaneously work with musical material, process professional speech, acquire specialized terminology, discuss artistic decisions, and present the results of their own activities in verbal form. In this context, music can be viewed not only as content within professional education but also as an educational resource for organizing specific types of work in language-related disciplines.

The practical relevance of this approach is supported by the study by Arkabayeva and colleagues, which examines the use of culturally marked vocabulary associated with the Kazakh musical tradition in teaching the Russian language [8]. The authors directly connect musical material with the linguocultural content of language education, making it possible to consider music–language interaction not only at the acoustic level but also at the lexico-semantic and cultural levels.

Music–speech interaction can therefore be regarded as a multilevel process combining neurocognitive mechanisms of auditory processing with different levels of linguistic organization. From an educational perspective, the potential of music should be associated with specific objectives of language-related disciplines in a creative university.

Theoretical and Methodological Foundations

Musical and speech perception involve the processing of complex temporal sequences in which the auditory system must identify relevant features, retain incoming information, relate it to the preceding context, and generate expectations concerning the subsequent development of the signal. Musical activity demonstrates the importance of these processes particularly clearly, since the perception of melody and rhythm is impossible without the sequential integration of auditory events.

Peretz demonstrates that musical ability has its own neurocognitive organization, including specialized mechanisms for analyzing musical material [2]. Koelsch, in turn, views music processing as an interaction among mechanisms of auditory analysis, memory, structural integration, emotional evaluation, and prediction [3]. This approach makes it possible to speak not of a single integrated music-and-language system but rather of a partial overlap between mechanisms involved in processing complex acoustic sequences.

Auditory processing constitutes the initial level of such interaction. Musical training requires continuous analysis of pitch, duration, timbre, intensity, and temporal organization of sound; therefore, sustained musical practice may be accompanied by changes in the processing of acoustic information. Research by Skoe and Kraus demonstrates an association between musical training and specific features of neural processing of auditory signals, supporting the plasticity of the auditory system [5].

The possibility of applying these mechanisms to speech material is of particular importance from an educational perspective. Experimental studies indicate that musical training may be associated with differences in the processing of speech characteristics that are acoustic in nature and require a high degree of temporal or frequency resolution. At the same time, the available evidence suggests an interaction between specific auditory-processing mechanisms rather than a direct effect of musical activity on the development of language ability.

Working memory is another important component, since both musical and speech sequences unfold over time and require the retention of preceding material in order to interpret subsequent information. The study by George and Coch demonstrates an association between musical training and characteristics of working memory and its neural processing [6]. These findings make it possible to consider musical activity in the context of broader mechanisms involved in the cognitive processing of sequential auditory information, while avoiding an identification of musical and verbal memory mechanisms.

Structural integration represents another level of overlap. Tillmann examines music and language from the perspective of expectations, structural integration, and cognitive sequencing, emphasizing the role of predictive processes in the perception of temporally organized sequences [7]. Research findings suggest that partially overlapping cognitive mechanisms may be involved in the processing of musical and linguistic structures; however, they do not indicate complete structural or functional correspondence between the two domains.

Thus, the neurocognitive relationship between music and speech can be described as an interaction among several processes: acoustic-signal analysis, temporal coordination, auditory attention, working memory, prediction, and structural integration. For language education, the components most directly associated with speech-signal perception are of particular importance.

From a linguistic perspective, music–speech interaction is multilevel and is most directly manifested in phonological, prosodic, intonational, and rhythmic organization, while at higher levels it extends to syntactic, lexico-semantic, and discourse processing.

Phonological processing involves the identification of acoustic features, their categorization, and their mapping onto the phonological system of a language. Musical activity likewise requires highly accurate auditory discrimination; however, musical categories do not coincide with the phonological categories of language. Therefore, any potential relationship

between musical experience and phonological processing should be understood in terms of shared demands for accurate auditory analysis. Research on musical training suggests that musical experience may be associated with differences in the neural processing of speech sounds and their acoustic characteristics [5]. In this case, the issue is not a direct transfer of musical hearing to linguistic competence but an interaction between mechanisms of auditory discrimination.

The most evident area of overlap between music and speech is prosody. Fundamental frequency, duration, intensity, tempo, and pausing contribute to both musical and speech organization. In speech, prosodic characteristics participate in utterance segmentation, the marking of information structure, and the expression of communicative meanings. Knyazev's study demonstrates the complex organization of phrase-level prosody and the importance of tonal characteristics in the phonological description of Russian [4]. In music, changes in pitch organize melodic movement, while duration and tempo contribute to the formation of rhythmic structure. In speech, the same acoustic parameters are incorporated into a system of intonational and prosodic relationships. Consequently, the comparison of musical and speech material is methodologically justified primarily in tasks that require awareness of pitch movement, tempo, rhythm, or pausing.

At the same time, intonation should not be regarded as fully equivalent to musical intonation. In speech, it is directly associated with communicative intention and the semantic organization of an utterance, whereas in music it performs different structural and expressive functions. It is therefore more scientifically accurate to speak of similarities in acoustic characteristics and a partial overlap in the mechanisms involved in their perception.

Rhythm represents an independent area of music–speech interaction. Patel demonstrates that musical and linguistic rhythm share certain similarities while also exhibiting fundamental differences; empirical evidence particularly supports the commonality of rhythmic grouping and the relationship between linguistic rhythm and musical organization in certain cultural contexts [1]. In speech activity, rhythm is important as a means of temporal organization and segmentation of the speech stream. In music, rhythmic organization has a more formalized metric character. This distinction makes it possible to use musical rhythmic patterns in language education as material for developing awareness of the temporal structure of spoken utterances.

The similarity between music and language at the syntactic level is primarily associated with the sequential organization of elements and the need to integrate individual components into a larger structure. Patel identifies this aspect as one of the central points of comparison between music and language [1]. Tillmann relates musical and linguistic perception to processes of expectation and structural integration. Experimental research likewise provides grounds for suggesting a partial overlap in the resources involved in the structural processing of music and language [7]. However, musical structure does not possess a grammar fully equivalent to that of natural language. Therefore, in language education, it is more productive to employ the concepts of structural prediction and sequential integration.

At the lexico-semantic level, the relationship between music and language is less direct, since music does not possess a lexical system equivalent to that of natural language. Nevertheless, musical material can provide a context for interpreting verbal messages, activate cultural and emotional associations, and direct attention toward particular components of a text.

This relationship is particularly evident in linguocultural education. Arkabayeva and colleagues examine culturally marked vocabulary associated with the Kazakh musical tradition specifically in the context of Russian-language instruction [8]. This study is important for the educational model of a creative university because it demonstrates a concrete way of incorporating musical material into a language course through lexical and cultural components.

At the discourse level, music may function as part of a complex communicative situation involving verbal content, intonation, context, emotional organization, and professional

interaction. For students at a creative university, situations requiring them to verbalize musical perception, justify an interpretation of a work, discuss performance decisions, or present the results of professional activity are particularly significant.

Thus, the relationship between music and speech progressively extends from the acoustic level to the communicative level: from the discrimination of acoustic features through prosody and rhythm to the structural, lexico-semantic, and discourse organization of speech activity.

Results

In the educational environment of a creative university, music–speech interaction acquires direct educational significance because students' musical and speech activities are integrated into a common professional context. The acquisition of musical material involves its perception, analysis, interpretation, and verbalization, while language-related disciplines provide the means for describing, explaining, and discussing professionally relevant phenomena [9]. As a result, auditory and musical experience can be transformed into linguistic analysis, interpretation, and professional communication.

For students at a creative university, this interrelationship is manifested in discussing musical works, characterizing performance interpretations, describing expressive means, providing arguments for artistic decisions, and participating in professional communication. According to A. A. Leontiev, speech is an activity carried out under specific communicative and social conditions, which makes it possible to relate the development of professional speech not only to the acquisition of linguistic resources but also to their use in specific activities [9]. In language-related disciplines, musical material can be used to develop prosodic perception, work with tempo, rhythm, and intonation, acquire professional vocabulary, construct analytical utterances, and develop argumentation skills. Its educational function is determined by the specific linguistic objective: work with prosody requires attention to the pitch and temporal characteristics of speech; vocabulary acquisition is oriented toward professional and linguocultural contexts; and the development of oral speech involves describing, interpreting, and discussing musical material.

A methodologically productive sequence is one in which a musical stimulus serves as the basis for identifying acoustic characteristics, conducting linguistic analysis, developing an interpretation, and subsequently producing a spoken response. For example, the identification of tempo and rhythm can lead to an analysis of speech rate and pausing, work with intonation and professional vocabulary, and subsequently to independent description or argumentation. Such an approach integrates the musical, linguistic, and communicative components within a single learning activity. Consequently, in language-related disciplines at a creative university, music functions not as an external addition to language instruction but as a meaningful perceptual and content-based resource through which professional musical experience acquires conceptual, verbal, and communicative form.

The integration of music and speech should primarily be based on the principle of functionality, which presupposes a clear correspondence between the educational objective, the linguistic task, and the way musical material is used. This sequence can be represented as follows: educational objective - linguistic task - musical material - learning activity - speech outcome. Such a sequence makes it possible to connect musical perception not with the formal use of musical material in class but with the specific transformation of professional auditory experience into linguistic and speech activity.

Equally important is the principle of correspondence to the learner's level of preparation. When selecting a musical fragment, its duration, tempo, rhythmic complexity, prominence of melodic structure, number of simultaneously analyzed parameters, and amount of accompanying verbal material should be taken into account. Excessive complexity of the musical stimulus may increase cognitive load and distract learners from the primary linguistic task.

Methodologically, it is appropriate to organize the work in three stages. Before listening, learners formulate hypotheses about the character and structure of the material; during the activity, they identify the required acoustic and speech characteristics; after listening, they proceed to interpretation, retelling, argumentation, or discussion.

Depending on the linguistic objective, several types of exercises can be employed. Phonological tasks focus on auditory discrimination of speech units; prosodic tasks address the perception and reproduction of pitch, tempo, intensity, and pausing; rhythm-and-speech tasks focus on synchronizing speech with temporal structure; lexico-semantic tasks involve interpreting verbal material within a musical and cultural context; and communicative tasks focus on independent speech production and argumentation.

A more methodologically grounded approach is to compare different ways of presenting the same speech material and assess specific indicators, including perceptual accuracy, accuracy of intonation reproduction, retention, processing speed, and the quality of spoken production.

Research Prospects

Further research into music–speech interaction requires a transition from general theoretical propositions to experimental testing of specific mechanisms. A promising direction is to compare learners with different levels of musical experience in terms of their perception of phonological contrasts, intonation, rhythmic organization of speech, auditory memory, structural processing, and verbal communication.

Particular attention should be paid to distinguishing correlational relationships from causal relationships. Future studies should take into account the duration and intensity of musical training, age at onset of training, linguistic experience, and individual characteristics of participants.

Additional opportunities are associated with contemporary digital technologies. Language-related courses can employ visualizations of fundamental frequency, duration, intensity, pausing, and intonation contours, making it possible to translate acoustic characteristics of speech into a form accessible to conscious analysis. For students at a creative university, this format is particularly relevant because it combines auditory and visual representations of sound organization.

The use of artificial intelligence for the automated analysis of musical and speech parameters and for the creation of adaptive learning tasks represents another promising area. When difficulties in intonation perception are detected, a system could offer additional exercises involving the comparison of pitch contours; when difficulties with rhythmic organization are identified, it could provide tasks involving synchronization of speech and musical material. Automated analysis should be regarded as an auxiliary tool, since pedagogical interpretation of the results requires consideration of the communicative and educational context.

The study of individual differences also remains important, since musical experience, language proficiency, professional specialization, and characteristics of auditory perception may determine different patterns of music–speech interaction. For universities specializing in music and the arts, this creates prerequisites for the development of differentiated models of language instruction.

Conclusion

Music–speech interaction is a multilevel phenomenon integrating acoustic, neurocognitive, linguistic, and educational processes. The similarity of certain parameters of the sound signal, including pitch, duration, intensity, tempo, and rhythmic organization, provides a basis for comparison; however, musical and speech systems perform different structural and communicative functions.

The neurocognitive relationship between music and speech is manifested in auditory processing, attention, working memory, prediction, and structural integration. At the linguistic

level, the closest relationships are observed in phonological, prosodic, intonational, and rhythmic organization. At the syntactic, lexico-semantic, and discourse levels, the interaction is associated with structural processing, interpretation, and the communicative use of material.

In the educational environment of a creative university, music–speech interaction acquires professional and educational significance. Students' musical activity involves auditory perception and interpretation of a work, its description and discussion, the use of professional terminology, and the justification of artistic decisions. Accordingly, language-related disciplines provide conditions for transforming professional musical experience into conceptual and verbal form.

The practical integration of music and language-related disciplines requires musical material to correspond to a specific educational objective. Musical material can be used to develop prosodic sensitivity, acquire professional vocabulary, develop awareness of tempo and rhythm in speech, construct analytical utterances, and develop professional communication skills. From this perspective, music becomes a meaningful component of educational activity, integrating learners' professional, linguistic, and communicative experience.

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Қазақ тілі мен әдебиеті сабақтарында жасанды интеллект арқылы сыни оқу мен дәлелді жазылымды дамыту

Момбекова Айгуль Мырзабаевна
Қазақ тілі мен әдебиеті пәні мұғалімі, «Абай атындағы №31 жалпы білім беретін мектеп» КММ, Түркістан облысы, Түркістан қаласы

Аннотация. Мақалада қазақ тілі мен әдебиеті сабақтарында генеративті жасанды интеллектіні оқушының сыни оқуын және дәлелді жазылымын дамытуға бағыттап қолдану жолдары қарастырылады. Түпнұсқаны өздігінен оқу, жасанды интеллект жауабын тексеру, мәтіндік дәлелді іріктеу және жеке тұжырымды жазу әрекеттеріне негізделген әдістемелік тәсіл ұсынылады. Абайдың он тоғызыншы қара сөзі мен мектеп өміріне қатысты пікірталас тақырыбы арқылы тапсырма үлгілері сипатталады. Оқу нәтижесін бағалау, авторлық ұстанымды сақтау, қазақ тілінің қолданыс ерекшеліктерін ескеру және цифрлық құралды жауапкершілікпен пайдалану мәселелері талданады.

Кілт сөздер: қазақ тілі мен әдебиеті, жасанды интеллект, сыни оқу, дәлелді жазылым, мәтін талдау, академиялық адалдық.

Кіріспе

Қазақ тілі мен әдебиеті сабағында оқушының мәтінді түсінуі оның мазмұнын қайталап беруінен ғана көрінбейді. Оқушы автордың ұстанымын ажыратып, пікірге негіз болған дәлелді тауып, өз тұжырымын түсіндіре алуы қажет. Жасанды интеллект дайын мазмұндама, талдау немесе эссе ұсына алатын жағдайда осы әрекеттерді сабақта қалай ұйымдастыру керектігі өзекті бола түседі. Мұғалім үшін негізгі мәселе — оқушының ойлау жұмысын сақтай отырып, цифрлық құралдың мүмкіндігін оқу міндетіне бағындыру.

Генеративті жасанды интеллект (ЖИ) берілген сұрауға сәйкес жаңа мәтін құрастырады. Оның жауабы тілдік тұрғыдан жинақы көрінгенімен, ондағы дерек, дәйексөз немесе әдеби түсіндіру қосымша тексеруді қажет етуі мүмкін. Сондықтан мұндай жауапты сабақта талданатын қосымша мәтін ретінде қолдануды ұсынамыз. Оқушы оның мазмұнын түпнұсқамен салыстырып, қандай тұжырымның негізді екенін және қай пікірге дәлел жетіспейтінін анықтайды.

Мақаланың мақсаты — ЖИ қолданылатын тапсырмаларда оқушының дербес оқуын, мәтінмен дәлелдеуін және өз жазбасын саналы редакциялауын қамтамасыз ететін жұмыс тәртібін ұсыну. Мақала әдістемелік сипатта жазылды: халықаралық ұсынымдар мен оқу сауаттылығы тұжырымдары талданып, пән мазмұнына бейімделген тапсырмалар құрастырылды. Ұсынылған тәсілдің тиімділігі жөнінде эксперименттік деректер келтірілмейді; оның нәтижесін нақты сыныптағы жұмыстар негізінде бағалау қажет.

Сыни оқу мен жасанды интеллект сауаттылығының байланысы

ЮНЕСКО-ның білім беру мен зерттеудегі генеративті ЖИ туралы нұсқаулығында адамға бағдарланған ұстаным, жас ерекшелігін ескеру және деректердің құпиялығын қорғау мәселелері қарастырылады [1]. Осы ұстанымды пән сабағына қолданғанда технологияны таңдау оқу мақсатына тәуелді болуы керек. Мысалы, мақсат автор позициясын анықтау болса, оқушының қолында шығарманың түпнұсқасы болуы және оның қорытындысы сол мәтінге сүйенуі қажет.

Экономикалық ынтымақтастық және даму ұйымының PISA оқу сауаттылығы шеңберінде мәтінді түсіну, пайдалану, бағалау және ол туралы ой қорыту өзара байланысты әрекеттер ретінде сипатталады. Әртүрлі дереккөздегі қайшылықты байқап, ақпараттың сенімділігін бағалау да осы үдеріске жатады [2]. Бұл тұжырым қазақ тілі мен әдебиеті сабақтарындағы салыстырмалы оқуға негіз бола алады: оқушы түпнұсқа мәтін мен ЖИ түсіндірмесінің арақатынасын тексереді.

ЮНЕСКО-ның оқушыларға арналған ЖИ құзыреттері шеңберінде технологияны сыни бағалау мен жауапты қолдануға назар аударылады [3]. Пәндік тапсырмада мұны нақты әрекетке айналдыруға болады. Оқушы жауапты кім немесе қандай жүйе жасағанын көрсетеді, тексеруге болатын тұжырымдарды белгілейді және қабылдаған шешіміне түсінік береді. Тілдік сауаттылық осылайша ақпаратпен жұмыс істеу мәдениетімен байланысады.

Қазақ тілі мен әдебиетін оқытуда мұндай жұмыстың өзіндік ерекшелігі бар. Әдеби ұғымның мағынасы, сөздің реңкі, кейіпкер сөзі мен автор ұстанымының айырмасы контекске қарай анықталады. Жалпылама сипаттама шығарманың көркемдік ерекшелігін ашуға жеткіліксіз. Сол себепті мұғалім «Бұл пікірді қай сөйлем дәлелдейді?», «Сөздің осы қолданысы қандай мағына үстеп тұр?» деген сұрақтар арқылы оқушыны мәтінге қайта бағыттайды.

Түпнұсқадан жеке тұжырымға дейінгі жұмыс тәртібі

ЖИ қатысатын тапсырманы төрт кезеңмен ұйымдастыруға болады. Алғашқы кезеңде оқушы мәтінді өздігінен оқып, қысқа бастапқы жауап жазады. Мұғалім негізгі сұрақты алдын ала береді, ал оқушы екі маңызды үзіндіні белгілеп, олардың сұраққа қатысын түсіндіреді. Осы шағын жазба кейінгі салыстыру үшін сақталады. Алғашқы пікірдің болуы оқушыға өз ойын сыртқы жауаптың ықпалынан ажыратуға көмектеседі.

Екінші кезеңде мұғалім дайындаған ЖИ жауабы ұсынылады. Бірдей жауаппен жұмыс істеу сыныптағы талқылауға ортақ негіз жасайды. Мұғалім материалдың жасанды интеллект көмегімен алынғанын ашық көрсетеді. Оқушылар оның ішіндегі мәтінмен расталатын тұжырымды, тек түсіндіру ретінде берілген пікірді және негізі жеткіліксіз пайымды ажыратады. Мұнда әр сөйлемнен міндетті түрде қате іздеу талап етілмейді: дұрыс тұжырымның неге дұрыс екенін де дәлелдеу маңызды.

Үшінші кезеңде оқушылар таңдаған пікірін түпнұсқамен тексереді. Дәйексөздің дәл берілуі, сөйлеушінің кім екені және үзіндінің алдындағы не кейінгі оймен байланысы қаралады. Егер ЖИ жауабында тарихи дерек немесе шығарма туралы сыртқы мәлімет болса, оны мұғалім ұсынған сенімді дереккөзбен салыстыру қажет. Түпнұсқада жоқ мәліметті тек мәтіннің өзіне сүйеніп растауға болмайтыны арнайы түсіндіріледі.

Төртінші кезеңде оқушы жеке қорытындысын қайта жазады. Жазылымда нақты тезис, оны растайтын мәтіндік дәлел және дәлелдің тезиске қатысын ашатын түсіндіру болуы көзделеді. Оқушы соңында алғашқы пікірінде нені өзгерткенін және өзгеріске қандай негіз болғанын көрсетеді. Бұл түсініктеме мұғалімге тек дайын жауапты емес, оқушының ойлау барысын да бағалауға мүмкіндік береді.

Сұрауды нақтылау мұғалімнің дайындығын жеңілдетеді. Мәселен, мынадай нұсқа қолдануға болады: «Берілген мәтін бойынша негізгі ойдың ықтимал түсіндірмесін ұсын. Әр тұжырымның қай үзіндіге сүйенетінін көрсет. Мәтінде жоқ дерек қоспа. Дәлел жетпейтін жерде оны ашық белгіле». Мұндай сұрау жауаптың дұрыстығына кепілдік бермейді, сондықтан мұғалім материалды сабаққа дейін тексереді. Сыныпқа таратылатын нұсқада талдауға қажетті көлем ғана қалдырылады.

Әдебиет сабағында Абайдың қара сөзін талдау

Әдістемелік үлгі ретінде Абайдың он тоғызыншы қара сөзін қарастыруға болады. Мәтінде адамның танып-білуі есту, көру, ескеру және білгенін іс жүзінде қолдану әрекеттерімен байланыстырылған [4]. Сабақтағы зерттеу сұрағын «Абай түсінігінде естіген

ақпарат қандай жағдайда білімге айналады?» деп құру ұсынылады. Тапсырма шығарманың оқу бағдарламасындағы орны мен оқушылардың дайындық деңгейіне қарай бейімделеді.

Алдымен оқушы қара сөзден сұраққа жауап беруге көмектесетін екі үзіндіні таңдайды. Мысалы, «Естілердің айтқан сөздерін ескеріп жүрген кісі өзі де есті болады» деген сөйлемдегі «ескеріп» сөзінің мағынасын мәтіннің кейінгі ойымен байланыстырады [4]. Одан кейін естігенді ұғыну мен оны ісіне жарату арасындағы байланысты өз сөзімен түсіндіреді. Талдауда үзіндіні көшіріп жазу жеткіліксіз: таңдалған сөздің неліктен маңызды екені ашылуы тиіс.

Келесі қадамда мұғалім салыстыруға арналған қысқа пікір береді: «Абайдың ойынша, көп ақпарат естіген адам өздігінен білімді болады». Бұл сөйлем мақаладағы оқу тапсырмасы үшін әдейі құрастырылған; оны ЖИ жүйесінен алынған нақты жауап деп ұсынуға болмайды. Оқушылар пікірдің нені тым жеңілдеткенін анықтап, қара сөзден түзетуге негіз болатын тұсты табады. Егер сабақта нақты ЖИ жауабы қолданылса, оның мәтіні бөлек сақталып, қай жүйеден және қашан алынғаны белгіленеді.

Талқылауда оқушылардың түсіндіруі әртүрлі болуы мүмкін. Бір оқушы сұрақ қойып ұғынуды, екіншісі естігенін әрекетіне енгізуді басым көрсетеді. Мұғалім әр жауаптың мәтінге сәйкестігін тексеріп, негізді балама пікірлерге орын береді. Сонымен бірге Абайдың ойы мен бүгінгі цифрлық орта арасындағы байланыс қазіргі оқырманның түсіндіруі екенін айқындайды. Авторға қазіргі технологиялар туралы айтылмаған пікірді телуге жол берілмейді.

Қорытынды жазылым ретінде «Дайын жауапты оқу мен өзің түсініп үйренудің арақатынасы» тақырыбында шағын пікір ұсынуға болады. Оқушы қара сөзден бір дәлел келтіріп, оны қазіргі оқу жағдайымен байланыстырады. Жазба көлемін сынып деңгейіне сай мұғалім анықтайды. Негізгі бағалау нысаны — мәтіндік дәлелдің орынды қолданылуы және оқушының өз пайымын түсіндіруі.

Қазақ тілі сабағында дәлелді жазылымды ұйымдастыру

Қазақ тілі сабағында ЖИ арқылы жасалған мәтінді пікірталасқа дайындық және редакциялау материалы ретінде пайдалануға болады. Мысалы, «Мектеп кітапханасында қағаз және электронды кітапты қалай үйлестіруге болады?» деген сұрақ оқушыға таныс ортадан алынады. Алдымен оқушы өз ұсынысын жазады. Оған негіз ретінде мұғалім әзірлеген қысқа ақпараттық мәтін немесе кітапхана туралы тексерілген ашық мәлімет беріледі. Дерексіз сандық көрсеткішті дәлел ретінде қолдануға рұқсат етілмейді.

Одан кейін мұғалім ЖИ көмегімен алынған балама пікірді ұсынады. Оқушы екі ұстанымның дәлелін салыстырады: қай дәлел сұраққа тікелей жауап береді, қайсысы жалпылама, қай тұжырымға қосымша ақпарат қажет? Мысалы, «Барлық оқушы электронды кітапты көбірек ұнатады» деген пайымға қандай дерек керектігі талқыланады. Егер мұндай дерек жоқ болса, сөйлемнің аясын тарылту немесе оны болжам ретінде белгілеу ұсынылады.

Жазылым барысында оқушы өз тезисін білдіріп, нақты негіз келтіреді, оның маңызын түсіндіреді және ықтимал қарсы пікірге жауап береді. Осы құрылым дайын қалыпты механикалық толтыруға айналмауы керек. Мұғалім әр дәлелдің мазмұнмен байланысын сұрап, артық сөйлемді қысқартуды немесе жетіспейтін түсіндіруді қосуды ұсынады. Нәтижесінде мәтіннің көлемінен гөрі ойдың қисындылығы мен тілдік дәлдігіне назар аударылады.

Редакциялау үшін ЖИ-ге бүкіл мәтінді қайта жаздырудың орнына жекелеген мәселеге қатысты сұрақ қою пайдалы. Мысалы: «Бұл абзацта тезис анық көріне ме? Қай сөйлемге түсіндіру жетіспейді? Жаңа мәтін жазбай, екі сұрақ ұсын». Мұғалім оқушының аты-жөні мен басқа деректерін алып тастаған үлгіні ғана қолданады. Оқушы ұсынылған сұрақтардың қайсысын орынды деп санағанын түсіндіреді және соңғы нұсқаны өзі жазады.

Қазақша мәтінді өңдеу кезінде сөз тіркесінің табиғилығы, септік жалғауларының қолданысы, есімдіктердің қай сөзге қатысты тұрғаны және сөйлемдердің байланысы тексеріледі. Мәселен, мағынасы көмескі «Бұл оны жақсартады» деген сөйлемде «бұл» мен «оны» сөздерінің нені білдіретінін нақтылау қажет. Әдеби талдауда терминдерді орынсыз тізбектемей, олардың мәтіндегі қызметін көрсету талап етіледі. Осындай редакциялау оқушыға әр түзетудің мазмұнға әсерін байқауға мүмкіндік береді.

Оқушының дербестігін бағалау және жұмысты бейімдеу

Бағалаудың өлшемдері тапсырма берілген кезде түсінікті болуы керек. Бұл тәсілде төрт өлшемді қолдануға болады: мәтінді дұрыс түсіну, дәлелдің сәйкестігі, өз пайымының негізділігі және тілдік рәсімдеу. Оқушыдан алынған дәйексөзді түсіндіру, негізі жеткіліксіз пікірді анықтау және енгізген түзетуінің себебін айту күтіледі. ЖИ қолданылғанын ашық көрсету бөлек жұмыс ережесі ретінде белгіленеді. Құралға қолжетімділік бағалауда артықшылық бермеуі тиіс.

Кері байланыс нақты әрекетке бағытталғаны жөн. «Талдауың әлсіз» деген жалпы ескертпенің орнына «Дәйексөз орынды таңдалған, енді оның тезисіңді қалай растайтынын бір сөйлеммен түсіндір» деген ұсыныс оқушыға келесі қадамды көрсетеді. Қажет болса, мұғалім қысқа ауызша сұрақ арқылы жазбадағы ойды оқушының қалай түсінгенін анықтайды. Бірдей құрылыммен жазылған мәтіндердің өзінде пайымдау сапасы әртүрлі болуы мүмкін.

Тілдік қолдауды қажет ететін оқушыға шағын сөздік, мағыналық бөліктерге бөлінген мәтін немесе сөйлем бастамалары беріледі. Мысалы, «Менің тұжырымымды ... үзіндісі растайды, себебі ...» деген тірек ой мен дәлелді байланыстыруға көмектеседі. Дайындығы жоғары оқушы екі негізді түсіндіруді салыстырып, қайсысының мәтінмен толығырақ дәлелденетінін талдай алады. Қолдау деңгейі өзгергенімен, барлық оқушы түпнұсқамен жұмыс істейді.

Интернет немесе жеке құрылғы қажет болмас үшін мұғалім ЖИ жауабын алдын ала қағазға шығарып бере алады. Оқушының өз аккаунтымен жұмыс істеуі міндетті шартқа айналмайды. Егер цифрлық сервис қолданылса, оның жас шектеуі мен мектептің ішкі ережелері ескеріледі. Оқушының фотосы, бағасы, жеке хаттары және сәйкестендіруге болатын басқа мәліметтері сыртқы сервиске енгізілмейді. Бұл шешімдер ЖИ қолдануды қауіпсіз әрі баршаға қолжетімді ұйымдастыруға көмектеседі [1].

Авторлық үлесті көрсету үшін жазба соңында құралдың атауы, қолданылған күні, атқарған қызметі және оқушының өзі тексерген тұсы қысқаша берілуі мүмкін. ЖИ қолданылмаса, мұндай белгі талап етілмейді. Дәйексөз бен деректің қайдан алынғанын көрсету ережесі барлық жұмыста сақталады. Мұғалім бұл тәртіпті жазалау құралына айналдырмай, мәтін жасау үдерісін түсіндірудің қалыпты бөлігі ретінде енгізеді.

Ұсынылған жұмысты бағалау үшін мұғалім бастапқы және соңғы жазбаларды бірдей өлшемдермен салыстыра алады. Мәтінге сүйенген түсіндірудің нақтылануы, дәлелсіз жалпылаудың түзетілуі және редакция себебінің түсінікті берілуі назарға алынады. Мұндай бақылау келесі тапсырманы жоспарлауға көмектеседі. Алайда бір сабақтағы өзгеріс әдістің тиімділігі толық дәлелденді деген қорытынды жасауға жеткіліксіз; тұрақты ілгерілеу бірнеше жұмыс арқылы қарастырылады.

Қорытынды

Қазақ тілі мен әдебиеті сабақтарында жасанды интеллектіні қолданудың педагогикалық құндылығы оқушы орындайтын әрекеттерге байланысты. Түпнұсқаны өздігінен оқу, ұсынылған түсіндіруді тексеру және қорытындыны мәтінмен дәлелдеу технологияны саналы қолдануға негіз болады. Оқушы өз пікірінің қалай қалыптасқанын түсіндіре алса, мұғалім оның оқуына мазмұнды кері байланыс бере алады.

Ұсынылған тәсілді бір шағын салыстыру тапсырмасынан бастауға болады. Әдебиетте ол автор ойының реңкін байқауға, қазақ тілінде тезис пен дәлелдің байланысын нығайтуға бағытталады. Мұғалімнің мәтінді іріктеуі, сұрақты дәл қоюы және бағалау өлшемдерін түсіндіруі осы жұмыстың сапасын айқындайды. Осындай ұйымдастыруда оқушының өз сөзі мен жауапкершілігі сабақтың негізгі нәтижесі болып қалады.

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METHODOLOGICAL CONDITIONS FOR DEVELOPING PRIMARY SCHOOL PUPILS' CRITICAL THINKING THROUGH MATHEMATICAL PROBLEM SOLVING

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Primary school mathematics offers a natural setting for teaching children to question, evaluate, and justify, yet word problems are often solved by routine operations without attention to meaning. This article examines which methodological conditions allow problem solving to develop critical thinking in primary school pupils. The study is a conceptual-analytic integrative review of ten purposively selected sources from Kazakhstan, the United States, Europe, China, Japan, and South Korea. Documented findings were coded against the components of critical thinking, the features of problems, and teacher practices. The analysis yields five methodological conditions: interpretation-demanding tasks, structured critical questioning, multiple solution strategies with justification, reflection and self-checking, and teacher preparation within a coherent methodological system. The conditions are hypotheses derived from existing evidence, not tested effects. The article contributes a classroom-oriented framework, a coding frame for future studies, and implications for Kazakhstani primary education, and it proposes quasi-experimental research to validate the conditions.

Keywords: critical thinking; primary school; mathematical problem solving; word problems; methodological conditions; metacognition; teacher preparation; Kazakhstan

Introduction

Educating pupils who can question information, weigh evidence, and justify decisions is a stated goal of modern school systems, and primary school is widely regarded as the stage at which the foundations of such thinking are laid. Kazakhstani researchers have recently argued that critical thinking should be integrated into primary education as a core competence, and they have proposed methodological systems for doing so, for example in Kazakh language instruction (Almukhanbet et al., 2025). Mathematics is at least as promising a setting. Su et al. (2016) contend that a teacher who emphasizes reasoning, logic, and validity gives pupils access to mathematics as an effective way of practicing critical thinking, because pupils confront problems, identify possible solutions, and then evaluate and justify their results.

The Kazakhstani context makes the question pressing. Kazakhstani pupils perform well in competitions, yet their results in functional mathematical literacy remain modest: in the 2018 cycle of the Program for International Student Assessment, Kazakhstan scored 423 points in mathematics (Ontuganova et al., 2023). Studies also describe a mathematics classroom that still leans on rote learning and content memorization and that hardly emphasizes creative, critical,

systematic, analytical, and logical thinking (Popova et al., 2022). A study of third graders in Kentau found that primary teachers pay little attention to the development of logical thinking in mathematics, partly because school practice assumes that the necessary thinking skills will develop on their own (Ontuganova et al., 2023).

International research shows why solving a problem is not the same as thinking critically about it. When Belgian fifth graders met word problems whose realistic context made a routine operation inappropriate, only an alarmingly small number responded realistically (Verschaffel et al., 1994). Japanese children displayed a comparable tendency to exclude realistic considerations from their interpretation of such problems (Yoshida et al., 1997), and a recent survey of word-problem research offers the broader frame for these findings (Verschaffel et al., 2020). Pupils who apply operations without asking whether the answer makes sense are not yet engaged in the interpretation, analysis, evaluation, inference, explanation, and self-regulation that define critical thinking in the expert consensus (Facione, 1990).

Critical thinking is understood here in the sense of that consensus: purposeful, self-regulatory judgment that results in interpretation, analysis, evaluation, and inference, together with an explanation of the evidence, concepts, methods, criteria, or context on which the judgment rests (Facione, 1990). The consensus also describes dispositions, such as being inquisitive, open-minded, willing to reconsider, and persistent. For primary pupils, these skills and dispositions must take an age-appropriate form: asking whether an answer is reasonable, comparing two solutions, explaining a choice, and checking one's own work. Methodological conditions are understood as the organizational and didactic requirements, concerning tasks, questioning, classroom norms, and teacher preparation, whose joint presence makes it likely that such behaviors occur and develop.

Several lines of evidence suggest how instruction might change the situation. Ill-structured problems, which require pupils to define the problem and to decide which information and skills are needed, raised the level of mathematical abstraction among Korean fifth graders (Hong & Kim, 2016). In China, a study of elementary mathematics teachers showed that the capability to pose problems did not necessarily grow with teaching experience (Peng et al., 2022), which implies that teachers' ability to design thought-provoking problems cannot be taken for granted. In Kazakhstan, an integrative technology that added stages to the structure of a mathematics lesson improved third graders' logical thinking without changing the curriculum or increasing the load on pupils (Ontuganova et al., 2023).

Despite this progress, three gaps remain. First, most of the studies address logical thinking, realistic modeling, or problem solving, and few connect them explicitly to the named components of critical thinking. Second, the expert consensus was formulated for post-secondary education (Facione, 1990), so its translation into primary mathematics requires methodological work. Third, in the sources reviewed here, Kazakhstani studies rarely specify which combination of conditions, rather than which single technique, turns problem solving into a vehicle for critical thinking.

The aim of this article is to identify and justify the methodological conditions under which solving mathematical problems develops primary school pupils' critical thinking. Two questions guide the analysis. (1) Which features of problems, questioning, and teacher practice are documented as supporting interpretation, evaluation, justification, and reflection in primary mathematics? (2) How can these features be organized into methodological conditions that a Kazakhstani primary teacher can apply within the existing curriculum? The article contributes a five-condition framework and a coding frame for future studies. It proceeds in five parts: this introduction, the materials and methods, a literature review, the results and their discussion, and a conclusion.

Materials and Methods

This study is a conceptual-analytic integrative review. It does not report primary data collected from pupils, teachers, or schools. Its purpose is to synthesize documented findings from strands of research that are seldom combined, namely the theory of critical thinking, research on word problems and sense-making, and classroom studies of mathematics teaching, and to derive from them a framework of methodological conditions. An integrative design was chosen over a conventional systematic review because the relevant evidence is dispersed across fields and publication types, and because very few studies address critical thinking, primary mathematics, and teacher practice at the same time. The price of this choice is a loss of exhaustiveness, which is discussed under limitations.

Sources were selected purposively in 2026 through searches of publisher platforms, journal websites, and repositories, using combinations of the terms critical thinking, primary school, elementary school, mathematics, problem solving, word problems, realistic considerations, ill-structured problems, metacognition, and teacher practice. A source was eligible if it (a) was a peer-reviewed article or a consensus report; (b) addressed critical thinking, logical or mathematical thinking, word-problem solving, or teacher practice in primary mathematics or in closely related contexts; (c) appeared between 1990 and 2025; and (d) offered a complete bibliographic record that could be checked.

Because the study aims at both local relevance and international perspective, the corpus was stratified. It contains ten sources: three by Kazakhstani scholars and seven by scholars from the United States (two), Europe (two), China (one), Japan (one), and South Korea (one). The corpus is intentionally small. Each source was chosen as the most suitable representative of a distinct strand: the definition of critical thinking, evidence on realistic considerations, task design, teaching strategies, teacher capability, and Kazakhstani classroom experiments. All DOIs, volume numbers, and page ranges were checked against publisher, repository, or indexing records.

The unit of analysis was a documented finding, claim, or recommendation. Each unit was coded on three dimensions derived from the research questions and refined during reading. The first dimension was the component of critical thinking addressed: interpretation, analysis, evaluation, inference, explanation, or self-regulation, as named in the consensus statement. The second was the feature of the task: routine, problematic, ill-structured, or open, and the authenticity of its context. The third was the teaching or system practice: questioning, comparison of strategies, reflection, teacher preparation, lesson structure, or curriculum integration. Each unit also received a label for the type of evidence: expert consensus, classroom experiment, survey, teacher study, or conceptual analysis.

Analysis proceeded in two passes. In the first pass, coded units were arranged in a matrix, and recurring combinations of task features, questioning practices, and teacher practices were identified. In the second pass, each unit was checked against the source text, and categories were merged or split where the sources justified it. Findings from one region or design type were compared with findings from others, and discrepancies were examined rather than averaged. A condition was retained only if it was supported by at least two independent sources, preferably from different regions. To limit overinterpretation, claims were graded as documented, when stated by the source, or inferred, when they follow from documented findings but have not been tested for primary pupils. Statistics are reported as the sources present them, and no effect sizes were recomputed.

No human participants took part in this study, no personal data were processed, and institutional ethics approval was therefore not required. Sources are paraphrased and acknowledged in the reference list. The principal limitations of the design are the purposive selection and small size of the corpus, the absence of primary data, and the fact that several sources concern older pupils, teachers, or adults rather than primary pupils. These limitations

shape how the results should be read: the conditions are analytically derived hypotheses, not empirically established effects.

Literature Review

Critical Thinking: Definition and Dispositions

The most widely cited definition in educational research comes from the Delphi project, in which a panel of experts reached consensus that critical thinking is purposeful, self-regulatory judgment resulting in interpretation, analysis, evaluation, and inference, together with explanation of the evidential, conceptual, methodological, criteriological, or contextual considerations on which the judgment is based (Facione, 1990). The same consensus describes an ideal critical thinker as habitually inquisitive, open-minded, fair-minded in evaluation, willing to reconsider, and persistent in seeking precise results. Two features matter for primary education. First, skills and dispositions are treated as inseparable, which implies that instruction must shape habits of mind as well as procedures. Second, the project addressed post-secondary education, so its components must be translated into forms accessible to young pupils.

Problem Solving, Sense-Making, and Realistic Considerations

Research on word problems provides the strongest evidence that routine problem solving does not automatically produce critical thinking. Verschaffel et al. (1994) administered ten pairs of word problems to 75 fifth graders. The second problem in each pair could not be modeled sensibly by a straightforward operation if the realities of its context were taken seriously, and the pupils' reactions showed an alarmingly small number of realistic responses. Yoshida et al. (1997) compared Japanese and Belgian children, and their title already indicates the result of interest: the difficulties were not confined to a single educational system. A recent survey of word-problem research argues that word problems cannot be sharply separated from other kinds of mathematical problems (Verschaffel et al., 2020), which suggests that the sense-making issues identified in word problems concern primary mathematics more broadly. Task design can counter the tendency. Korean fifth graders who worked on ill-structured problems, which require learners to define the problem and decide which information and skills are needed, reached higher levels and forms of mathematical abstraction during the problem-solving process (Hong & Kim, 2016).

Teaching Approaches and Teacher Practice

Teaching approaches determine whether such tasks lead to critical thinking. Su et al. (2016) argue that pupils develop critical thinking in mathematics when they confront problems, identify possible solutions, and evaluate and justify the reasons for their results, and they link this process to metacognition, that is, thinking about one's own methods of thinking. Teachers' own capacities are therefore decisive. Peng et al. (2022) found that elementary mathematics teachers in Southwest China could pose a considerable number of appropriate problems, but the flexibility of the problems differed by teaching experience, and capability did not necessarily grow with experience. Kazakhstani studies point to systemic needs: a methodological system for fourth graders that combines objectives, active learning tasks, methods, technologies, forms, digital resources, and expected outcomes (Almukhanbet et al., 2025); a lesson structure that activates attention, guides logical operations, and leads pupils to discover solution algorithms (Ontuganova et al., 2023); and evidence that mathematical intuition and logic are positively related to the effectiveness of learning (Popova et al., 2022).

Results and Discussion

Five Methodological Conditions

Coding of the ten sources produced five methodological conditions, summarized in Table 1. The conditions run from the design of tasks to the preparation of teachers, and they are intended to operate jointly rather than as a menu of separate techniques.

Table 1. Methodological conditions for developing critical thinking through mathematical problem solving

Condition	Documented evidence	Classroom implication	Indicator of success
1. Interpretation-demanding tasks	Few realistic responses to problematic word problems (Verschaffel et al., 1994; Yoshida et al., 1997); gains in abstraction with ill-structured problems (Hong & Kim, 2016).	Include problems whose context must be interpreted, not only calculated.	Pupil asks whether the answer is reasonable.
2. Structured critical questioning	Critical thinking as interpretation, analysis, evaluation, inference, explanation, and self-regulation (Facione, 1990).	Use a few recurring questions mapped to these components (inferred).	Pupil explains a choice with the prompts.
3. Multiple strategies with justification	Pupils identify, evaluate, and justify solutions (Su et al., 2016); flexibility varies among teachers (Peng et al., 2022).	Ask for a second solution and a reason for preferring one.	Pupil compares two solutions.
4. Reflection and self-checking	Metacognition as thinking about one's methods (Su et al., 2016); self-regulation in the consensus (Facione, 1990).	End each lesson with a check and a short reflection (inferred).	Pupil finds and corrects an error.
5. Teacher preparation and system coherence	Little attention to logical thinking (Ontuganova et al., 2023); coherent methodological systems (Almukhanbet et al., 2025); rote culture (Popova et al., 2022).	Train teachers in problem selection and posing; add lesson stages without enlarging the curriculum.	Teacher applies the conditions routinely.

Note. Entries labeled "inferred" follow from documented findings but have not been tested with primary school pupils.

Task Design and Questioning

Condition 1 follows from the convergence of three traditions. The Belgian, Japanese, and Korean studies differ in method, yet they agree that routine tasks invite routine answers (Verschaffel et al., 1994; Yoshida et al., 1997) and that tasks requiring interpretation open space for abstraction (Hong & Kim, 2016). The implication for a Kazakhstani classroom is practical: lesson plans should contain a deliberate share of problems whose context must be interpreted. A problem asking how many buses are needed for 150 pupils when each bus holds 40 is one such example, because the arithmetic result of 3.75 must be interpreted before it becomes an answer.

Condition 2 translates the consensus statement into routines of pupil size. Interpretation can become "What is the problem asking, in my own words?" Analysis becomes "Which numbers matter?" Evaluation becomes "Is this answer sensible?" Inference becomes "What happens if a number changes?" Explanation becomes "Why did I choose this operation?" Self-regulation becomes "How can I check?" These prompts are an adaptation proposed here, not a tested

instrument. They illustrate how a construct formulated for post-secondary education (Facione, 1990) can be operationalized for young pupils.

Strategies, Reflection, and Teacher Preparation

Condition 3 rests on Su et al. (2016), who link critical thinking to identifying possible solutions and justifying results. A routine that asks pupils for a second solution, and for a reason for preferring one, creates a natural occasion for evaluation. Condition 4 adds reflection. Because metacognition is thinking about one's own methods (Su et al., 2016) and self-regulation is a component of the consensus (Facione, 1990), each lesson should end with a brief check of the answer and of the method. Popova et al. (2022) reported a positive influence of mathematical intuition and logic on the effectiveness of senior pupils' education, which suggests that reflective, logic-oriented habits matter beyond primary school.

Condition 5 addresses the system. Ontuganova et al. (2023) improved third graders' logical thinking by adding stages to the lesson without altering the curriculum. In their logical-thinking test, the high-level share rose from 8 to 29 of 76 pupils in the experimental group, against a rise from 10 to 15 of 74 in the control group. This finding makes the conditions feasible for teachers. Yet the same study reports that teachers pay little attention to logical thinking, and Peng et al. (2022) show that problem-posing capability does not automatically grow with experience. Teacher preparation therefore cannot be left to chance. Almukhanbet et al. (2025) offer a model of coherence by aligning objectives, tasks, methods, and expected outcomes in one system.

Relation to Previous Research

The framework agrees with research that treats problem solving as a route to critical thinking (Su et al., 2016). It differs from studies that measure logical thinking alone (Ontuganova et al., 2023; Popova et al., 2022) because it links each condition to named components of critical thinking, and logical thinking is not identical with critical thinking. It also differs from word-problem research, which documents the difficulty well but seldom prescribes the full set of classroom conditions (Verschaffel et al., 2020). These differences arise from purpose: earlier studies describe phenomena or test single techniques, whereas this article integrates findings into conditions that a teacher can apply together.

Implications, Limitations, and Directions for Future Research

For practice, the conditions can be converted into five questions that a teacher asks when planning a lesson. Does the task require interpretation? Which question prompts will the pupils use? Will they produce and compare two solutions? When will they check and reflect? What preparation does the teacher need? For policy, the findings suggest that training in problem selection and posing deserves a place in teacher education.

Several limitations constrain these conclusions. The study collected no primary data, and its corpus is small and purposive. Several sources concern older pupils, teachers, or adults, so transfer to primary pupils is inferred. The consensus statement was formulated for post-secondary education, and the pupil-sized prompts are untested. Future research should test the conditions in grades 3 and 4 through a quasi-experimental design with a critical-thinking-in-mathematics test, classroom observation, and teacher training, and it should develop and validate an age-appropriate instrument. Cross-national replication would show whether the conditions hold in Kazakh-, Russian-, and English-medium classrooms.

Conclusion

This article asked which methodological conditions allow the solving of mathematical problems to develop critical thinking in primary school pupils. Through an integrative analysis of ten sources from Kazakhstan and five other regions, it identified five conditions: interpretation-demanding tasks, structured critical questioning, multiple strategies with justification, reflection and self-checking, and teacher preparation within a coherent methodological system. The first research question is answered by the documented features of tasks, questioning, and teacher

practice that support interpretation, evaluation, justification, and reflection. The second is answered by the organization of these features into conditions that can be applied within the existing curriculum, as the Kazakhstani experiment with added lesson stages suggests (Ontuganova et al., 2023).

The theoretical contribution lies in connecting two literatures that rarely meet. Research on realistic considerations in word problems shows that pupils often suspend sense-making (Verschaffel et al., 1994; Yoshida et al., 1997), while the expert consensus defines critical thinking as a set of judgments that include evaluation and self-regulation (Facione, 1990). The framework links the two by treating sense-making as a classroom manifestation of critical thinking and by assigning each component of the consensus a pupil-sized routine. This link also gives researchers a way to distinguish logical thinking from critical thinking when they design measures.

The practical contribution is a set of conditions that teachers, methodologists, and policymakers can use. Teachers can include problems that require interpretation, ask a small set of recurring questions, request a second solution, and close the lesson with a check. Methodologists can embed these routines in lesson structures and textbook design, following the example of coherent methodological systems (Almukhanbet et al., 2025). Teacher educators can add training in problem selection and posing, since experience alone does not guarantee flexibility (Peng et al., 2022). For Kazakhstan, where functional mathematical literacy remains a concern and rote learning persists in classrooms (Ontuganova et al., 2023; Popova et al., 2022), these steps offer a feasible path that does not require a new curriculum.

The limitations are clear. The study is conceptual, its corpus is small, and the conditions are hypotheses. The pupil-sized prompts are proposals that await empirical testing, and several supporting studies concern older pupils or adults. Future work should test the conditions in grades 3 and 4, measure critical thinking directly, and examine teacher training as a mediating factor. If such studies confirm the conditions, the framework could guide textbook design and teacher education. If they refute some of them, it will have served its purpose by making its assumptions explicit. In either case, the central message holds: pupils learn to think critically through mathematics when problems ask them to interpret, when questions ask them to justify, and when teachers are prepared to make both routine.

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THE ROLE OF AR/VR TECHNOLOGIES IN DEVELOPING COGNITIVE ENGAGEMENT AMONG PRIMARY SCHOOL STUDENTS: THEORETICAL AND PRACTICAL ASPECTS

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Augmented reality (AR) and virtual reality (VR) are increasingly promoted as tools for strengthening primary school students' cognitive engagement, yet the evidence base is fragmented across age groups, technologies, and theoretical traditions. This article examines the role of AR/VR technologies in developing cognitive engagement among primary school students from theoretical and practical perspectives. Using a theory-driven integrative review of ten peer-reviewed sources, supplemented by a design-based component, the study synthesizes evidence on learning outcomes, motivational and affective mechanisms, cognitive load, and implementation barriers. The analysis shows that the reviewed meta-analytic and systematic evidence reports positive effects of AR and VR on learning outcomes, with two AR syntheses reporting medium effects (d = .64 and d = .68) and motivation consistently listed among the most frequently reported advantages. At the same time, the literature indicates that immersion and interactivity do not automatically translate into deeper learning: they can raise extraneous cognitive load and crowd out reflection unless instruction is deliberately designed. Usability problems, technical failures, limited accessibility features, and the scarcity of explicit learning theories further constrain classroom practice. On this basis, the article proposes a four-phase instructional framework (Prepare, Explore, Reflect, Transfer) and an evaluation protocol that operationalizes behavioral, emotional, and cognitive engagement. Theoretically, the study links cognitive load theory, the Cognitive Affective Model of Immersive Learning, and the multidimensional construct of school engagement. Practically, it offers teachers and designers evidence-informed principles for selecting technologies, structuring lessons, and assessing engagement in primary classrooms. Because most reviewed studies include mixed age groups, the findings are best interpreted as evidence-informed hypotheses for primary education that require empirical validation.

Keywords: augmented reality; virtual reality; primary education; cognitive engagement; cognitive load; immersive learning; instructional design

Introduction

The primary school years are the period in which children build the cognitive habits that shape later learning: sustained attention, curiosity, the ability to connect new information to prior knowledge, and the willingness to persist with demanding tasks. Educational researchers have long argued that these habits are not fixed traits but outcomes of the learning environment. In

their widely cited review, Fredricks et al. (2004) described school engagement as a multifaceted construct comprising behavioral, emotional, and cognitive dimensions, and emphasized that engagement is malleable and responsive to contextual features. This premise is central to the present article: if cognitive engagement can be shaped by the learning environment, then the design of that environment, including the technologies embedded in it, becomes a legitimate object of scientific inquiry.

Cognitive engagement is closely related to what many national education traditions call cognitive activity: the learner's active, self-directed mental work in observing, comparing, questioning, and constructing meaning. In primary classrooms, this work is often constrained by the abstract nature of curricular content. Concepts such as the structure of a cell, the movement of planets, or the geometry of solids are difficult to grasp when they are presented only through text and static images. Technologies that make such content visible, manipulable, and spatially explorable therefore attract considerable interest.

Augmented reality and virtual reality are the most prominent of these technologies. Augmented reality overlays digital information on the physical environment, allowing the learner to experience the virtual and the real world simultaneously, whereas immersive virtual reality, typically accessed through a head-mounted display, largely shuts out the physical world and places the learner inside a computer-generated environment (Makransky & Petersen, 2021). Both technologies offer perceptual richness and interaction that conventional media cannot provide, and both have attracted a rapidly growing body of educational research. A systematic review of 68 articles from journals indexed in the Social Sciences Citation Index documented a marked increase in AR studies over the preceding four years and cataloged both the advantages and the challenges of AR in educational settings (Akçay & Akçay, 2017). An earlier review of 32 studies had already identified uses, advantages, limitations, and effectiveness as the key themes of AR research and called attention to personalization and inclusive learning as emerging directions (Bacca et al., 2014).

The accumulating evidence is encouraging but uneven. A meta-analysis of 64 quantitative studies (N = 4,705) reported that AR has a medium effect on students' learning gains ($d = .68$, $p < .001$) and examined moderators such as control treatment, learning environment, learner type, and subject domain (Garzón & Acevedo, 2019). A second review covering 61 studies reported a comparable effect ($d = .64$) and identified learning gains and motivation as the most frequently reported advantages of AR (Garzón et al., 2019). For VR-based instruction, a meta-analysis covering K-12 and higher education found that games produced higher learning gains than simulations and virtual worlds, that individual play outperformed group play, and that repeated treatment sessions were inversely related to learning gains for games (Merchant et al., 2014). These findings suggest that effectiveness depends heavily on design, and they warn against treating AR/VR as uniformly beneficial.

Several problems limit the practical value of this literature for primary education. First, much of the evidence comes from mixed or older samples, and findings from higher education cannot be transferred automatically to children aged six to ten. Second, a systematic review of immersive VR in higher education found that learning theories were not often considered in the development of VR applications (Radianti et al., 2020), which suggests that many applications are built around technological novelty rather than around an understanding of how learners process information. Third, reviews consistently report usability issues and frequent technical problems (Akçay & Akçay, 2017), and only a small share of AR systems include accessibility features (Garzón et al., 2019).

Theoretical frameworks can help address the second problem. Cognitive load theory holds that human working memory is limited and that instruction must conserve processing capacity for schema acquisition (Sweller, 1988). The Cognitive Affective Model of Immersive Learning (CAMIL)

extends this logic to immersive media by identifying presence and agency as the core psychological affordances of immersive virtual reality and by specifying six affective and cognitive factors through which these affordances influence learning: interest, intrinsic motivation, self-efficacy, embodiment, cognitive load, and self-regulation (Makransky & Petersen, 2021). Empirical work has begun to test this model by separating the effects of immersion from those of interactivity (Petersen et al., 2022). Together, these frameworks predict that immersive technologies can raise interest and motivation while simultaneously increasing extraneous load, and that the net effect on cognitive engagement depends on instructional design.

The purpose of this article is therefore threefold: to synthesize what the selected literature reveals about the role of AR/VR in developing cognitive engagement; to translate this synthesis into a practical, theory-based instructional framework suitable for primary classrooms; and to specify an evaluation protocol that allows future studies to test the framework empirically. The study addresses three research questions. RQ1: What does the reviewed evidence indicate about the effects of AR/VR on learning outcomes and motivation? RQ2: Which cognitive, affective, and contextual mechanisms moderate these effects? RQ3: What design principles and evaluation procedures follow for primary school practice?

The remainder of the article is organized as follows. The next section reviews the theoretical and empirical literature. The methods section describes the integrative review and design-based procedures. The results and discussion section presents the synthesized findings and the proposed framework, and the conclusion summarizes theoretical and practical implications and outlines directions for future research.

Literature Review

Cognitive engagement as a theoretical construct

Fredricks et al. (2004) reviewed definitions, measures, precursors, and outcomes of school engagement and concluded that behavioral, emotional, and cognitive engagement should be studied together as a multifaceted construct. Behavioral engagement concerns participation and effort, emotional engagement concerns affective reactions to learning and school, and cognitive engagement concerns investment in learning and the willingness to exert the mental effort required to master complex ideas. The authors also argued that richer characterizations of how students behave, feel, and think are needed to design finely tuned interventions. This three-part structure is useful for AR/VR research because immersive technologies obviously influence emotional engagement, but their influence on cognitive engagement is far less certain.

Cognitive load and the architecture of learning

Sweller (1988) argued that domain-specific schemas are the primary factor distinguishing experts from novices and that conventional problem-solving activity can be ineffective for schema acquisition because it consumes processing capacity that is then unavailable for learning. The implication for technology-enhanced instruction is that richer stimulation is not inherently beneficial: material that is engaging but irrelevant to the learning goal can compete for the same limited resources. For young learners, whose prior knowledge in most domains is limited, this consideration is especially important.

Immersive learning models

CAMIL integrates these ideas into a model specific to immersive media. It proposes that instructional methods validated with less immersive media generalize to immersive virtual reality, but that media and method interact: methods that facilitate presence and agency are particularly effective in immersive environments (Makransky & Petersen, 2021). The model predicts that presence and agency raise interest, motivation, self-efficacy, and embodiment, but may also raise extraneous cognitive load and, unless lessons include opportunities for reflection, reduce self-regulation. A subsequent empirical study examined the unique and combined effects of interactivity and immersion on the cognitive and affective variables specified by CAMIL and

reported findings that support the framework while suggesting important additions to it (Petersen et al., 2022).

Evidence on effectiveness

Evidence on AR is relatively consistent. Garzón and Acevedo (2019) found a medium overall effect on learning gains across 64 studies, and Garzón et al. (2019) found a similar effect across 61 studies, with learning gains and motivation as the most frequently reported advantages. Evidence on VR is more heterogeneous. Merchant et al. (2014) showed that effects differed by type of VR-based instruction and by instructional design variables, including whether students played individually or in groups and how many treatment sessions they completed. These patterns support the view that the instructional method matters at least as much as the medium.

Challenges and research gaps

Akçay and Akçay (2017) reported that usability issues and frequent technical problems are the main challenges of AR in education, alongside several others. Bacca et al. (2014) noted the need for personalization and inclusive learning, and Garzón et al. (2019) found that only one of the analyzed AR systems included accessibility features. Radianti et al. (2020) identified a lack of explicit learning theory in VR application development, although their review focused on higher education. Taken together, these reviews reveal a gap: few studies explicitly connect AR/VR design to a theory of cognitive engagement in young learners. The present article addresses this gap by combining cognitive load theory, CAMIL, and the engagement construct in a single framework for primary education.

Materials and Methods

Research design

The study employed a theory-driven integrative review combined with a design-based component. An integrative review is appropriate when a research field includes heterogeneous designs, such as systematic reviews, meta-analyses, theoretical models, and experimental studies, and when the aim is to build a conceptual synthesis rather than to estimate a pooled effect. The design-based component translated the synthesis into an instructional framework and an evaluation protocol, following the logic that theoretical principles should be expressed as concrete, testable design decisions. No primary data were collected from children, teachers, or schools. All quantitative values reported in this article are taken from the cited sources and are attributed to them.

Research questions and analytical constructs

The analysis was organized around the three research questions stated in the introduction. Five analytical constructs guided coding. The first was learning outcomes, including learning gains and effect sizes. The second was motivational and affective factors, including interest, motivation, and self-efficacy. The third was cognitive factors, including cognitive load, presence, agency, and self-regulation. The fourth was implementation factors, including usability, technical reliability, accessibility, and instructional design variables. The fifth was theoretical grounding, that is, the extent to which a source relied on, tested, or called for explicit learning theory. These constructs were derived from the engagement framework of Fredricks et al. (2004) and the model structure of Makransky and Petersen (2021).

Source selection

Sources were selected through purposive sampling. Inclusion criteria were as follows: (a) publication in a peer-reviewed journal; (b) a primary focus on AR, VR, or the cognitive and motivational mechanisms of learning with these technologies, or a foundational contribution to the theory of cognitive load or school engagement; (c) a verifiable bibliographic record, including a digital object identifier or a publisher or repository record; and (d) relevance to at least one analytical construct. Ten sources met these criteria. Four are review or meta-analytic syntheses of AR in education (Akçay & Akçay, 2017; Bacca et al., 2014; Garzón & Acevedo, 2019; Garzón et

al., 2019). Two are syntheses of VR-based instruction (Merchant et al., 2014; Radianti et al., 2020). Two address the cognitive and affective mechanisms of immersive learning (Makransky & Petersen, 2021; Petersen et al., 2022). Two supply foundational theory (Fredricks et al., 2004; Sweller, 1988).

Each bibliographic record was checked against publisher or repository metadata, including title, authors, journal, volume, pages, and DOI, before the source was included in the reference list. Reported statistics were extracted from abstracts or publisher records. Because the sample is purposive rather than exhaustive, the review does not claim to represent all research on the topic, and its conclusions are limited accordingly.

Analytical procedure

The analysis proceeded in four steps. In the first step, each source was summarized in a standardized matrix that recorded its type, scope, population, technology, principal findings, and stated limitations. In the second step, findings were coded against the five analytical constructs, and each coded statement was linked to the dimension of engagement it most directly informed: behavioral, emotional, or cognitive. In the third step, the coded findings were compared across sources to identify convergence, divergence, and gaps, with particular attention to whether sources focused on higher education, K-12, or mixed samples. In the fourth step, convergent findings were translated into design principles, which were then organized into an instructional framework. A finding was treated as convergent only when at least two independent sources supported it, and it was treated as tentative when it rested on a single source or on a theoretical prediction that had not been tested with primary-age learners.

Design-based component: framework development

The framework was developed using three rules. First, every design principle had to trace to at least one source and to at least one engagement dimension. Second, principles that follow from theory but have limited direct empirical support in primary education were labeled as hypotheses. Third, the framework had to be feasible in an ordinary classroom, where teachers have limited time, limited devices, and varying technical support. The resulting framework consists of four phases, described in the results section, each linked to a CAMIL factor and to a measurable engagement indicator.

Proposed evaluation protocol

To make the framework testable, the study specifies a protocol for future classroom research. The recommended design is a quasi-experimental pretest-posttest comparison between classes taught with the framework and classes taught the same content with conventional media, with a delayed posttest to assess retention. Behavioral engagement would be measured through structured classroom observation of on-task behavior, participation, and persistence. Emotional engagement would be measured through short, age-appropriate pictorial self-report scales administered immediately after lessons. Cognitive engagement would be measured through indicators such as the number and quality of student questions, the use of explanatory language, the completion of reflection tasks, and performance on transfer items that require applying knowledge in a new context. Learning outcomes would be measured through content knowledge tests aligned to the curriculum. Teacher ratings would provide additional triangulation. Cognitive load could be approximated through simple, child-appropriate effort ratings and through observed signs of overload, such as disengagement or repeated task abandonment.

Operational definitions

To keep the analysis consistent, the key terms were defined in advance. Augmented reality refers to technology that overlays digital content on the physical environment so that the learner experiences the virtual and the real world simultaneously. Immersive virtual reality refers to technology, typically a head-mounted display, that largely shuts out the physical world and places the learner inside a computer-generated environment (Makransky & Petersen, 2021). Cognitive

engagement refers to the learner's investment of mental effort in understanding and mastering the target content, in line with the three-part structure proposed by Fredricks et al. (2004). Extraneous cognitive load refers to the processing demand that arises from how information is presented rather than from the content itself, a distinction rooted in cognitive load theory (Sweller, 1988). Primary school students are defined as children in the early years of formal schooling, approximately six to ten years of age, although the exact range differs between national education systems. These definitions were applied uniformly when coding the sources, and any source that used a term in a different sense was noted in the extraction matrix.

Coding reliability and handling of mixed-age evidence

Because the coding involved interpretive judgments, several procedures were used to limit bias. The coding scheme was written before the extraction began, and each source was coded twice at separate times, with discrepancies resolved by returning to the original text and, where necessary, refining the category definition. Statements were coded only when they were explicitly present in the abstract, the publisher record, or the full text that was available to the author, and inferences beyond the text were recorded separately and labeled as inferences. A particular problem was the mixed-age evidence. Several sources include learners from K-12 and higher education or do not report age-specific results (for example, Merchant et al., 2014; Garzón & Acevedo, 2019), whereas others focus on higher education (Radianti et al., 2020). To avoid overstating the relevance of such evidence, each finding was tagged according to the extent to which it could plausibly apply to primary education: directly reported for K-12, reported for mixed samples, or reported for other populations and extrapolated only by theoretical argument. Findings in the third category were never used on their own as the basis of a design principle; they were used only when a theoretical mechanism, such as the limited capacity of working memory, could reasonably be expected to apply to young learners as well.

Rationale for the methodological choices

Three considerations justified the chosen approach. First, the research problem is conceptual as much as empirical: the field has many studies of outcomes but fewer attempts to explain how technology-mediated experiences become cognitive engagement. An integrative review is well suited to this problem because it can combine theoretical models, meta-analytic estimates, and design recommendations in a single argument. Second, the absence of primary data collection was a deliberate choice, since the framework needed to be specified and made testable before it could responsibly be taken into classrooms with children. Third, the design-based component forces the synthesis to produce concrete, falsifiable proposals, which reduces the risk that the review ends in general statements that no future study could contradict. The approach also has costs. It cannot estimate effect sizes for primary education, it cannot establish causal relationships, and it depends on the quality of the sources selected. These costs are acknowledged in the limitations and shape how the results should be read.

Ethical and practical considerations

Any future classroom implementation should obtain informed consent from parents or guardians and assent from children, follow institutional ethics review procedures, and protect student data collected through applications and devices. Device selection and session length should follow manufacturer age guidance and local safety regulations, and teachers should be prepared to stop a session if a child reports discomfort. Because head-mounted displays are subject to age recommendations that vary by product, tablet-based or smartphone-based AR may be a more practical entry point in primary classrooms, a design inference that should be tested rather than assumed.

Trustworthiness and limitations

Credibility was supported by verifying all bibliographic records and attributing all statistics to their sources. Dependability was supported by documenting selection criteria and the coding

scheme. The principal limitations are the purposive and relatively small source set, the reliance on abstracts and publisher records for some quantitative details, and the fact that several sources address mixed or higher-education populations. These limitations are addressed by labeling primary-education implications as hypotheses.

Results and Discussion

Learning outcomes and motivation (RQ1)

The reviewed evidence converges on the conclusion that AR and VR can support learning, but with qualifications. The two AR syntheses with quantitative estimates reported medium effects on learning gains (d = .68 in Garzón & Acevedo, 2019; d = .64 in Garzón et al., 2019), and the latter identified learning gains and motivation as the two most frequently reported advantages. The VR meta-analysis by Merchant et al. (2014) similarly concluded that VR-based instruction can be effective, but it showed that the size of the effect depends on the type of instruction and on design variables. For cognitive engagement, the motivational advantage is relevant mainly as an entry condition: a student who is interested is more likely to attend and invest effort, but interest does not guarantee deep processing. This interpretation is consistent with the multidimensional view of engagement, in which emotional engagement can support but cannot replace cognitive engagement (Fredricks et al., 2004).

The immersion paradox and cognitive load (RQ2)

The most important mechanism identified in the synthesis is what may be called the immersion paradox. CAMIL predicts that presence and agency increase interest, motivation, and self-efficacy, which should foster engagement, but that they also tend to increase extraneous cognitive load and may reduce self-regulation when lessons do not provide time for reflection (Makransky & Petersen, 2021). This prediction aligns with the foundational claim that irrelevant processing competes with schema acquisition (Sweller, 1988). The empirical study by Petersen et al. (2022) provides evidence that interactivity and immersion operate through the cognitive and affective variables the model specifies, and it suggests that the model requires additions, which implies that practitioners should treat the model as a guide rather than a finished prescription. For primary learners with limited prior knowledge, the practical implication is that the design should restrict decorative detail, limit the number of simultaneous interaction options, and build in structured pauses.

Design variables and implementation barriers (RQ2)

The sources show that design variables moderate effects. Merchant et al. (2014) reported advantages for games over simulations and virtual worlds, for individual over group play, and an inverse relationship between the number of sessions and gains for games, which suggests that novelty effects or fatigue may influence outcomes. Garzón and Acevedo (2019) examined control treatment, learning environment, learner type, and subject domain as moderators, which underscores that effects cannot be generalized across contexts. On the implementation side, usability issues and technical problems are recurrent challenges (Akçay & Akçay, 2017), and accessibility remains largely unaddressed (Garzón et al., 2019). In primary classrooms, where one teacher manages many children, even small technical failures can interrupt the lesson and erode engagement, so technical reliability should be treated as a pedagogical requirement rather than a mere logistical one.

The theoretical gap (RQ2)

The review of immersive VR by Radianti et al. (2020) found that learning theories were not often considered in application development, and the present synthesis found little explicit connection between AR/VR design and a theory of cognitive engagement in young learners. This gap is consequential: without a theoretical account, applications tend to maximize realism and interactivity, which are the features most likely to raise extraneous load. The proposed framework addresses this by anchoring each phase of a lesson in a specific theoretical mechanism.

A four-phase framework for primary classrooms (RQ3)

The synthesis yields a framework of four phases. In the Prepare phase, the teacher activates prior knowledge and introduces key vocabulary before students use the technology. CAMIL's discussion of media-and-method experiments describes pre-training as a method that benefits immersive learning, because learners with some prior knowledge can interpret what they experience (Makransky & Petersen, 2021). The associated engagement indicator is the quality of students' initial questions. In the Explore phase, students use a bounded AR or VR experience with a clear task, limited interaction options, and minimal decorative content. The theoretical rationale is to harness presence and agency while limiting extraneous load (Makransky & Petersen, 2021; Sweller, 1988). The indicator is on-task behavior and persistence. In the Reflect phase, students leave the technology and engage in generative activities such as explaining, summarizing, or teaching a peer, which the CAMIL literature associates with better learning from immersive lessons because they provide the time for reflection that high presence can suppress. The indicator is the quality of explanation. In the Transfer phase, students apply the concept to a new problem or real-world observation, which tests whether cognitive engagement has produced usable knowledge. The indicator is performance on transfer items.

Two additional principles follow from the evidence. First, session design should consider the possibility of declining returns with repeated sessions (Merchant et al., 2014), so that technology use is varied and purposeful. Second, accessibility and personalization should be planned from the beginning (Bacca et al., 2014; Garzón et al., 2019), including alternatives for children who cannot use a particular device or interaction mode.

Discussion and implications

Theoretically, the findings suggest that AR/VR research on young learners benefits from treating engagement as a multidimensional construct. Interest and enjoyment are necessary but insufficient; cognitive engagement requires that the learner's limited processing capacity be directed toward the target concept. Practically, the framework implies that the teacher's role becomes more, not less, important in technology-rich lessons: teachers prepare, constrain, and debrief. The study's limitations are significant. The synthesis is based on ten sources, several of which do not focus on primary education, and the framework has not been tested empirically. The primary-education recommendations are therefore hypotheses grounded in theory and in indirect evidence, and the evaluation protocol is offered as a means of testing them.

Conclusion

This article examined the role of AR/VR technologies in developing cognitive engagement among primary school students through a theory-driven integrative review of ten peer-reviewed sources and a design-based component. Three conclusions follow. First, the reviewed evidence indicates that AR and VR can support learning and motivation, with medium effects reported in two AR syntheses ($d = .64$ and $d = .68$), but that effects depend on instructional design, the type of VR-based instruction, and contextual moderators. Second, the same literature indicates that immersion and interactivity are double-edged: they can raise interest, motivation, and self-efficacy, yet they can also increase extraneous cognitive load and reduce opportunities for reflection and self-regulation. Cognitive engagement is therefore not an automatic by-product of immersive technology but an outcome of lesson design. Third, implementation barriers, including usability problems, technical failures, and limited accessibility, remain significant and are especially consequential in primary classrooms.

The theoretical contribution of the study lies in integrating cognitive load theory, the Cognitive Affective Model of Immersive Learning, and the multidimensional construct of school engagement into a single analytical lens. This integration clarifies why high engagement in the emotional sense may coexist with weak engagement in the cognitive sense, and it identifies the conditions under which immersive technologies are more likely to direct mental effort toward

learning goals. The practical contribution is the four-phase framework (Prepare, Explore, Reflect, Transfer) and the accompanying evaluation protocol, which together give teachers and designers a structured way to plan lessons and to assess behavioral, emotional, and cognitive engagement.

Several limitations should be acknowledged. The source set was purposive and relatively small, some quantitative details were drawn from abstracts and publisher records, and several sources address mixed-age or higher-education populations. Most importantly, no primary data were collected from primary school students, so the framework should be regarded as a theoretically grounded proposal rather than a validated intervention. Findings regarding primary education should be read as hypotheses.

Future research should proceed in four directions. First, quasi-experimental and design-based studies in primary classrooms should test the framework using the proposed protocol, including delayed posttests and transfer measures. Second, studies should compare AR and immersive VR with young learners under equivalent instructional conditions, since the reviewed literature suggests that the two technologies differ in how they relate learners to the physical environment. Third, researchers should investigate optimal session length, frequency, and novelty effects in relation to cognitive engagement. Fourth, studies should examine accessibility and personalization so that the benefits of AR/VR are available to all learners. Teacher education and professional development should also be investigated, because the framework assumes teachers who can prepare, constrain, and debrief immersive lessons. Progress along these lines would allow the field to move from general claims about the promise of AR/VR toward precise, evidence-based guidance for primary education.

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Interaction and Corrective Feedback: Pushing Learners toward Accurate Use of Complex Structures

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Abstract. Corrective feedback gives second language learners what input cannot provide: evidence about the accuracy of their own use of the language. This is especially important for complex structures, whose incorrect use seldom impedes communication and therefore seldom attracts correction in ordinary conversation. The article examines how interaction and corrective feedback contribute to the mastery of such structures. It reviews the interaction hypothesis, the taxonomy of feedback types, classroom studies comparing recasts and prompts, and meta-analytic evidence, and it identifies the conditions under which feedback is most effective: perceived corrective intent, learner readiness, the nature of the target structure, focus and consistency, and affective climate. Three illustrations (English articles, Azerbaijani suffixation, and the English third person -s) show that the best feedback depends on the source of the difficulty. The article concludes that feedback on complex structures must be planned rather than left to chance.

Keywords: corrective feedback, recasts, prompts, interaction hypothesis, complex structures, focus on form, second language learning

Introduction

Complex language structures, that is, forms whose morphology is intricate, whose meaning is opaque, or whose phonetic realization is weak, are learned only when learners attend to them, and instruction can create the conditions for that attention. Attention, however, is only the first step. A learner who has noticed a form still needs evidence about whether his or her own use of it is correct, and such evidence is precisely what ordinary input does not provide. Input shows what the language looks like; it does not show which of the learner's own utterances deviate from it. Corrective feedback fills this gap, and it is therefore one of the most important mechanisms in instructed second language learning.

This article examines how interaction and corrective feedback contribute to the mastery of complex structures. It begins with the interaction hypothesis, which holds that conversational adjustments made when communication breaks down help learners to process input and to notice gaps in their knowledge [4, pp. 413–468]. It then reviews classroom research on feedback types, in particular the contrast between recasts and prompts [7, pp. 37–66; 6, pp. 399–432; 1, pp. 543–574], and the meta-analytic evidence on effectiveness [8, pp. 265–302; 9, pp. 407–452]. Finally, it addresses the conditions under which feedback is most useful, illustrates them with three complex structures, and draws pedagogical implications.

The central claim is that the effectiveness of feedback depends on whether it enables learners to notice the mismatch between their output and the target form and to produce a corrected form themselves. For complex structures, which often do not impede communication when used incorrectly, feedback must be deliberately designed rather than left to the chance events of conversation.

1. Why Input Alone Cannot Provide Feedback

Language learners form hypotheses about how the target language works and test them in their own speech and writing. The hypotheses are often partly correct and partly wrong, and the wrong parts can persist for a long time if nothing signals that they are wrong. The available input contains only positive evidence, that is, examples of what is possible in the language, and no negative evidence, which is information about what is not possible. A learner who overgeneralizes a rule, for example by adding a regular past tense ending to an irregular verb, will find no counterexample in the input that directly says the form is incorrect. In first language acquisition, whether children receive and use negative evidence has been debated at length, and some researchers argue that positive evidence alone suffices. For second language learners the situation is different: adults have already acquired one language, typically have much less exposure, and are often unable to recover from errors that have become entrenched. Researchers therefore generally accept that negative evidence plays a more significant role in second language learning, and that its provision can speed up development and reduce the persistence of errors [4, pp. 413–468].

Feedback can be explicit, as when a teacher states that an utterance is incorrect and supplies the correct form, or implicit, as when a partner simply reformulates the utterance without comment. It can be reactive, given in response to an error, or preemptive, given to forestall one. This article concerns reactive feedback provided in the course of communicative activity, since it has been most extensively studied and most directly combines meaning-focused interaction with attention to form. For complex structures the need for negative evidence is particularly acute. Because these forms are frequently redundant, their omission or misuse seldom impedes understanding, and conversational partners rarely react to it. A learner who omits an article, uses the wrong suffix, or fails to mark agreement will usually be understood and receive no signal that anything is amiss. Without feedback the incorrect form may become established as a habit, which is what researchers mean by fossilization.

2. The Interaction Hypothesis

The interaction hypothesis grew out of observations of conversations between native speakers and learners. Long [4, pp. 413–468] argued that when communication breaks down, participants engage in negotiation of meaning, using clarification requests, confirmation checks, and comprehension checks to restore mutual understanding. These adjustments make input more comprehensible, but they also draw the learner's attention to the form of the utterance that caused the difficulty and provide information about how it might be reformulated. In its later version, the hypothesis assigns a special role to negative feedback arising during interaction, which can connect input, the learner's internal capacities, particularly selective attention, and output in productive ways. Interaction is beneficial not because it provides more input but because it provides the right input at the right moment, when the learner has just produced an utterance and can compare it with the target model.

Support has come from many studies. Mackey and Goo [9, pp. 407–452] conducted a meta-analysis of interaction research and found a positive effect on learning that was durable over time. The effect was larger for lexical than for grammatical targets, but it was present for grammar. This suggests that not all grammatical features benefit equally and that complex structures may require more than incidental interaction. Negotiation is triggered by communication breakdowns, which occur mainly when lexical items are misunderstood, whereas grammatical errors that do not threaten comprehension seldom trigger it. To promote attention to such errors, the interaction must be shaped by a teacher or a task so that the target structure becomes communicatively necessary. Swain's output hypothesis [13, pp. 235–253] complements this view: if learners are pushed to produce precise, coherent, and appropriate output and receive feedback when they fail to do so, they are more likely to process the form of the language. The most valuable

interaction is thus one in which learners must produce target forms and then receive informative reactions to their productions.

3. A Taxonomy of Corrective Feedback

Research on classroom feedback has been shaped by Lyster and Ranta [7, pp. 37–66], who analyzed interaction in four French immersion classrooms in Canada and identified six types of teacher feedback. Explicit correction clearly indicates that the utterance was incorrect and supplies the correct form. Recasts reformulate all or part of the utterance without the error and without explicitly indicating that an error was made. Clarification requests signal that the utterance was not understood or contained a mistake. Metalinguistic feedback comments on the well-formedness of the utterance without providing the correct form. Elicitation directly requests a reformulation from the learner, for example by asking the learner to complete the teacher's sentence. Repetition repeats the erroneous utterance, usually with a change in intonation to highlight the error.

A fundamental distinction emerging from this taxonomy is between reformulations and prompts. Recasts and explicit correction supply the correct form and are sometimes called input-providing feedback, whereas clarification requests, metalinguistic feedback, elicitation, and repetition withhold the correct form and push the learner to produce it. The distinction reflects the processing each is thought to encourage: reformulations give the learner a model to compare with his or her own utterance, while prompts require the learner to retrieve or construct the correct form.

Lyster and Ranta also introduced uptake, the learner's immediate response to feedback, which can be repair, when the learner produces the correct form, or needs-repair, when the utterance still contains an error. Teachers used recasts more often than any other type, accounting for more than half of all feedback, but recasts produced relatively little uptake, whereas prompts were more likely to lead to repair. The authors suggested that recasts were frequently ambiguous, because learners could interpret them as confirmation or as an alternative way of saying the same thing rather than as a correction. The limitations of the study are, however, widely recognized. Uptake is an immediate and observable reaction but not the same as learning: a learner may repair an utterance without having acquired the form, or fail to respond and yet benefit later. Ellis, Basturkmen, and Loewen [2, pp. 281–318] found that uptake varied with the type of feedback and with whether the learner or the teacher initiated the attention to form, so it should be treated as one piece of evidence among others.

4. Recasts and Prompts: Comparing Their Effects

Lyster [6, pp. 399–432] conducted a quasi-experimental study in French immersion classrooms in which students received instruction on grammatical gender. Some groups received recasts, others prompts, and a comparison group no feedback. The groups that received prompts outperformed those that received recasts on measures of gender knowledge, suggesting that feedback requiring self-repair is more effective than feedback that supplies the correct form, at least for the structure and context examined. Ammar and Spada [1, pp. 543–574] investigated a similar question in intensive English classes for French-speaking learners in Quebec. The target was the English possessive determiners his and her, which are difficult for learners whose first language marks the gender of the possessed noun rather than the possessor. Both recasts and prompts were beneficial, but prompts were more effective overall, and proficiency interacted with feedback type: higher proficiency learners benefited from both, whereas lower proficiency learners benefited more from prompts.

Ellis and Sheen [3, pp. 575–600] offered a critical examination of recast research. They pointed out that recasts are a family of techniques that vary in whether they are isolated or incorporated into a longer turn, whether they involve one change or several, and whether they are accompanied by other signals, so results may differ because the recasts themselves differed.

They also argued that the ambiguity of recasts is not necessarily a disadvantage, since it allows interaction to proceed without interruption, and that recasts may be effective when they are salient and the learner is oriented toward form.

The two types of feedback may also work through different mechanisms. Recasts provide a model immediately after the error, when the learner's utterance is still in working memory, and so facilitate cognitive comparison. Prompts push the learner to retrieve or generate the form, which strengthens memory and is consistent with the output hypothesis. Which mechanism is more effective may depend on whether the learner already has some knowledge of the form. A learner with no knowledge of the correct form cannot be prompted to produce it, so recasts or explicit correction may be more useful, whereas a learner with partial knowledge may benefit more from a prompt that encourages retrieval. This helps to reconcile conflicting results and has a practical consequence: a teacher should vary feedback according to the learner's state of knowledge and the nature of the error. For complex structures, where knowledge is often incomplete, a sequence beginning with a prompt and proceeding to a recast or explicit correction if the prompt fails allows the learner to self-repair while ensuring that the correct form is ultimately supplied.

5. Meta-Analytic Evidence

Lyster and Saito [8, pp. 265–302] reviewed research on oral corrective feedback in classroom settings and reported a significant positive effect on learning that was maintained on delayed posttests. Prompts were more effective than recasts, and effects were larger in studies using measures requiring free constructed responses than in those using more controlled measures. Effects were observed in both foreign language and second language classrooms and were not restricted to laboratory contexts, which supports the conclusion that feedback can be effective in regular instruction. The authors also reported that the advantage of feedback was particularly marked among younger learners, although the evidence on this point is limited. Mackey and Goo [9, pp. 407–452] likewise concluded that interaction, including the feedback it contains, has significant effects on second language development that persist on delayed posttests.

The broader meta-analyses of instruction also bear on the question. Norris and Ortega [10, pp. 417–528] concluded that focused instruction was effective, with explicit techniques generally showing an advantage, and Spada and Tomita [12, pp. 263–308] found that explicit instruction was more effective than implicit instruction for features of both low and high complexity. Because corrective feedback can be explicit or implicit, these results indicate that more explicit feedback may be more useful for structures that are difficult to notice, which is consistent with the view that complex structures require deliberate attention. These syntheses have limitations, however. The number of studies for some comparisons is small, target structures, learner populations, and outcome measures vary widely, and most studies involve single structures and short treatment periods. It is not known how feedback operates when learners deal with many structures at once, as in real classrooms, so the conclusions should be regarded as indications of general tendencies rather than precise prescriptions.

6. Conditions That Shape the Effectiveness of Feedback

The effectiveness of feedback depends on several conditions, which help to explain variation in research findings. The first is whether the learner perceives the feedback as corrective. A teacher may intend a recast as a correction, but the learner may interpret it as a continuation of the conversation. Recasts are more likely to be perceived as corrections when they are prominent, for example stressed or repeated, and when the context makes clear that the focus is on form; in a classroom devoted to language study, learners more readily expect teacher reformulations to be corrections than in a classroom devoted to content. The second condition is the learner's readiness to use the information. A learner far from being able to use a structure

may notice the correction but be unable to benefit from it, so feedback is most effective when it targets structures that the learner is on the verge of acquiring.

The third condition is the nature of the target structure. Feedback on a transparent and salient form can be brief and implicit, since learners can easily perceive the contrast between their form and the target. Feedback on a complex form may need to be more explicit and to include some explanation. If a learner uses the wrong article, a recast may fail to reveal what should have been noticed, because the difference lies in the speaker's assumptions about what the hearer knows and not in any audible feature; a brief metalinguistic comment, such as a reminder that the noun has already been mentioned, may make the difference visible. The fourth condition is focus and consistency. Much classroom feedback is unsystematic: teachers respond to some errors and ignore others, so learners receive scattered information on many structures and little sustained information on any one. Feedback appears more effective when focused on a small number of target structures over an extended period, because this gives learners repeated evidence about the same form [12, pp. 263–308].

The fifth condition is the affective climate. Feedback can provoke anxiety, particularly when public or perceived as criticism, and learners who feel threatened may avoid the language or risky structures, which reduces learning opportunities. The tone, timing, and privacy of feedback therefore affect its success, and teachers can reduce the threat by establishing a norm in which errors are a normal part of learning and correction is expected and welcomed.

7. Feedback within Focus-on-Form Instruction and Learner Responses

Corrective feedback is one of the main techniques of focus on form, the approach that draws learners' attention to linguistic elements as they arise incidentally in lessons whose primary focus is meaning. Long and Robinson [5, pp. 15–41] described it as preserving the advantages of communicative instruction while avoiding its typical limitations, and distinguished it from focus on forms, which isolates structures for teaching in a predetermined sequence, and from a pure focus on meaning, which ignores form entirely. Focus on form can be reactive, when teachers respond to errors as they occur, or proactive, when they design activities that create opportunities for using particular forms. Corrective feedback is the paradigm case of the reactive kind. Its advantages are timeliness and relevance to the individual learner's difficulties; its drawbacks are unpredictability, since the teacher cannot be sure that a particular structure will be addressed, and the burden of deciding quickly whether and how to respond. Proactive tasks address these drawbacks: a picture-sequence narration, for example, creates frequent occasions for past tense forms, whose errors can then be treated consistently. Combining a proactive task with reactive feedback increases both the probability that the structure will arise and the probability that it will be addressed.

Brief, targeted feedback does not require learners to shift from communication to grammar analysis for long, but when the structure demands more extended explanation, the teacher may move into a short episode of explicit instruction, keep it short, and return quickly to communicative activity so that the newly noticed information can be used at once. Delayed feedback, in which errors recorded during an activity are discussed afterward with the whole class, allows teachers to select the most important errors, present them without identifying individuals, and offer fuller explanation, which may be most practical for complex structures, although the learner's memory of the utterance may have faded.

The value of feedback lies not in the teacher's act alone but in what the learner does with it. Swain [13, pp. 235–253] emphasized that learners must be pushed to produce output, and feedback that prompts learners to modify their utterances creates exactly this kind of pushed output, giving them an opportunity to apply the information, test a new hypothesis, and receive further confirmation or correction. The learner's response also informs the teacher: a successful repair suggests that the knowledge exists but was not retrieved, while a failure suggests that it is lacking and that a more explicit intervention is needed. Feedback is thus a diagnostic assessment

as well as a teaching technique. Whether its benefits generalize probably depends on whether it led to an understanding of the underlying pattern or only to memorization of a particular form, so for rule-governed structures, feedback that highlights the pattern is more likely to produce generalizable learning. Peer interaction offers an additional context: learners working in pairs have many more opportunities to speak and sometimes correct one another. Peer feedback is variable in quality, but it can promote noticing, particularly when learners have been trained and tasks require accurate use of the target structure.

8. Feedback on Complex Structures: Three Illustrations

The first illustration is the English article system. Errors in articles rarely cause communication breakdown, and recasts often pass unnoticed because the difference between a and the is neither stressed nor semantically obvious on the surface. A learner who says that he bought car yesterday will probably be understood, and a teacher who replies that he bought a car yesterday may simply appear to be confirming the statement. More effective feedback might combine a prompt, such as repeating the utterance with rising intonation on the noun phrase, with a brief metalinguistic comment about whether the car is known to the listener. The aim is to draw attention to the contrast that has to be noticed [11, pp. 129–158] and to give the learner an opportunity to produce the form.

The second concerns case and possessive suffixes in an agglutinative language such as Azerbaijani. The forms are audible and often stressed, so perceptual salience is less of a problem, but assembling the word requires selecting the right suffix, the right vowel, and the right order. Errors are frequent and varied, and a single recast may not reveal the source of the difficulty. A teacher might respond with an elicitation, asking the learner to name the function of the suffix, followed by a recast showing the complete, correctly assembled form. Because the system is regular, feedback that highlights the pattern, for instance by showing how the same suffix combines with stems of different vowel types, is likely to generalize to new words.

The third is the third person singular -s in English. Learners often know the rule, and errors are typically slips arising when attention is directed elsewhere, so brief implicit feedback, such as a repetition with rising intonation or a clarification request, may be sufficient to prompt self-repair. The greater challenge is to provide enough opportunities for practice under communicative conditions that the correct form becomes automatic, which requires many occasions for use and steady feedback across many lessons.

These examples show that the optimal feedback depends on the nature of the difficulty. Where the problem is a missing concept, as with articles, explicit information must accompany the feedback; where it is complexity of assembly, as with agglutinative morphology, feedback should reveal the structure of the form; where it is automatization, as with the third person -s, brief prompts and abundant practice are most appropriate. A teacher who diagnoses the source of the difficulty is better placed to choose an appropriate response, and in each case the target structure must be deliberately elicited, the errors recognized, and the response calibrated to the learner's state of knowledge. This is the combination of attention-directing input and personalized evidence that exposure alone cannot supply.

9. Pedagogical Implications

The research reviewed here has several implications for the treatment of complex structures. First, teachers should not rely on incidental feedback. Because complex structures seldom cause breakdown, they are unlikely to attract feedback in ordinary conversation, so feedback must be planned: a teacher who has identified a structure as a focus can design tasks that require it and commit to responding to errors in it consistently. Second, teachers should use a repertoire of techniques and select among them according to learner and error. Prompts are generally more effective than recasts for learners with some knowledge of the form, because they encourage retrieval and self-repair [8, pp. 265–302]; recasts and explicit correction suit learners

who lack the knowledge needed to self-repair; and brief metalinguistic comments are especially useful for forms whose function is not evident from their surface, such as articles.

Third, feedback should be made noticeable. If a recast is to function as a correction it must be perceived as one, and emphasizing the corrected element, pausing, or following the recast with a brief check can increase its salience. Fourth, feedback should be focused: responding to every error overwhelms both teacher and learner, whereas concentrating on a few target structures provides the repeated evidence that learners need. Fifth, learners should have an opportunity to act on feedback, for example by repeating a task with a new partner or rewriting a text after receiving comments, since a correction that is acknowledged but not used is unlikely to have lasting effects. Finally, teachers should monitor the affective dimension, because a learner who feels embarrassed or criticized may become reluctant to speak, which defeats the purpose of interaction.

Teacher education and curriculum planning have a role in making these practices possible. Many teachers have never been trained to distinguish among types of feedback and may use recasts almost exclusively because they are the most natural conversational response. Awareness-raising activities, such as recording and analyzing one's own lessons, can help teachers see what feedback they actually give, notice how learners respond, and experiment with alternatives. A syllabus crowded with content that leaves no time for learners to produce language and receive reactions to it cannot meet the conditions for effective feedback, so regular periods for communicative tasks that elicit target structures, and opportunities to revisit those structures in later units, allow feedback to accumulate over time.

Conclusion

Corrective feedback gives learners what input cannot: information about the accuracy of their own use of the language. For complex structures, which are frequently redundant and therefore seldom corrected in ordinary conversation, this information is especially valuable. The interaction hypothesis explains how feedback arising in communication can direct attention to form, and classroom studies and meta-analyses show that feedback is generally effective, with prompts often having an advantage over recasts when learners have partial knowledge of the target form.

The effectiveness of feedback is not uniform, however. It depends on whether learners perceive the feedback as corrective, whether they are ready to use it, whether the difficulty of the target structure can be addressed by a brief reaction, and whether the feedback is sustained and focused. Teachers who plan feedback around a small number of complex structures, vary techniques according to learners' knowledge, and give learners opportunities to act on what they receive are likely to obtain the best results. Future research should examine how feedback operates over longer periods and across many structures at once, and how it can be coordinated with the sequencing of structures and the design of tasks at the level of the curriculum.

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СОВРЕМЕННЫЕ ФОРМЫ ОРГАНИЗАЦИИ УЧЕБНОГО ПРОЦЕССА В ВЫСШЕЙ ШКОЛЕ ОТ ТРАДИЦИОННОГО ОБУЧЕНИЯ К ИНТЕРАКТИВНЫМ ТЕХНОЛОГИЯМ

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Аннотация

Статья посвящена библиометрическому анализу научных исследований современных форм организации учебного процесса в высшей школе в контексте перехода от традиционных моделей обучения к интерактивным и цифровым образовательным технологиям. Актуальность исследования обусловлена интенсивной цифровой трансформацией высшего образования и фрагментарностью научных подходов к изучению интерактивных педагогических моделей. Цель исследования заключается в выявлении основных тенденций развития научного поля за 2005–2025 гг., определении динамики публикационной активности, географической структуры исследований и ключевых тематических направлений с учётом положения Казахстана в международном научном пространстве. Методологическую основу составил библиометрический анализ публикаций международной базы данных Scopus. Первоначально идентифицированы 952 публикации, из которых после многоэтапного отбора по критериям PRISMA в итоговую выборку включены 306 научных статей. Для анализа использованы показатели публикационной активности, цитирования, географического распределения и совместной встречаемости ключевых слов с применением программы VOSviewer. Результаты исследования выявили устойчивое увеличение научного интереса к интерактивным образовательным технологиям, особенно в 2020–2025 гг. Лидирующие позиции по количеству публикаций занимают США, Великобритания и Испания, тогда как Казахстан представлен четырьмя исследованиями в сформированной выборке. Анализ 54 ключевых слов позволил выделить четыре тематических кластера, охватывающих интерактивные формы обучения, цифровую образовательную среду, искусственный интеллект и педагогические стратегии. Установлено, что современное исследовательское поле характеризуется тесной интеграцией педагогических подходов и цифровых технологий. Научная значимость исследования заключается в систематизации тематической и географической структуры научных публикаций, посвящённых трансформации университетского обучения. Практическая значимость определяется возможностью использования выявленных международных тенденций для развития интерактивных образовательных практик и совершенствования стратегий цифровой трансформации высшего образования Казахстана.

Ключевые слова: высшее образование, интерактивное обучение, цифровая трансформация образования, образовательные технологии, активное обучение, смешанное обучение, искусственный интеллект, библиометрический анализ, Scopus, VOSviewer.

Abstract

This article presents a bibliometric analysis of scientific research on contemporary forms of organizing the educational process in higher education, focusing on the transition from

traditional teaching models to interactive and digital educational technologies. The relevance of the study is determined by the rapid digital transformation of higher education and the fragmentation of scholarly approaches to examining interactive pedagogical models. The aim of the study is to identify the major trends in the development of this research field from 2005 to 2025, examine publication dynamics, analyze the geographical distribution of research, and determine key thematic areas, with particular attention to Kazakhstan's position within the international scientific landscape. The methodological framework is based on a bibliometric analysis of publications indexed in the international Scopus database. Initially, 952 publications were identified, of which 306 scientific articles were included in the final dataset following a multi-stage selection process based on PRISMA criteria. The analysis employed indicators of publication activity, citation performance, geographical distribution, and keyword co-occurrence, using VOSviewer software for bibliometric mapping and network visualization. The findings reveal a sustained increase in scholarly interest in interactive educational technologies, particularly during 2020–2025. The United States, the United Kingdom, and Spain emerged as the leading countries in terms of publication output, while Kazakhstan was represented by four publications in the selected dataset. The analysis of 54 keywords identified four thematic clusters encompassing interactive learning approaches, digital learning environments, artificial intelligence, and pedagogical strategies. The findings demonstrate that the contemporary research landscape is characterized by the close integration of pedagogical approaches and digital technologies. The scientific significance of the study lies in the systematic mapping of the thematic and geographical structure of scholarly publications addressing the transformation of university teaching and learning. The practical significance is associated with the potential application of the identified international trends to the development of interactive educational practices and the improvement of digital transformation strategies in Kazakhstan's higher education system.

Keywords: higher education, interactive learning, digital transformation of education, educational technologies, active learning, blended learning, artificial intelligence, bibliometric analysis, Scopus, VOSviewer.

Актуальность исследования

Современное высшее образование находится в процессе существенной трансформации форм организации учебного процесса, обусловленной одновременно технологическими, педагогическими и институциональными изменениями. Традиционная модель университетского обучения, основанная преимущественно на лекционной передаче знаний и доминирующей роли преподавателя, постепенно дополняется и трансформируется посредством активного обучения (active learning), смешанного обучения (blended learning), перевернутого класса (flipped classroom), совместного и проблемно-ориентированного обучения, геймификации, цифровых образовательных платформ и других интерактивных технологий. В результате изменяется не только технологическая среда университета, но и сама логика взаимодействия между преподавателем, студентом и образовательным контентом. Одним из принципиальных изменений становится переход от преимущественно преподаватель-центрированной модели к образовательным практикам, предполагающим более активное участие обучающегося в производстве и освоении знаний. Эмпирические исследования подтверждают образовательный потенциал такого перехода. В частности, метаанализ 225 исследований в области STEM показал, что применение активных методов обучения связано с повышением академической успеваемости студентов, тогда как вероятность неуспешного прохождения курса оказывается выше при традиционном лекционном формате (Freeman et al., 2014). Следовательно, распространение интерактивных форм обучения следует рассматривать не только как следствие

технологического развития, но и как часть более глубокой трансформации педагогической модели высшей школы.

Особенно интенсивно данный процесс развивается в условиях цифровой трансформации университетов. Цифровизация высшего образования предполагает значительно больше, чем внедрение отдельных информационно-коммуникационных технологий: она затрагивает образовательные практики, институциональное управление, способы коммуникации, профессиональные компетенции преподавателей и организацию образовательной среды в целом (Castro Benavides et al., 2020). При этом исследования показывают, что цифровая трансформация высших учебных заведений остается неоднородным процессом и требует согласования технологических инноваций с педагогическими и организационными изменениями (Fernández et al., 2023). За последние два десятилетия сформировались многочисленные направления исследований, посвященные blended learning, flipped classroom, active learning, e-learning, collaborative learning, online learning, gamification и другим образовательным технологиям. Однако стремительное расширение данной области приводит к фрагментации научного знания: различные формы и технологии обучения зачастую рассматриваются как самостоятельные исследовательские направления, что затрудняет понимание общей траектории трансформации высшего образования. Данная проблема актуальна и для Казахстана, так как цифровизация казахстанской системы высшего образования существенно ускорила внедрение электронных образовательных платформ, дистанционных и смешанных форм обучения. Пандемия COVID-19 стала дополнительным фактором ускорения этих процессов, поскольку казахстанские университеты были вынуждены массово перейти к дистанционному формату и использовать Moodle, Canvas, Platonus, Univer и другие цифровые платформы (Askarkyzy & Zhunusbekova, 2021). Последующие исследования показывают дальнейшее развитие blended learning и других гибридных форм преподавания в казахстанском образовании (Kaliaskarova et al., 2022).

Вместе с тем внедрение цифровых технологий само по себе не означает полноценного перехода к новой педагогической модели. Исследования казахстанского контекста фиксируют как преимущества онлайн- и гибридного обучения гибкость, доступность материалов и возможности индивидуализации, так и сохраняющиеся проблемы, связанные с недостаточностью непосредственного взаимодействия преподавателя и студентов, обратной связи, техническими ограничениями и неодинаковой готовностью участников образовательного процесса к цифровым форматам (Chsherbakova et al., 2025). Современные исследования цифровой трансформации университетов Казахстана также указывают на необходимость одновременного развития инфраструктуры, инновационных методов преподавания, цифровых компетенций и институциональной готовности вузов (Zhukabayeva et al., 2025). Для Казахстана международный опыт развития современных форм организации обучения имеет не только теоретическое, но и практическое значение. Определение глобальных тенденций, наиболее влиятельных исследовательских направлений и новых тематических кластеров позволяет установить, какие педагогические модели и образовательные технологии находятся в центре современной международной дискуссии и насколько эти направления представлены в научной и образовательной повестке Казахстана.

Проблема исследования. Несмотря на значительный объем исследований цифровизации и инновационных методов преподавания, современное научное поле характеризуется концептуальной и тематической фрагментацией. Active learning, blended learning, flipped classroom, collaborative learning, problem-based learning, e-learning, online learning и другие интерактивные технологии сформировали собственные исследовательские направления. В результате переход от традиционной организации учебного процесса к интерактивным и технологически опосредованным формам обучения изучается

преимущественно через отдельные педагогические модели или технологии, тогда как общая структура и динамика данного научного поля остаются недостаточно систематизированными. Существующие обзоры подтверждают эту фрагментацию. Например, библиометрические исследования отдельно рассматривают flipped classroom в высшем образовании (Limaymanta et al., 2021), тогда как другие работы концентрируются непосредственно на цифровой трансформации университетов и технологической инфраструктуре высшего образования (Castro Benavides et al., 2020; Fernández et al., 2023). В библиометрическом исследовании цифровой трансформации вузов за 2010–2023 гг. также основное внимание уделяется digital transformation, новым технологиям, пользовательскому опыту и социальной инклюзивности, а не эволюции форм организации самого учебного процесса от традиционных к интерактивным (Kumar et al., 2024). Для Казахстана данная проблема приобретает дополнительное измерение. Национальные исследования преимущественно анализируют отдельные аспекты цифровизации: дистанционное обучение, blended learning, flipped classroom, цифровые платформы или институциональную цифровую трансформацию. Например, применение flipped classroom исследовалось на материалах преподавателей 11 казахстанских университетов (Baigunissova et al., 2023), тогда как другие исследования сосредоточены на blended learning (Kaliaskarova et al., 2022) и цифровой трансформации высшего образования в более широком институциональном контексте (Zhukabayeva et al., 2025).

Research gap. Анализ существующей литературы выявляет существенную фрагментарность научного поля, посвященного трансформации форм организации учебного процесса в высшей школе. Большинство библиометрических и обзорных исследований сосредоточено на отдельных педагогических моделях и технологических направлениях, включая flipped classroom, blended learning, e-learning, learning analytics и digital transformation (Limaymanta et al., 2021; Ragazou & Antonis, 2026), что обеспечивает детальное понимание отдельных сегментов литературы, но не позволяет целостно реконструировать эволюцию форм университетского обучения от традиционных моделей к интерактивным и цифровым технологиям. В то же время исследования цифровой трансформации высшего образования преимущественно рассматривают вопросы цифровой инфраструктуры, институциональных стратегий, управления, цифровой зрелости и внедрения новых технологий (Castro Benavides et al., 2020; Fernández et al., 2023), тогда как изменение педагогической организации учебного процесса значительно реже выступает самостоятельным объектом библиометрического картирования. Недостаточно изученной остается и долгосрочная интеллектуальная и тематическая эволюция данного научного поля, включая изменение доминирующих концептов, формирование тематических кластеров и интеграцию таких направлений, как active learning, blended learning, flipped classroom, learning analytics и искусственный интеллект. Дополнительный исследовательский пробел связан с географическим измерением: несмотря на наличие исследований blended learning, flipped classroom, дистанционного обучения и цифровой трансформации университетов Казахстана (Askarkyzy & Zhunusbekova, 2021; Kaliaskarova et al., 2022; Baigunissova et al., 2023; Zhukabayeva et al., 2025), положение Казахстана в глобальном исследовательском пространстве современных форм организации университетского обучения остается недостаточно систематизированным. В связи с этим настоящее исследование направлено на восполнение обозначенного пробела посредством библиометрического анализа публикаций, индексируемых в базе данных Scopus за 2005–2025 гг., с целью проследить двадцатилетнюю динамику развития данного научного направления, определить наиболее продуктивных авторов, журналы и страны, выявить структуру международного научного сотрудничества и основные тематические кластеры, а также установить эволюцию исследовательской повестки от традиционных моделей обучения к интерактивным и

цифровым образовательным технологиям с особым вниманием к положению Казахстана в глобальном научном пространстве и значению выявленных тенденций для дальнейшего развития национальной системы высшего образования.

Цель исследования выявить и систематизировать основные тенденции развития научных исследований современных форм организации учебного процесса в высшей школе за 2005–2025 гг., определить динамику публикационной активности, географическую и авторскую структуру научного поля, а также проследить тематическую эволюцию исследований от традиционных моделей обучения к интерактивным и цифровым образовательным технологиям с учетом положения Казахстана в глобальном научном пространстве.

Объект исследования научные публикации, посвященные современным формам организации учебного процесса в высшем образовании и индексируемые в международной базе данных Scopus за 2005–2025 гг.

Предмет исследования библиометрические характеристики, структура и тематическая эволюция научных исследований форм организации учебного процесса в высшей школе, отражающие переход от традиционных моделей обучения к интерактивным и цифровым образовательным технологиям.

Исследовательские вопросы:

RQ1. Как изменялись динамика публикационной активности и географическая структура исследований современных форм организации учебного процесса в высшей школе в 2005–2025 гг. и какое место в данном научном поле занимает Казахстан?

RQ2. Какие основные тематические кластеры сформировались в исследованиях современных форм организации учебного процесса в высшей школе и как их эволюция отражает переход от традиционных моделей обучения к интерактивным и цифровым образовательным технологиям?

Значимость исследования. Значимость исследования определяется комплексным рассмотрением научного поля современных форм организации учебного процесса в высшей школе, которое в существующей литературе преимущественно представлено отдельными направлениями, такими как blended learning, flipped classroom, active learning, e-learning, collaborative learning и цифровая трансформация образования. В отличие от исследований, ограниченных анализом отдельных образовательных технологий, библиометрическое картирование публикаций Scopus за 2005–2025 гг. позволит представить целостную картину двадцатилетней эволюции данного научного направления, выявить ведущих авторов, журналы и страны, структуру международного научного сотрудничества, ключевые тематические кластеры и изменение исследовательских приоритетов. Теоретическая значимость работы заключается в систематизации и структурировании накопленного научного знания о трансформации форм университетского обучения, тогда как практическая значимость связана с возможностью использования выявленных глобальных тенденций при развитии интерактивных и цифровых образовательных практик в высшей школе Казахстана. Сопоставление положения Казахстана с международной структурой исследований позволит определить степень его интеграции в глобальную научную повестку и перспективные направления дальнейших исследований и модернизации образовательных практик в национальной системе высшего образования.

Материалы и методы исследования

Исследование выполнено с применением библиометрического подхода, позволяющего систематизировать научные публикации и выявить основные тенденции развития исследований современных форм организации учебного процесса в высшей школе. В качестве источника библиографических данных использована международная база данных Scopus, обеспечивающая широкий охват рецензируемой научной литературы в

области социальных наук и образования. Временной диапазон исследования охватывал 2005–2025 гг., что позволило проследить двадцатилетнюю динамику развития научного интереса к интерактивным формам обучения в высшем образовании. Поиск осуществлялся по полям названия публикации, аннотации и ключевых слов с использованием комбинации основных понятий *“higher education” и “interactive learning”*. Итоговая поисковая стратегия имела следующий вид:

> *TITLE-ABS-KEY ("higher education" AND "interactive learning") AND (LIMIT-TO (SUBJAREA , "SOCI")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND PUBYEAR > 2004 AND PUBYEAR < 2026*

В выборку включались публикации, непосредственно относящиеся к проблематике высшего образования и интерактивного обучения, опубликованные на английском языке в формате научных статей и отнесенные в Scopus к предметной области Social Sciences (SOCI). Первичный поиск позволил идентифицировать 952 публикации. Последующий отбор осуществлялся поэтапно в соответствии с логикой PRISMA (см. рисунок 1).

На этапе предварительной фильтрации было исключено 267 записей, не соответствовавших установленным формальным критериям исследования, после чего для скрининга осталось 685 публикаций. В процессе анализа названий и аннотаций были исключены еще 184 работы как не соответствующие предметной направленности исследования, в результате чего 501 публикация была отобрана для дальнейшего рассмотрения. На этапе получения полных текстов 38 публикаций оказались недоступными, поэтому 463 исследования были подвергнуты оценке на соответствие критериям включения. После содержательной оценки были исключены еще 157 публикаций, и окончательный библиометрический массив составил 306 научных статей. Таким образом, от первоначально идентифицированных 952 документов к итоговому библиометрическому анализу было отобрано 306 публикаций. Критериями включения являлись: публикация в период 2005–2025 гг.; индексация в Scopus; принадлежность к предметной области Social Sciences; тип документа Article; английский язык публикации; непосредственная тематическая связь с высшим образованием и интерактивными формами организации обучения.

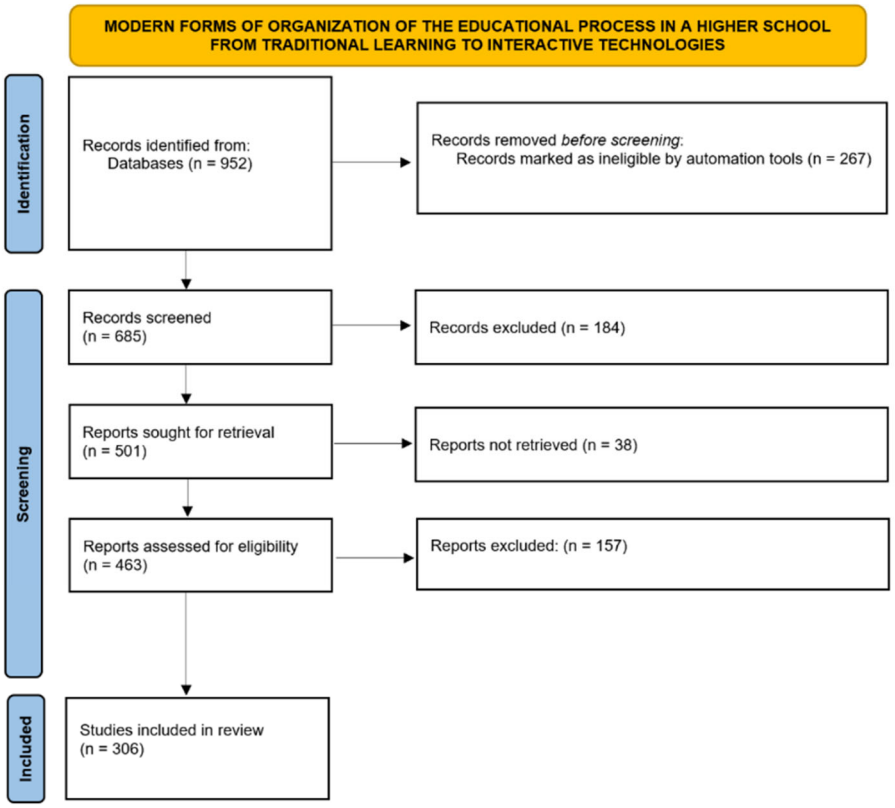


Рисунок 1. - PRISMA-схема отбора публикаций для библиометрического анализа

Критериями исключения выступали несоответствие тематике высшего образования, отсутствие содержательной связи с интерактивным обучением, исследования школьного, дошкольного или иного уровня образования без компонента высшей школы, публикации, в которых интерактивность рассматривалась исключительно в техническом или программном контексте без анализа образовательного процесса, а также документы, не соответствовавшие установленным ограничениям по типу публикации, языку, предметной области и временному периоду. Для библиометрического анализа итогового массива предполагается использование показателей годовой динамики публикационной активности, продуктивности авторов, распределения публикаций по научным журналам и странам, а также анализа международной структуры научного поля. Для выявления интеллектуальной и тематической структуры исследований применяется программное обеспечение VOSviewer, позволяющее построить сети совместной встречаемости ключевых слов (keyword co-occurrence) и визуализировать основные тематические кластеры.

Результаты и обсуждение

Библиометрический анализ научных публикаций, индексируемых в базе данных Scopus за 2005–2025 гг., позволил выявить основные тенденции развития исследований интерактивных форм организации учебного процесса в высшей школе. Особое внимание уделено динамике публикационной активности и цитирования, наиболее влиятельным

научным работам, а также представленности казахстанских исследований в международном научном пространстве (см. рисунок 2).

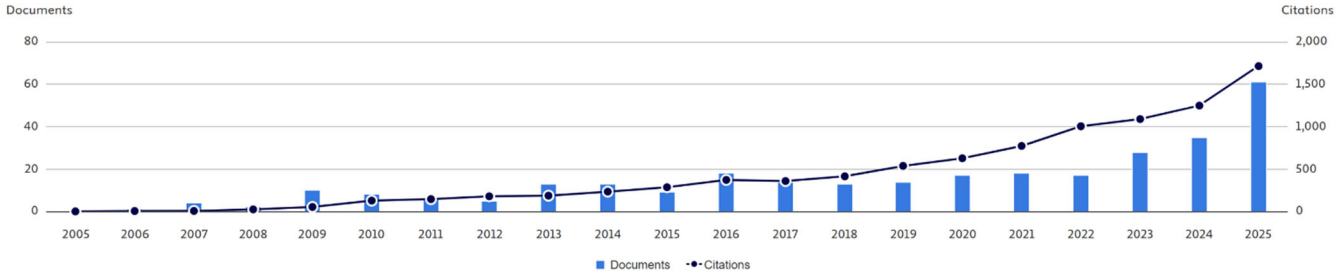


Рисунок 2. Динамика публикационной активности и цитирования исследований интерактивного обучения в высшем образовании, 2005–2025 гг.

В 2005–2012 гг. наблюдалась относительно низкая публикационная активность, что характеризует начальный этап формирования данного исследовательского направления. В 2013–2019 гг. отмечается постепенное увеличение количества научных работ, сопровождаемое ростом цитирования, что указывает на укрепление позиций интерактивного обучения в международном академическом дискурсе. Наиболее интенсивный рост приходится на 2020–2025 гг., когда ежегодное количество публикаций увеличилось приблизительно с 17 до 61, достигнув максимального значения за весь рассматриваемый период. Одновременно существенно возросло количество цитирований, превысившее 1500 в 2025 г. Выявленная динамика позволяет выделить три условных этапа развития научного направления: первоначальное формирование (2005–2012 гг.), устойчивое расширение (2013–2019 гг.) и ускоренный рост (2020–2025 гг.). Последний этап совпадает с периодом активной цифровизации высшего образования, распространения гибридных образовательных моделей и внедрения технологий искусственного интеллекта. Вместе с тем временное совпадение этих процессов не позволяет однозначно утверждать наличие причинно-следственной связи. В целом результаты свидетельствуют о возрастающей значимости интерактивных образовательных технологий в международной исследовательской повестке.

Далее в таблице 1 представлены десять наиболее цитируемых публикаций, отражающих основные направления развития интерактивных и цифровых образовательных технологий.

Таблица 1. Десять наиболее цитируемых научных публикаций в области интерактивного обучения в высшем образовании

№	Авторы	Название публикации	Год	Цитирования
1	*Chen Y., Wang Y., Kinshuk, Chen N.-S.*	Is FLIP enough? Or should we use the FLIPPED model instead?	2014	491
2	*McGill T. J., Klobas J. E.*	A task-technology fit view of learning management system impact	2009	452
3	*Jarmon L., Traphagan T., Mayrath M., Trivedi A.*	Virtual world teaching, experiential learning, and assessment: An interdisciplinary communication course in Second Life	2009	406
4	*Malik A. R., Pratiwi Y., Andajani K., et al.*	Exploring Artificial Intelligence in Academic Essay: Higher Education Student's Perspective	2023	398
5	*Schrire S.*	Knowledge building in asynchronous discussion groups: Going beyond quantitative analysis	2006	315
6	*Nouri J.*	The flipped classroom: For active, effective and increased learning – especially for low achievers	2016	309
7	*Cerezo R., Sanchez-Santillan M., Paule-Ruiz M. P., Nunez J. C.*	Students' LMS interaction patterns and their relationship with achievement: A case study in higher education	2016	304
8	*Dunn T. J., Kennedy M.*	Technology Enhanced Learning in higher education; motivations, engagement and academic achievement	2019	295
9	*Molinillo S., Aguilar-Illescas R., Anaya-Sanchez R., Vallespin-Aran M.*	Exploring the impacts of interactions, social presence and emotional engagement on active collaborative learning in a social web-based environment	2018	283
10	*Strobl C., Ailhaud E., Benetos K., et al.*	Digital support for academic writing: A review of technologies and pedagogies	2019	277

Примечание: составлено на основе данных Scopus

Анализ наиболее цитируемых публикаций показывает, что интеллектуальная структура исследований интерактивного обучения формировалась вокруг нескольких взаимосвязанных направлений. На ранних этапах значительное внимание уделялось использованию систем управления обучением, виртуальных образовательных сред и асинхронных коммуникационных технологий (Schrire, 2006; McGill & Klobas, 2009; Jarmon et al., 2009). В последующий период усилился интерес к педагогическим моделям, ориентированным на активное участие студентов в образовательном процессе, прежде всего к flipped classroom, collaborative learning и technology-enhanced learning (Chen et al., 2014; Nouri, 2016; Molinillo et al., 2018; Dunn & Kennedy, 2019). Наиболее цитируемой работой является исследование Chen et al. (2014), получившее 491 цитирование и посвященное совершенствованию модели перевернутого обучения. Особого внимания заслуживает исследование Malik et al. (2023), посвященное применению искусственного интеллекта в академическом письме, которое получило 398 цитирований, несмотря на

относительно недавнюю публикацию. Это свидетельствует о значительном научном интересе к интеграции интеллектуальных цифровых инструментов в университетское образование. Примечательно, что семь из десяти наиболее цитируемых публикаций представлены в журнале *Computers & Education*, что указывает на его значимую роль в развитии данного исследовательского направления.

Отдельное внимание в рамках библиометрического анализа уделено научным публикациям, связанным с Казахстаном. Их рассмотрение позволяет охарактеризовать основные направления национальных исследований и определить особенности представленности казахстанской научной повестки в международном академическом пространстве.

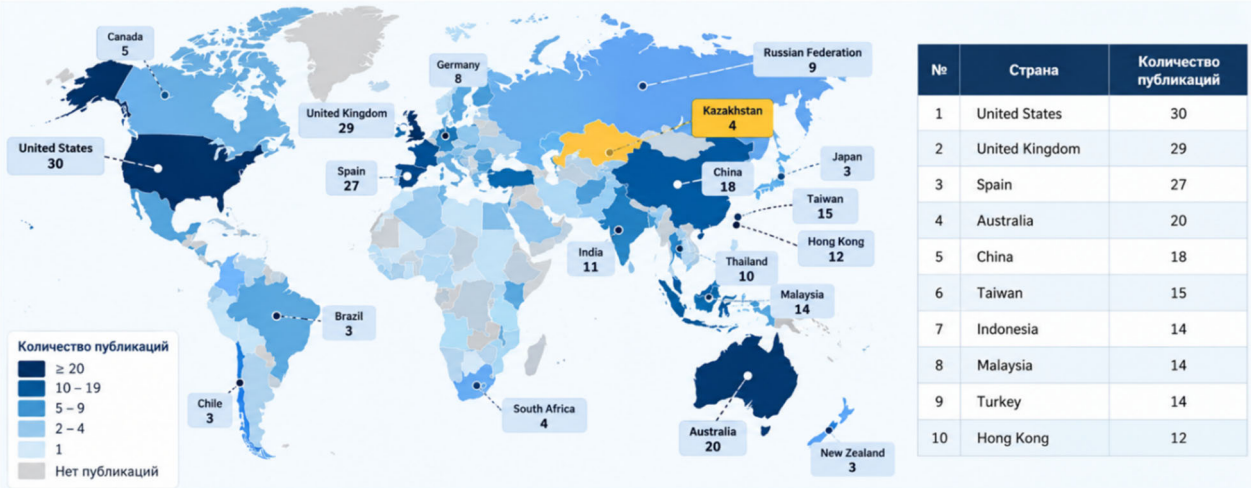
Таблица 2. Научные публикации, связанные с Казахстаном, в области современных образовательных технологий

№	*Авторы*	*Название публикации*	*Год*	*Цитирования*
1	Abishev N. K., Bidaibekov Y. Y., Dalinger V. A., Knyazyev O. V.	Higher education in Russia and Kazakhstan in modern condition	2016	39
2	Stambekova A., Zhakipbekova S., Tussubekova K., et al.	The model of pre-university training for people with disabilities in the system of inclusive higher education	2022	53
3	Aibekkyzy S. P., Atmaca T., Sarsenbaikyzy S. G., Kadyrovna S. K.	Pedagogical approaches to teaching soft skills in higher education contexts	2025	81
4	Kabassova K., Nyamsuren K., Miller A. D., Piven I., Kravtsov Y.	Innovative technologies and educational quality: Insights from Mongolia and Kazakhstan	2025	0
5	Seifullina B. S., Shokybayev Z. A.	Educational implications of incorporating contemporary interactive techniques into the curriculum	2024	0

Анализ представленных публикаций свидетельствует о тематическом разнообразии исследований, связанных с развитием высшего образования Казахстана. Наиболее ранняя работа Abishev et al. (2016) посвящена сравнительному рассмотрению состояния высшего образования России и Казахстана, тогда как последующие исследования демонстрируют расширение научного интереса к вопросам инклюзивного образования, развитию профессиональных компетенций и внедрению инновационных педагогических технологий. Исследование Stambekova et al. (2022), получившее 53 цитирования, рассматривает организационные и педагогические аспекты подготовки лиц с инвалидностью к обучению в системе инклюзивного высшего образования. Наибольшее количество цитирований среди представленных казахстанских публикаций имеет работа Aibekkyzy et al. (2025), посвященная педагогическим подходам к развитию гибких навыков студентов (81 цитирование). В свою очередь, исследования Seifullina и Shokybayev (2024), а также Kabassova et al. (2025) непосредственно затрагивают внедрение современных интерактивных методов и инновационных технологий в образовательный процесс. В целом представленные работы отражают постепенное расширение тематической направленности исследований высшего образования Казахстана: от общих вопросов организации университетского обучения к изучению инклюзивности, компетентностного подхода и

технологических инноваций. Вместе с тем ограниченное количество представленных публикаций не позволяет делать окончательные выводы о масштабах участия Казахстана в международном научном поле, что требует дальнейшего анализа географического распределения публикаций и международного научного сотрудничества.

Далее анализ географического распределения научных публикаций свидетельствует о неравномерной представленности стран в международном исследовательском пространстве интерактивного обучения в высшем образовании (рисунок 3).



№	Страна	Количество публикаций
1	United States	30
2	United Kingdom	29
3	Spain	27
4	Australia	20
5	China	18
6	Taiwan	15
7	Indonesia	14
8	Malaysia	14
9	Turkey	14
10	Hong Kong	12

Рисунок 3. Географическое распределение научных публикаций по проблематике интерактивного обучения в высшем образовании за 2005–2025 гг.

Лидирующие позиции по количеству публикаций занимают США (30), Великобритания (29) и Испания (27), за которыми следуют Австралия (20), Китай (18) и Тайвань (15). Значительная публикационная активность также наблюдается в Индонезии, Малайзии и Турции (по 14 публикаций), а также Гонконге (12), что свидетельствует о заметном участии стран и территорий Азиатско-Тихоокеанского региона в развитии данного научного направления. Среди европейских стран, помимо Великобритании и Испании, выделяются Германия и Португалия (по 8 публикаций), Нидерланды (6), Италия, Финляндия и Швеция (по 5). В Центральной Азии Казахстан представлен четырьмя научными публикациями, что указывает на его ограниченную, но фиксируемую представленность в международном научном поле. При этом по количеству публикаций Казахстан уступает ведущим странам, однако находится на одном уровне с Францией, Грецией, Южно-Африканской Республикой и Объединенными Арабскими Эмиратами (по 4 публикации). Полученные результаты демонстрируют концентрацию исследовательской активности в странах с развитой научно-образовательной инфраструктурой, одновременно указывая на расширение географии исследований за счет азиатских и развивающихся образовательных систем. В контексте Центральной Азии наблюдается ограниченная представленность научных исследований, посвящённых интерактивным формам обучения в высшем образовании. Казахстан является единственной страной региона, представленной в сформированной выборке Scopus (4 публикации), тогда как публикации из Узбекистана, Кыргызстана, Таджикистана и Туркменистана в исследуемом массиве не выявлены. Подобная географическая диспропорция свидетельствует о недостаточной представленности центральноазиатских стран в международном научном дискурсе по данной тематике и актуализирует необходимость расширения региональных исследований, международного академического сотрудничества и публикационной активности в области инновационных образовательных технологий. Следует учитывать, что количество публикаций характеризует научную продуктивность стран в пределах сформированной

выборки Scopus, но само по себе не отражает уровень внедрения интерактивных технологий или качество высшего образования в соответствующих государствах.

Анализ совместной встречаемости ключевых слов (co-occurrence analysis), проведённый с использованием программы VOSviewer, позволил выявить тематическую структуру научных исследований, посвящённых современным формам организации учебного процесса в высшем образовании.

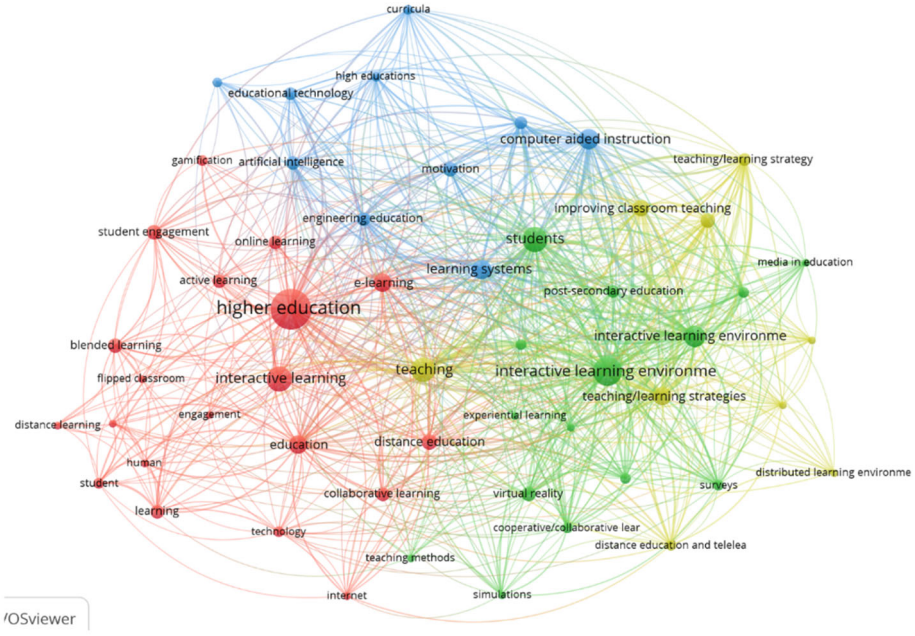


Рисунок 4. Сетевая визуализация совместной встречаемости ключевых слов в исследованиях современных форм организации учебного процесса в высшей школе

Как показано на рисунке 4, библиометрическая сеть включает 54 ключевых слова, объединённых в четыре тематических кластера, отражающих основные направления развития исследований в области интерактивного обучения и образовательных технологий. Визуализация демонстрирует высокую степень взаимосвязанности исследовательских направлений, что свидетельствует о междисциплинарном характере изучаемой проблематики. Центральное положение в сети занимают ключевые слова higher education, interactive learning, teaching, interactive learning environment и computer aided instruction, формирующие основные тематические узлы исследовательского поля. При этом размер узлов отражает частоту встречаемости соответствующих терминов, а линии между ними обозначают связи совместного использования ключевых слов в научных публикациях.

Первый кластер (красный), включающий 20 ключевых слов, характеризует исследования, ориентированные на внедрение интерактивных и цифровых форм организации образовательного процесса. Наиболее заметными элементами данного кластера выступают higher education, interactive learning, active learning, blended learning, flipped classroom, collaborative learning и student engagement. Центральное положение термина higher education и его многочисленные связи с другими ключевыми словами указывают на значимость высшего образования как основного контекста изучения интерактивных педагогических практик. Содержательно данный кластер объединяет исследования, рассматривающие переход от преимущественно преподавательско-ориентированных моделей к образовательным подходам, предполагающим активное участие студентов, совместную деятельность и использование цифровых инструментов. Присутствие терминов gamification, online learning и e-learning дополнительно подчёркивает интеграцию технологических решений в организацию учебного процесса.

Второй кластер (зелёный), состоящий из 15 ключевых слов, отражает исследования педагогических технологий и формирования интерактивной образовательной среды. Его тематическое ядро образуют понятия interactive learning environment, students, teaching methods, experiential learning, simulations и virtual reality. В отличие от первого кластера, ориентированного преимущественно на формы и модели обучения, второй кластер концентрируется на условиях, инструментах и методах реализации интерактивного образовательного взаимодействия. Наличие терминов, связанных с виртуальной реальностью, симуляционным обучением и экспериментальными образовательными практиками, свидетельствует о внимании исследователей к технологически опосредованным способам организации учебной деятельности. Значительное количество межкластерных связей указывает на тесную взаимосвязь педагогических методов с цифровыми образовательными технологиями и практиками вовлечения студентов.

Третий кластер (синий), объединяющий 10 ключевых слов, характеризует технологическое направление исследований, связанное с применением искусственного интеллекта и интеллектуальных образовательных систем. В его структуре представлены artificial intelligence, ChatGPT, computer aided instruction, educational technology, learning systems, curricula и motivation. Особое значение имеет присутствие искусственного интеллекта и ChatGPT, отражающее включение генеративных и интеллектуальных технологий в исследовательскую повестку высшего образования. Расположение данного кластера в верхней части сети и его связи с другими тематическими группами демонстрируют интеграцию технологических инноваций в существующие педагогические подходы. Вместе с тем представленная сетевая визуализация не позволяет самостоятельно установить хронологическую динамику появления данных направлений, для чего необходим дополнительный анализ временного распределения ключевых слов.

Четвёртый кластер (жёлтый), включающий 9 ключевых слов, объединяет исследования педагогических стратегий, оценивания образовательных технологий и совершенствования преподавания. Его основными понятиями являются teaching, teaching/learning strategies, improving classroom teaching, pedagogical issues и distributed learning environment. Данный кластер отражает методологические и организационно-педагогические аспекты трансформации учебного процесса, включая совершенствование методов преподавания, разработку стратегий обучения и оценку эффективности образовательных решений. Его расположение между технологическими и педагогическими тематическими группами свидетельствует о связующей роли исследований, ориентированных на практическое применение образовательных инноваций.

Таким образом, результаты кластерного анализа свидетельствуют о формировании четырёх взаимосвязанных тематических направлений, охватывающих интерактивные формы обучения, цифровую образовательную среду, интеллектуальные технологии и педагогические стратегии. Наиболее выраженным тематическим центром сети выступает высшее образование, вокруг которого группируются исследования интерактивного обучения и цифровой трансформации образовательного процесса. Полученные результаты позволяют заключить, что современное исследовательское поле характеризуется интеграцией педагогических и технологических подходов, при которой цифровые инструменты рассматриваются не только как вспомогательные средства преподавания, но и как компоненты организации образовательного взаимодействия. Вместе с тем наличие отдельных кластеров, связанных с искусственным интеллектом и педагогическим оцениванием, указывает на тематическую дифференциацию научных исследований и необходимость дальнейшего изучения взаимосвязей между технологическими инновациями, образовательными стратегиями и результатами обучения.

Заключение

Проведённое библиометрическое исследование позволило систематизировать основные тенденции развития научных исследований современных форм организации учебного процесса в высшей школе за 2005–2025 гг. На основе анализа 306 научных публикаций, индексируемых в международной базе данных Scopus, выявлены особенности динамики публикационной активности, географического распределения исследований, структуры научного цитирования и тематической организации исследовательского поля. Полученные результаты свидетельствуют о существенном расширении научного интереса к интерактивным образовательным технологиям и постепенном усложнении исследовательской повестки, охватывающей педагогические, технологические и организационные аспекты трансформации высшего образования. Анализ публикационной динамики позволил выделить три основных этапа развития данного научного направления: первоначальное формирование исследовательского поля в 2005–2012 гг., постепенное расширение в 2013–2019 гг. и ускоренный рост публикационной активности в 2020–2025 гг. Наиболее интенсивное увеличение количества исследований наблюдалось в последний период, когда ежегодное число публикаций достигло приблизительно 61 работы. Данная тенденция совпадает с активным распространением цифровых образовательных платформ, смешанных и дистанционных форм обучения, а также внедрением интеллектуальных технологий в университетскую образовательную среду. Анализ наиболее цитируемых публикаций показал значимость исследований, посвящённых перевёрнутому обучению, системам управления обучением, виртуальным образовательным средам и технологиям искусственного интеллекта, что отражает разнообразие концептуальных и технологических подходов к модернизации учебного процесса. Географический анализ выявил неравномерное распределение исследовательской активности между странами. Ведущие позиции занимают США, Великобритания и Испания, тогда как значительная часть научных публикаций также приходится на страны Азиатско-Тихоокеанского региона. Казахстан представлен четырьмя публикациями в сформированной библиометрической выборке, что свидетельствует об ограниченной представленности национальных исследований в международном научном поле по рассматриваемой тематике. При этом анализ казахстанских публикаций показал наличие исследовательского интереса к инклюзивному образованию, развитию профессиональных компетенций, инновационным педагогическим подходам и цифровым образовательным технологиям. Полученные результаты указывают на необходимость расширения международного научного сотрудничества и развития комплексных исследований трансформации форм организации университетского обучения в Казахстане.

Анализ совместной встречаемости 54 ключевых слов с использованием VOSviewer позволил выделить четыре тематических кластера: интерактивные и цифровые формы организации обучения; педагогические технологии и интерактивная образовательная среда; искусственный интеллект и интеллектуальные образовательные технологии; педагогические стратегии, оценивание и совершенствование преподавания. Выявленная структура демонстрирует тесную взаимосвязь педагогических моделей и технологических инноваций, а также формирование исследовательских направлений, ориентированных на активное участие студентов, персонализацию обучения и развитие цифровой образовательной среды. Особое значение приобретает интеграция искусственного интеллекта в образовательный процесс, расширяющая возможности разработки и применения интерактивных методов преподавания. Таким образом, результаты исследования позволяют рассматривать трансформацию форм организации учебного процесса в высшей школе как многокомпонентный процесс, в котором развитие интерактивных педагогических подходов сопровождается расширением цифровых и

интеллектуальных образовательных технологий. Научная значимость исследования заключается в систематизации международного исследовательского поля и выявлении его основных тематических направлений, тогда как практическая значимость связана с возможностью использования полученных результатов при совершенствовании образовательных стратегий университетов Казахстана. Вместе с тем исследование имеет ограничения, обусловленные использованием исключительно базы данных Scopus, включением англоязычных научных статей предметной области Social Sciences и применением конкретной поисковой стратегии, что не позволяет охватить весь спектр исследований современных образовательных технологий. Перспективы дальнейших исследований связаны с расширением библиографических источников, проведением сравнительного анализа национальных образовательных систем и изучением влияния интерактивных и интеллектуальных технологий на образовательные результаты, вовлечённость студентов и качество университетского обучения.

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Developing Creative Thinking in Primary School through Guided Digital Project Design with HOPPER APP PASSPORT

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Abstract

This practice-oriented conceptual paper presents an adaptation of HOPPER APP PASSPORT for project design in primary education. The supplied interface combines an idea laboratory, a mentor pathway, a screen studio, a testing space and a project passport. The proposed classroom model uses these elements to help pupils in Grades 3–4 identify a familiar problem, consider alternative solutions, organise a simple application concept, test a paper prototype and explain a revision. English-language interface adaptations accompany the paper as product illustrations. The model prioritises pupil explanations and teacher mediation rather than technical complexity. A four-lesson sequence, an illustrative project passport and an assessment rubric make the approach usable in classroom planning. No participant dataset or intervention outcomes were supplied; therefore, the paper reports a pedagogical design and a proposed evaluation procedure, not demonstrated effectiveness. The central proposition is that a project passport can make the development of an idea visible when it records the pupil's decisions, feedback and revisions.

Keywords: primary education; creative thinking; project-based learning; digital project design; HOPPER APP PASSPORT; teacher-mediated AI; formative assessment.

Introduction

Primary pupils regularly encounter problems that can become meaningful design tasks: remembering classroom jobs, choosing a book, sorting waste or caring for a plant. These situations offer opportunities to connect language, mathematics, environmental learning and digital literacy. Yet a pupil's first idea may remain a short statement such as "I want to make a game." The educational challenge is to help the child explain who the idea is for, what it should do and how another person would use it.

HOPPER APP PASSPORT provides a visual starting point for this work. In the supplied screenshots, the product invites users to write an idea, develop it through questions and obtain a passport. Its dashboard displays "My idea," "AI mentor," "Screen studio" and "Testing space." A separate screen offers an independent template or a mentor pathway. These visible elements suggest a structure for classroom design activities; they do not establish the application's technical functionality or educational impact.

The aim of this paper is to propose a developmentally appropriate teaching model for using that structure in Grades 3–4, approximately ages 8–10. The guiding question is: How can a teacher use a digital project passport to support pupils in explaining, testing and improving an application idea? The contribution is a concrete instructional sequence with pupil-facing questions, a worked project example and criteria for examining the resulting learning artifacts.

Pedagogical foundation

The proposed approach treats creativity as a process that can be discussed and documented. Pupils generate possibilities, select a useful option and reconsider it after feedback. A visually attractive screen can invite participation, but the teacher needs evidence of the reasoning behind

it. Project Zero's Visible Thinking work provides a relevant foundation for documenting how learners develop ideas (Project Zero, n.d.-b). In this model, initial sketches, short explanations and revision notes perform that documenting function.

A teacher can begin with the See, Think, Wonder routine: pupils observe a classroom situation, explain their interpretation and ask a question that deserves investigation (Project Zero, n.d.-a). For example, they may notice that books are returned to the wrong shelf and wonder how classmates could find the correct place. This creates an understandable purpose before any application screens are drawn.

The design activity can remain on paper or lead to a simple digital prototype. Scratch provides an age-relevant optional route because it is designed especially for learners aged 8–16 (Scratch Foundation, n.d.). However, pupils do not need to code to demonstrate clear project thinking. A paper screen with labelled buttons and a peer acting as the user can reveal whether the proposed sequence makes sense.

AI support requires a separate teaching decision. UNESCO (2023) recommends human-centred and age-appropriate approaches to generative AI in education. For the primary-school model proposed here, the mentor pathway is teacher-operated or implemented with prepared question cards. The child remains the source of the project idea. The adult checks any generated prompt, avoids sharing personal pupil information and accepts or rejects suggestions according to the lesson objective.

Materials and design method

The materials consist of one character illustration, three supplied application screenshots and a cropped author-name reference. The character and application screenshots inform the product illustrations; the name reference identifies the author. The educational content is designed from these visible materials. No source code, verified user interaction logs, classroom observations, consent records or test scores were available.

The design method has four stages. First, the visible interface is reviewed to identify the learning functions it suggests. Second, each function is translated into an age-appropriate classroom action. Third, a six-part project passport and a four-lesson sequence are proposed. Finally, assessment criteria are specified so that future classroom implementation can be examined through pupil artifacts and observations. The six passport fields below are an instructional adaptation, not a claim about the exact fields implemented in the original application.

The educational product

The adapted product is an English-language planning environment for young learners. The entry screen states "Turn your idea into an app" and offers a short progression from writing an idea to obtaining a passport. The dashboard provides access to planning, mentoring, screen design and testing. The choice screen supports two routes: pupils who can already explain their concept use a blank template, while pupils who need support respond to one question at a time. Both routes should produce the same planning artifact.

The proposed passport contains six fields: project name, problem and users, intended benefit, three main actions, screen plan, and test and revision. Pupils may write, dictate, draw or combine these forms. A teacher can add the child's spoken explanation without replacing its meaning. For a younger group, the fields can be completed across several lessons; for a more confident group, the teacher can reduce prompts and ask for alternative solutions.

The illustrated mentor is a Grace Hopper-inspired fictional guide. It can introduce curiosity about computing, but the article does not treat its dialogue as historical quotation. The guide's educational role is to ask manageable questions such as "Who will use your idea?" or "What happens after this button is pressed?" It should not supply an entire project that the pupil copies.

An illustrative pupil project

The following example is a teaching model, not a record of an actual pupil's work. The project is called Plant Helper. Its users are pupils responsible for the classroom plant. The problem is that the class sometimes forgets to check the soil, while watering without checking can also be unsuitable. The intended benefit is to make the care routine easier to remember and explain.

Its three main actions are "Choose today's plant helper," "Check the soil" and "Record the care decision." A paper prototype has a home screen, a checking screen and a class record screen. The checking screen asks the user to observe whether the soil feels dry or damp with teacher guidance. The application concept records the observation rather than independently prescribing watering. Plant-specific care remains the teacher's responsibility.

In a simulated peer test, one pupil follows the drawn screens while another moves between pages. The class asks whether the next action is clear and whether the buttons communicate their purpose. An example of a possible revision is changing a vague "Go" button to "Record my observation." This example illustrates how a small design change can be explained with a reason. It is not an empirical finding.

A four lesson classroom sequence

Lesson one Observe and choose

In a 35–40 minute lesson, the teacher introduces a familiar classroom problem and invites pupils to describe what they notice. Pairs suggest at least two possible solutions and choose one to investigate. The teacher records the initial idea in the pupil's own words. The exit response answers "Who needs this idea, and why?" The expected artifact is a problem statement with a first sketch.

Lesson two Build the passport

The teacher models one passport field, then pupils develop the first four fields in pairs. They use either the independent route or prepared mentor questions. A pupil who gives a broad answer such as "for everyone" is asked to identify one realistic user. The teacher checks that the proposed actions relate to the problem. The expected artifact is a draft passport and a short explanation of the selected solution.

Lesson three Draw and test

Pupils draw two or three screens with large labels and clear actions. Each pair exchanges its prototype with another pair. The user follows a small task without an explanation from the designer; the designer notes questions and points of confusion. Feedback uses two prompts: "I understood…" and "I needed help with…". The expected artifacts are a screen sequence and a brief test note.

Lesson four Revise and explain

Each pair selects one change supported by the feedback, updates the passport and presents the before-and-after design. Pupils explain "We changed… because…". The teacher compares the initial idea with the final artifact and discusses what remains to be tested. The completed passport, screen sequence and revision explanation form a compact project portfolio.

Assessment and proposed evaluation

Assessment focuses on the quality of decisions rather than the polish of the illustration. Four dimensions are proposed: clarity of the problem and user, consideration of alternatives, coherence of the action sequence, and revision based on feedback. Each dimension uses three levels: emerging, developing and independent. "Independent" means that the pupil can explain the decision with limited prompting; it does not require independent use of an AI service.

For problem clarity, an emerging response names a broad topic, a developing response identifies a user or need with support, and an independent response connects a specific user to an observable problem. For alternatives, the progression runs from a single unsupported idea to two ideas with prompting and then to a reasoned comparison. For sequence coherence, it runs from

disconnected actions to a partly understandable sequence and then to a sequence a peer can follow. For revision, it runs from a cosmetic change to a change linked to feedback and then to a clear explanation of why that change improves use.

A future pilot could collect initial and final passports, prototype pages, peer feedback and brief teacher observations. The teacher should document how much support each pupil receives and retain anonymised examples. Comparing artifacts within each pupil's portfolio can indicate changes in explanation quality. It cannot, by itself, establish that HOPPER caused those changes. A comparison condition, a defined scoring procedure and independent scoring checks would strengthen a later evaluation.

Design results and expected learning evidence

The results of this work are instructional design outputs: a six-field passport, a four-lesson sequence, translated product visuals and an assessment framework. Table 1 connects each intended learning outcome to evidence that a teacher could collect. These outcomes are expectations for implementation, not measured gains. No pupil sample or pre-test and post-test dataset is reported.

Table 1. Expected learning outcomes and observable evidence

Dimension	Expected outcome	Evidence to collect
Problem definition	Identifies a familiar need and a specific user.	Initial and final problem statements; oral explanation.
Creative alternatives	Proposes two possible solutions and explains a preference.	Two sketches and a recorded reason for selection.
Planning	Connects the problem to three useful actions.	Completed passport fields and action sequence.
Digital communication	Uses clear screen labels and understandable navigation.	Two or three paper screens; peer task notes.
Feedback and revision	Changes a feature in response to a user difficulty.	Before-and-after screens with a reason for the change.
Learner agency	Explains which ideas were chosen and what support was used.	Pupil reflection and teacher support log.

The passport makes assessment possible by preserving decisions across stages. A filled field is evidence of completion, but not necessarily evidence of understanding. The teacher therefore asks the pupil to explain one decision and records the support provided. A successful lesson artifact combines an understandable design with a reasoned account of how it developed.

Analytic rubric for project portfolios

Table 2 provides a proposed scoring instrument for future classroom use. Score each dimension from 1 to 3 using the pupil's portfolio and explanation. The total range is 4–12. These are rubric levels, not observed pupil scores; a higher total should not conceal a difficulty in one dimension.

Table 2. Proposed rubric for Grades 3–4

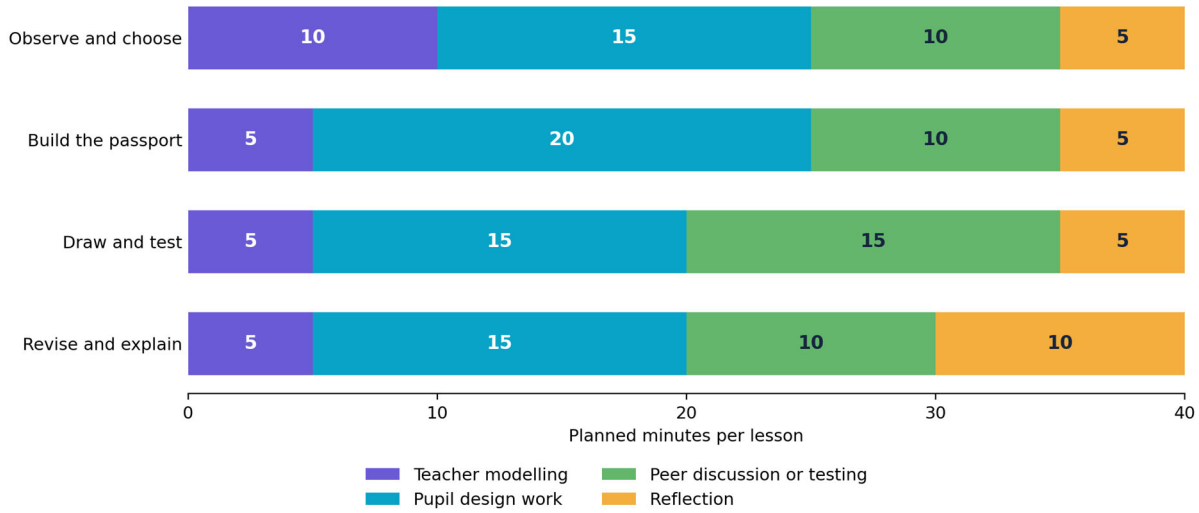
Criterion	1 Emerging	2 Developing	3 Independent
Problem and user	Names a topic without a clear need.	Identifies a need or user with prompts.	Connects a specific user to an observable need.
Alternatives	Offers one idea without a reason.	Suggests two ideas with support.	Compares two ideas and justifies a choice.
Action sequence	Actions are disconnected or unclear.	Sequence is partly usable with guidance.	A peer can follow the intended sequence.
Evidence based revision	Makes no change or a cosmetic change.	Links a change to feedback with prompts.	Explains how the change addresses a test difficulty.

Use the same criteria on an initial draft and a final portfolio, with equivalent opportunities to explain. Record teacher assistance separately. Report scores by dimension as well as totals, and retain examples that justify each rating. For a research study, independent second scoring and an explicit procedure for resolving disagreements would improve transparency.

A suitable reporting table for a later pilot would contain the number of pupils assessed, initial and final scores, missing artifacts and the level of adult support. Numerical gains should be added only after actual classroom collection. No numerical improvement is inferred from the interface screenshots.

Visual model of the lesson sequence

Figure 1. Proposed allocation of learning activities across four 40-minute lessons



Note. Author-designed schedule for classroom planning. Each bar totals 40 minutes. The figure does not show measured engagement, achievement or experimental results.

The visual model gives the largest share of lesson time to pupil work and opportunities to discuss or test ideas. Modelling is more prominent at the beginning; reflection receives extra time in the final lesson so pupils can explain the revision. Teachers can adjust these allocations to class size, language needs and access to devices.

The design links observation and inquiry to the See, Think, Wonder routine (Project Zero, n.d.-a), and connects portfolio documentation to Visible Thinking (Project Zero, n.d.-b). For pupils ready to implement a simple screen sequence, Scratch is an optional extension (Scratch Foundation, n.d.). These sources inform the instructional choices; they do not validate the effectiveness of HOPPER.

Discussion

The proposed model connects a digital product concept to a manageable classroom process. Its main pedagogical value is the possibility of revisiting the same idea at different stages. A pupil can compare the original problem statement with the screen plan and see whether a revision responds to a user's difficulty. This links creative generation with purposeful improvement.

Differentiation is central. Pupils who find extended writing difficult can draw or dictate, while pupils ready for greater challenge can compare two screen arrangements or build a simple Scratch prototype. The independent and guided routes should differ in the amount of support, not in the status of the learner. English interface labels can be introduced alongside the class's teaching language; the article's publication language should not create an unnecessary barrier to pupil participation.

The supplied screens contain an AI mentor label, but a screenshot cannot show whether the mentoring service is functional, what model it uses or how data are handled. The classroom procedure therefore remains usable with teacher questions and printed templates. The adapted English images are product visualisations, not evidence that an English version has been deployed or tested.

Conclusion

HOPPER APP PASSPORT can serve as the organising concept for a primary-school project design activity in which pupils move from a familiar problem to an explainable plan, a simple prototype and a justified revision. The paper provides a teacher-mediated adaptation for Grades 3–4, supported by an illustrative passport, four lessons and artifact-based assessment criteria. Its

proposed benefit is making pupil decisions visible. Classroom effectiveness remains a question for future evaluation with actual learner evidence.

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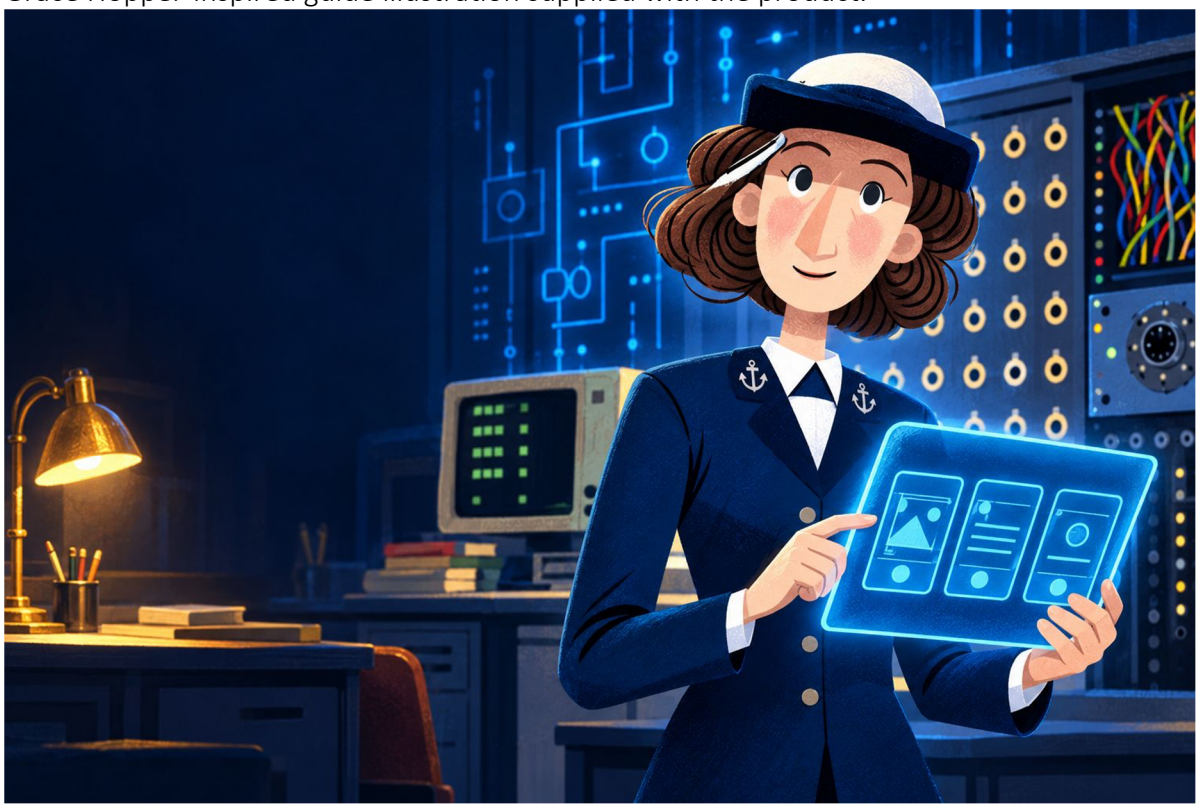
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Product illustration 1

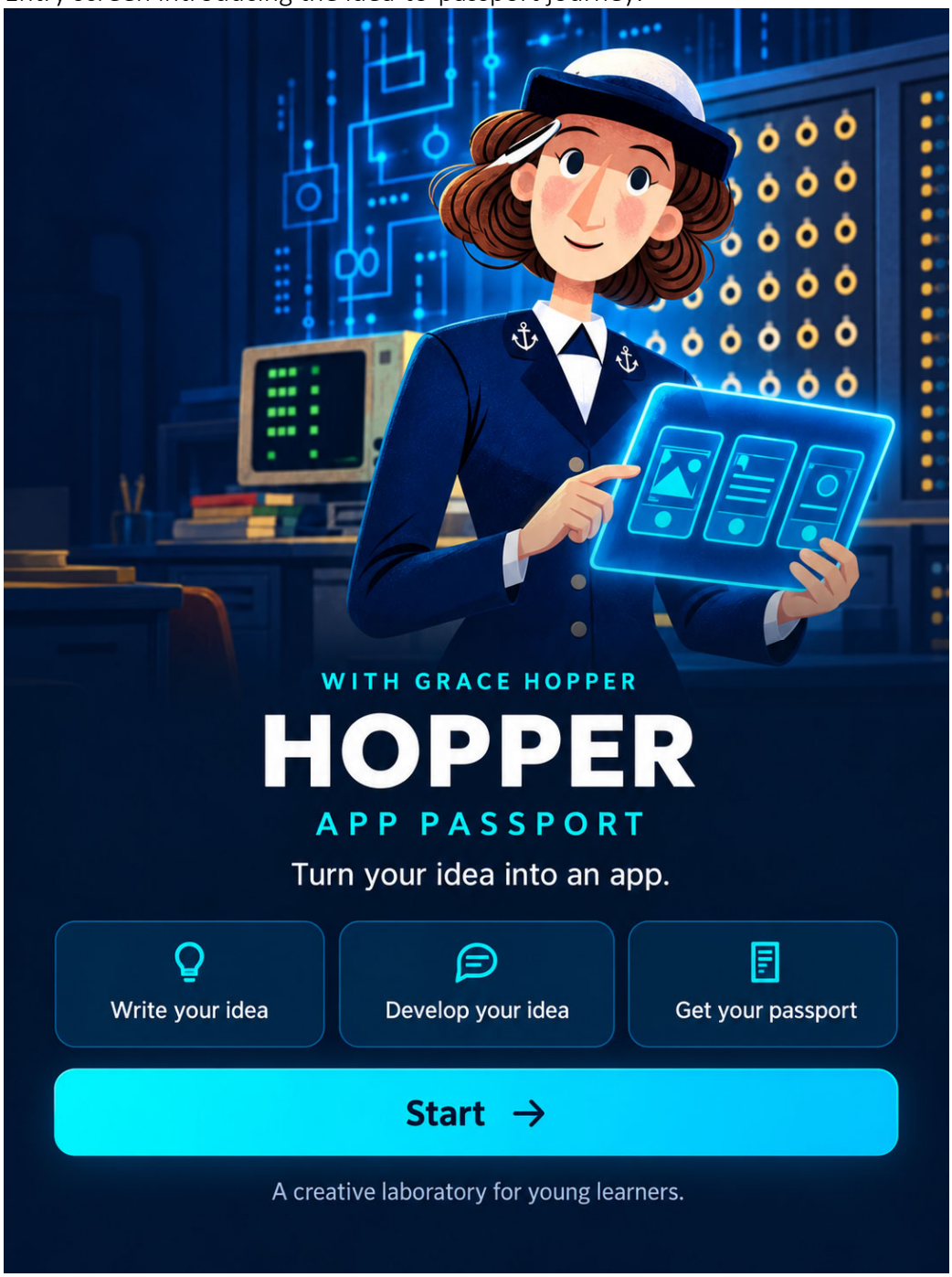
Grace Hopper-inspired guide illustration supplied with the product.



English-language adaptation of the supplied product visual. Illustration only; classroom use and application functionality were not independently tested.

Product illustration 2

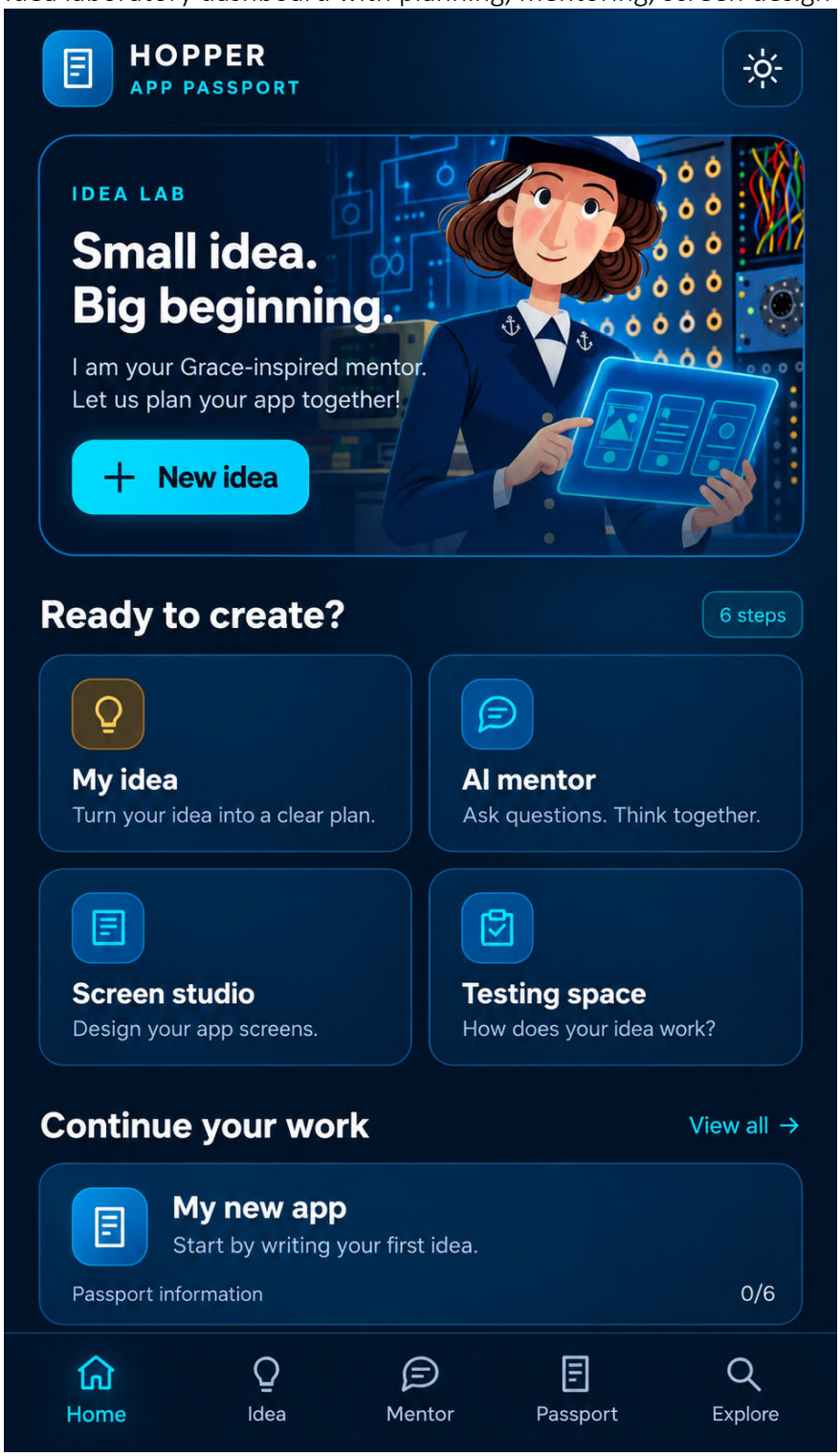
Entry screen introducing the idea-to-passport journey.



English-language adaptation of the supplied product visual. Illustration only; classroom use and application functionality were not independently tested.

Product illustration 3

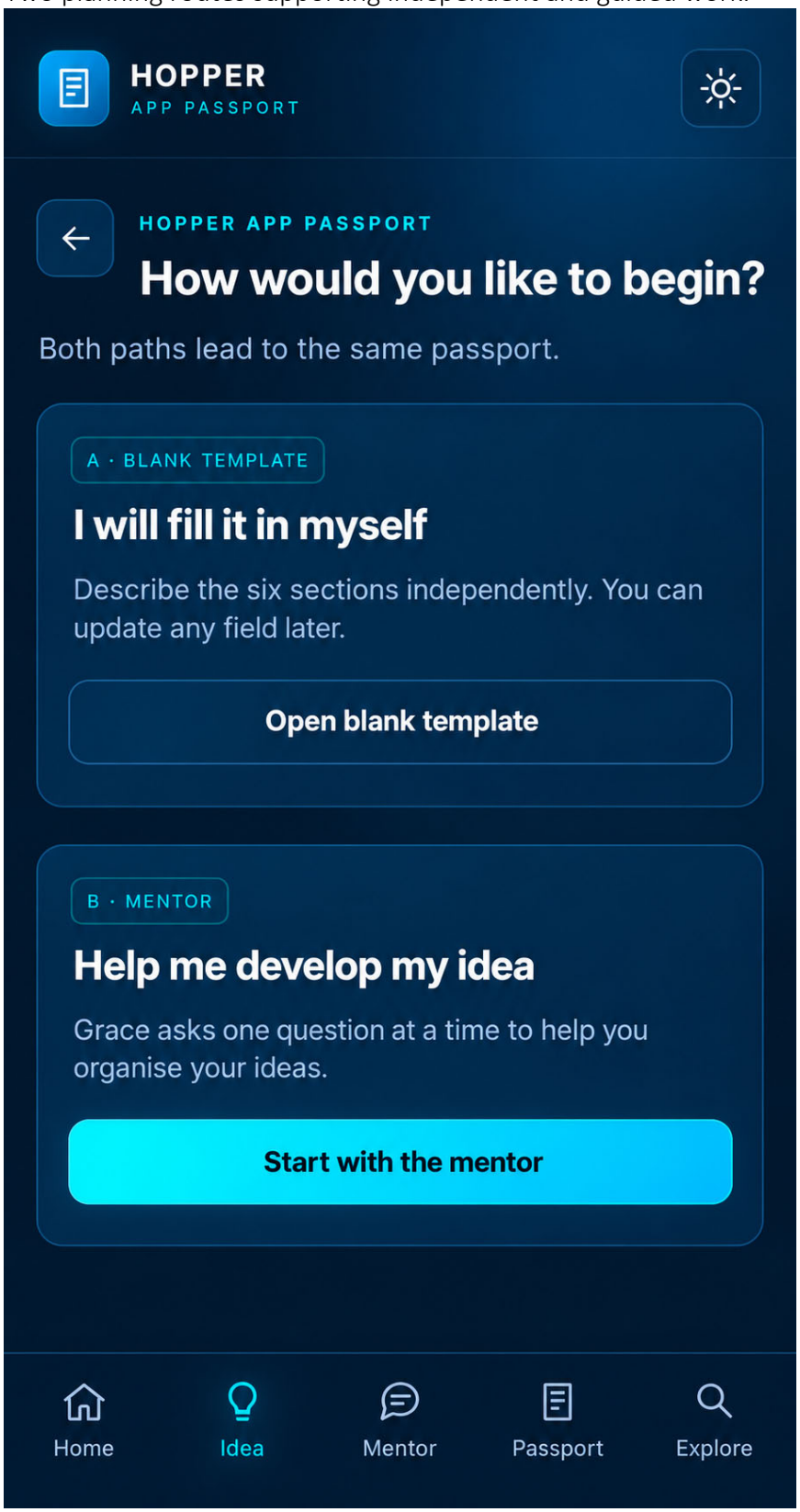
Idea laboratory dashboard with planning, mentoring, screen design and testing.



English-language adaptation of the supplied product visual. Illustration only; classroom use and application functionality were not independently tested.

Product illustration 4

Two planning routes supporting independent and guided work.



English-language adaptation of the supplied product visual. Illustration only; classroom use and application functionality were not independently tested.

Economic Sciences

International Discussions on Government Securities and Their Practical Purpose

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(abstract)

In this research we have examined government securities beyond the headline size of public debt. It argues that a bond's real value (adjusted for inflation) and market price (which moves inversely with interest rates) matter more than its face value. Its central question is how public debt affects the economy, which hinges on whether citizens anticipate the future taxes needed to repay it (Ricardian equivalence). Where they do not (incomplete equivalence), debt financing makes people feel wealthier and spend more, but a later tax rise reduces welfare. The paper therefore recommends issuing securities mainly during recessions to stimulate recovery, while noting that political misuse and the future tax burden are the trade-offs, with the Reagan-era and post-2007 U.S. debt growth as examples.
Keywords: Government debt, Ricardian equivalence, Bond’s yield, taxation, budget deficit

International Discussions on Government Securities and Their Practical Purpose

The size of public debt is a subject of particular interest in world society. Aggregate public debt is the sum of government securities individually issued by all kinds of state bodies. This figure is often published in the mass media and discussed in various television or political debates; however, a bare total figure is not very informative unless it is refined.

The refinement concerns, first of all, inflation. A bond's face value is the amount that will be paid when the bond is redeemed. This amount is known to the buyer of the bond from the outset. However, the real value of a bond is the sum of the units of goods and services that can be purchased with that bond in a given period. The face value of a bond is fixed and does not change along with changes in the inflation rate, although its real value changes from day to day.

Thus, a member of society who holds a government security is interested in its real, not its nominal, purchasing power.

A second important refinement concerns changes in the interest rate. The price of a debt bond in circulation changes along with changes in the market interest rate. The market price of a bond reacts instantly to changes in the interest rate, and a bond's face value can differ considerably from its market price (Butkiewicz 1983: 373). To illustrate this, suppose a citizen has purchased a one-year treasury bond worth GEL 5,000 (that is, they have lent the state GEL 5,000).

The bond carries an annual yield of 10 percent, which is expressed as receiving GEL 500 in interest at the end of each year. A few days after the purchase, the National Bank of Georgia makes a decision that causes the yield on new bonds similar to yours, to be issued subsequently, to fall to an annual rate of 9 percent. That is, your bond enjoys a greater privilege, because it still brings you an annual yield of 10 percent, instead of the 9 percent yield of the newly issued bonds. This gives us a logical and rational opportunity to sell the bond we hold at a price higher than GEL 5,000. The reason for this is the interest yield, since the new bond brings only GEL 450 of annual yield, instead of the GEL 500 of income brought by the asset we hold.

In this regard, the revaluation of previously issued bonds in light of the realities existing in the market causes the price of this debt instrument to rise or fall, depending on the specific financial situation. If the interest rate on a bond falls, this means that the price of an existing (previously issued) bond carrying a higher interest income rises, whereas if the opposite happens, the price of previously issued bonds falls. In this regard, the difference between market value and face value is expressed in the size of the interest rate. Unfortunately, complete information on securities issued by most states is not available in a timely manner to the broad investing public, because, as international practice shows, most states do not disclose this information, and it is not adequately reflected in the financial and economic literature (newspapers, journals) (Butkiewicz 1983: 373).

More important than the size of public debt is the influence that public debt has on the economy of a given country. There is no consensus among economists on this. When the state borrows money, it promises to repay it. To ensure this repayment (or repayments), the state raises taxes (if it needs to) in order to pay this debt along with many other current payments. In this regard, the economic outcome is largely determined by how the taxpayer perceives this future tax. Measuring this perception is extremely difficult, and neither economists nor practitioners of any other profession can construct an exact and realistic formula for tax perception.

To assess this phenomenon, let us consider a hypothetical example. Suppose the state purchases GEL 100 billion worth of goods and services every year. It makes this payment by collecting taxes, paid by households located in the territory of Georgia. With the funds received, the state purchases goods and services. There is equality here: revenue equals expenditure, and the state budget is balanced. Now let us imagine that the state decided to change the existing method of financing expenditure, while keeping the total amount of expenditure unchanged.

Suppose that in the first year the state reduces tax by GEL 10 billion and fills the reduced revenue portion by placing an issue of GEL 10 billion in government bonds, with an interest rate equal to 10 percent and a maturity equal to 1 year. In the following year this bond is redeemed, and the state is obliged to pay GEL 10 billion in principal, to which is added GEL 1 billion in interest. The tax in the first year is GEL 10 billion lower than the usual level, but in the second year the tax is GEL 11 billion higher. The main question here is what effect this temporary shift of the tax has on the population. In the first year, the population is wealthier, because it has to pay less tax. However, in the second year the population has to pay off a tax increased by GEL 11 billion, which is equal to the amount received by the population plus the interest received back on it. That is, the state receives funds in the form of a loan, to pay off which it raises tax. This approach is valid for a bond of any maturity, whether it is 1-year, 10-year, or an indefinite perpetuity.

Thus, the decisive factors are time and the population's level of awareness on this issue: how far it is able to determine the consequences that financing the economy through bond borrowing produces. If every member of society realizes that the future tax will cancel out the principal of the loan to be received and the interest accrued on it, then in this case the interest rate on the bond will become equal to the size of the tax rate. In such a situation public debt will no longer have any effect at all. This hypothesis is known as Ricardian equivalence (Seater 1993: 142), whose

author is the well-known economist David Ricardo. Ricardo was the first to examine this issue (Ricardo 1820).

If society does not take into account all future taxes arising from public debt, then people feel wealthier when the debt is issued and feel poorer in the future, when unexpectedly they must pay increased taxes in order to finance the principal and accrued interest of government bonds (Seater 1993: 142).

In this regard, the population's expectations are of primary importance. Unfortunately, as international discussion also attests, there is no reliable way to establish people's expectations about future taxes. Thus, a number of international researchers have used other methods to clarify the influence of public debt on the economy.

Research on this issue has been under way since the 1950s, although to this day no consensus has been reached among economists.

In principle it is possible to measure the influence of debt on economic activity, although reflecting this relationship in practice is quite difficult. The general view among economists favors Ricardian equivalence. If public debt is equivalent to the amount of tax, then in this case discussion of the so-called "deficit problem" by society is, in most cases, pointless. The concept of full equivalence implies that the state budget deficit only shifts the amount of tax in time, and by an amount such that every member of society is able to foresee this development and offset their position accordingly. If this is the case, no significant economic changes or consequences will occur (Seater 1993: 142). Under conditions of incomplete equivalence (Barro 1989: 37), the deficit does have an effect on the economy, although the consequence is difficult to foresee. According to the research of Butkiewicz, James L., Seater, John J., and Barro, Robert J., when making decisions the population does not factor in the introduction of a new tax or the increase of an existing one, despite the current deficit that exists in reality. In such a situation, if at the initial stage part of the tax amount is replaced with a government loan, this will create a feeling in society that current life has improved and that the population's income has increased. This hypothesis is accompanied by a rational decision: members of society begin to spend more money. However, the ultimate result will be that the state must collect tax in an amount sufficient for the state to repay the existing debt in full, together with the interest accrued on it.

Here there will be a surprise effect: since society did not expect the tax increase, each member will have to reduce expenditure regardless of when the tax is actually paid.

The conclusion that can be drawn in light of the above factors is as follows:

Filling the state budget through the issuance of government securities affects economic agents not only at the time of issuance but also in the subsequent period. This is a result of expectations. Moreover, it is quite difficult to forecast the size and duration of this phenomenon.

On the basis of this conclusion, the following recommendations can be developed:

A targeted issuance of government securities is needed, both under conditions of a state budget deficit and of a surplus, in order to ensure short-term and long-term stable economic growth. If Ricardian full equivalence holds, that is, if the deficit and the amount of tax are equal to one another, then any hypothesis of this kind is pointless, because this situation by its very nature rules out the need for a long-term and influential public debt.

The above-mentioned Ricardian condition of incomplete equivalence (Seater 1993: 142) has a direct and significant effect on economic processes and on people's standard of living. The main consequence of this disproportion is the state budget deficit. The theoretical aspect discussed and the practical scenario allow us to draw the following conclusion:

The issuance of government securities, and thereby the filling of the state budget deficit, is needed precisely when the economy is experiencing an economic downturn and an economic crisis. This view rests on the idea that the resources obtained through the issuance of government securities

will cover the tax revenue reduced during the period of economic decline and, moreover, may allow a reduction of the tax rate, which will ease the economic situation of the broad population. This approach also has a second, additional positive side: it will create a situation in which the broad strata of society feel wealthier and begin to spend more. The purpose of increased spending in the economy is to raise economic activity, revive business, and emerge from the economic crisis. This situation is accompanied by problems that might be called a "side effect." One such problem lies in the fact that, at the time government securities are issued, society and each of its members cannot perceive the future tax increase that will be used to redeem the current issue (Barro 1989: 37).

Accordingly, when taxes are reduced and the state budget deficit is filled through the issuance of government securities, society feels (and in reality is mistaken in this feeling) that it has become better off.

A new logical chain is added to the hypothesis presented: public debt, the deficit, and bringing the economy out of crisis are macroeconomic and political issues. Accordingly, influencing these issues and misleading society (improving today's everyday situation in exchange for paying increased tax in the future) often becomes the basis for political speculation and shifts in political trends. A notable example of this in the world is the economic policy pursued by U.S. President Ronald Reagan, during which U.S. public debt rose sharply, yet from 1980 to 1988 the population felt greater prosperity and paid less tax (public debt was long-term). An analogous phenomenon occurred in 2007–2012, when U.S. public debt grew on average by USD 1 trillion annually and reached a total of USD 16.7 trillion, while according to the latest data it exceeds USD 40 Trillion (US Treasury Data, http://www.treasury.gov/resource-center/data-chart-center).

The growth of public debt and the reduction of tax brought the U.S. economy out of the crisis, but in the near future the U.S. population will have to become acquainted with the negative side of this process: alongside the economic upturn, taxes will rise, which will be an event with an unexpected consequence (Ricardian incomplete equivalence) that will reduce the welfare of society.

Thus, incomplete equivalence causes the composition of the outstanding loan structure and the interest rate to change in the same direction. For example, during a recession the economy experiences a rise in the interest rate. This, in turn, reduces investment and economic growth. The result of this is a decline in the overall level of production. In such a situation, government bond policy and state policy should consist of steps in the opposite direction: the interest rate should be reduced, the issuance of government securities should be increased, and through the implementation of government investment the tendency of economic recession in the economy should be reversed toward economic growth. That is, the deficit is used to stimulate the economy in the existing crisis reality, in order to improve production indicators and halt the decline, although the price of this is paid in the form of increased taxes during the period of upturn.

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The Nature of Government Securities and its Origin

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(abstract)

In this research, we have studied the nature and the origin of a government security paper as tradable debt instrument issued by a national government to borrow money from investors. As a rule it is a formal promise to repay the principal at a fixed maturity date. Because it is backed by the government's taxing and borrowing power, it is generally regarded as low-risk and useful instrument to cover budget deficit, stimulate economic growth, but also may create financial instability and risk of default.

Keywords: Government debt, deficit, treasury securities, economic growth, default, bond

The Nature of Government Securities and its Origin

Government debt represents one of the macroeconomic parameters, objects, and instruments of a state's economic policy. The existence of government debt can have both positive and negative effects on the real, financial, and other sectors. The positive effect of debt is manifested in providing the government with financial resources and stimulating economic growth, while the negative consequence is the transfer of obligations to future generations. In this regard, government debt management is the development and implementation of a strategy aimed at raising the necessary volume of financing and achieving desired debt parameters — such as risk, cost of servicing, and other goals, in particular, creating an efficient market for domestic debt.
Government debt (Eisner 1989: 73) represents an unpaid obligation of the government. In order to borrow from the public, the state issues debt obligations. When the state takes out a loan, it promises creditors repayment of the debt and attracts them with loan terms specifying the principal amount, the interest rate to be charged on the principal, and the time period during which interest and principal will be paid. Thus, government debt represents the total sum of all government debt securities issued by the state that have not yet been repaid.
According to the Dictionary of Business Terms (1994: 259), a U.S. government security is "a security issued by the U.S. government — a treasury obligation, bond, note, and savings bond. The government represents the institution of highest credit reliability among all types of debt instruments, because they are protected and guaranteed by the full faith and credit of the U.S.

government." The interest rate fixed on such a security is called the "risk-free interest rate" (Dictionary of Business Terms 1994: 531).
The state issues (emits) several types of debt securities, which can be classified according to various categories (Cox 1985: 227).
One category may group together a similar type of issuing government body — the central government, local self-government, or an individual ministry. It is permissible to divide these categories into subcategories — for example, a local government security may be a debt security issued by a district, town, or city.
The second approach is the gradation of government securities according to their maturity. When we speak of a ten-year or thirty-year government bond, this means that the subject under discussion is the time span from the issuance of the government security to its maturity.
In international practice there exists a more widely accepted division. For example, U.S. federal government debt is divided into three broadly used categories according to maturity (Cox 1985: 227):

- A treasury obligation is a government security with a maturity of less than one year (it may be three-month, six-month, one-year, etc.);
- The maturity of a treasury note ranges from one year to ten years;
- The initial maturity of a treasury bond must not be less than ten years.

The commonly accepted and widely used name for securities issued by the state and local governments is "bond," which is not directly related to their maturity.
The name for a bond with no maturity is a perpetuity. In such a case, the bond has no repayment date — that is, interest always accrues on it, but there is no principal amount to be repaid. Such perpetual bonds were once issued by the British government, and they are called "consoles."
The third approach to classification ranks government securities according to the source responsible for their repayment.

- In international practice one finds "general obligation bonds," which are repaid from revenue obtained through public taxation;
- The repayment source of "revenue bonds" is the fee collected from a specific category of user — for example, a toll charged on vehicles for the construction of a bridge or tunnel. This approach is used only in the gradation of state and local debt securities.

A security, as an object of the market, performs a number of functions under conditions of a market economy (Ross 2002: 201): through it, it is possible both to accumulate the population's monetary savings and to mobilize organizations' temporarily free monetary resources to finance budget expenditures; this instrument is used to regulate monetary circulation; it is a source of investment, both for the creation of new enterprises and for the development of already existing ones; it is used as an instrument in performing credit-and-settlement operations. In addition to the above, a government security performs other functions as well: through the issuance of government securities, monetary resources are redistributed between spheres and branches of the economy, between territories and countries, between population groups and strata, and between the population and the state; through the issuance of government securities, the state incurs and creates government debt.
Historically, the issuance of government securities has been linked to states' aims of financing military operations. For this reason, such securities were called "war" bonds. In the early stages, many European states even issued perpetual bonds, the so-called "consoles" and "perpetual bonds" (Austin 2008: crs 2 and crs 3); (Garbade 2008: 32).
In the financial literature it is held that a government security is a risk-free type of instrument (Van Horne… 2005: 263); however, as the global financial crisis of 2007–2010 made clear, this view is far from the truth, since a number of states proved unable to service the securities they had issued. This phenomenon is known as default (that is, bankruptcy and insolvency). Beyond this, the

instrument also carries other risks — the devaluation of a given country's national currency, low levels of liquidity, and inflation risk.

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Physical and Mathematical Sciences

MODERN PROBLEMS OF NANOPHYSİCS

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Summary

Recent developments in the field of nanosciences and nanotechnology have generated great interest among researchers and scientists around the world. Rapidly increasing interest in the research and development needs of nanotechnology among various engineering fields has fueled growth in areas such as nanoelectronics, biotechnology, and the health care system and commerce in general. This article presents the state-of-the-art in nanofabrication, covering recent developments and key challenges related to this field.

In addition to the already existing fields of nanotechnology, there is a great expectation of technical progress and the solution of important economic, medical and environmental problems through nanotechnology. Nanotechnology can meet these expectations only if fundamental progress can be made behind the latest technology. Therefore, very important problems for nanotechnology are discussed here.

Nanomedicine, an interdisciplinary field at the intersection of nanotechnology and medicine, is rapidly revolutionizing healthcare by exploiting the unique properties of nanoscale materials and structures. The ability to manipulate matter at the nanoscale has opened new avenues for disease diagnosis, treatment and monitoring and marked a paradigm shift in the healthcare landscape.

As nanotechnology advances, so does the need for robust regulations and ethical guidelines. Ensuring the safety of nanomaterials, their responsible use and potential environmental impact are important issues. Researchers and policymakers are working together to create frameworks that balance innovation with security.

Keywords: Nanotechnology, quantum effects, nanomaterials, nanostructures, quantum tunneling.

İntroduction

Since the beginning of the 21st century, interest in studying micro- and nanoscale phenomena across all fields of science has grown significantly. This has led to the emergence of a new scientific discipline known as nanophysics. Nanophysics is the branch of science that investigates the physical properties and phenomena of matter within the size range of approximately 1 to 100 nanometers. At this scale, quantum effects dominate, and matter exhibits behavior that differs fundamentally from that described by classical physics [1].

Nanophysics directly impacts not only theoretical physics but also materials science, chemistry, biology, medicine, information technology, and engineering. It forms the scientific foundation of nanotechnology and has contributed to revolutionary advancements in modern electronics, biomedicine, optoelectronics, and energy systems [2]. The primary objective of nanophysics is to determine the size dependence of material properties, study the quantum characteristics observed in nanoscale objects, and explain the physical laws governing nanoparticles. For instance, the relatively large surface area of nanoparticles, the confinement of electrons in quantized states, and changes in energy bands significantly alter the thermal, electrical, magnetic, and optical properties of materials. As a new stage of scientific and technological development, nanophysics encompasses the creation of various nanostructures—

such as quantum dots, nanorods, nanotubes, as well as inorganic and organic nanoparticles—and the study of their underlying physical principles. In particular, nanomaterials based on graphene, carbon nanotubes, and metal oxides are considered among the most promising areas of research [3].

Advanced techniques employed in nanophysics research include scanning probe microscopy, scanning tunneling microscopy, scanning electron microscopy, and X-ray spectroscopy. These methods enable the investigation of the morphology, surface characteristics, electronic structure, and other physical parameters of nanoscale structures.

This article aims to analyze the theoretical and practical foundations of nanoscale structures, summarize the results of existing research, and provide detailed information on their practical applications and future prospects. Furthermore, issues regarding safety, environmental impact, and bioethics are also specifically addressed in nanophysics research[4]. The development of nanophysics is primarily driven by the specific needs of scientific and technological progress. Modern electronic devices are becoming increasingly compact, energy-efficient, and multifunctional. This necessitates the further miniaturization of materials and devices—scaling them down to the nanoscale. Consequently, nanophysics enables the effective utilization of quantum effects, the manipulation of the physical properties of materials, and the creation of next-generation technologies[5].

This article presents a comprehensive analysis of the theoretical and practical foundations of nanophysics. It examines the physical properties of materials at the nanometer scale, specifically highlighting quantum effects, size effects, and the phenomenon of quantum tunneling. The study elucidates the unique optical, electrical, and mechanical properties of nanostructures and demonstrates how they differ from conventional materials. Furthermore, the article analyzes applications of nanophysics across various fields, such as medicine, energy, information technology, and environmental science. Potential challenges regarding safety and bioethics in this field are also discussed. The findings presented are synthesized from modern scientific research and international experience, enabling conclusions to be drawn regarding the prospects and current issues of nanophysics.

The term "nanotechnology" refers to a broad field of scientific and technical activity dealing with small-scale objects and technical components. Typically, objects with at least two dimensions smaller than 0.1 µm are classified as "nano-objects." Based on this definition, many advanced materials, as well as modern electronic devices, are considered subjects of nanotechnology. Furthermore, many aspects of molecular biotechnology, as well as macromolecular and supramolecular chemistry and nanoparticle technologies, are grouped under the concept of "nanotechnology." Despite this size-based definition, nanotechnology—alongside physics and chemistry—deals with the implementation of technical functions in the realm between individual particles/molecules and larger objects. This encompasses the transition from classical physics to the quantum world of small molecules, as well as that of small groups or even single elementary particles [6].

Alongside the existing fields of nanotechnology, there are high expectations that technological progress in this area will solve significant economic, medical, and environmental problems. Nanotechnology can only meet these expectations if fundamental breakthroughs are achieved and state-of-the-art technologies are applied. Therefore, the challenges that are crucial for nanotechnology are discussed here.

Materials and Methods

This study was conducted based on a theoretical analysis and comparative assessment of existing experimental and applied research in the fields of nanophysics and nanotechnology. The methodological approach includes a systematic review of scientific literature, an analytical

synthesis of published data, and an evaluation of nanomaterial-based water purification technologies. Furthermore, a comparative methodology was employed to assess the performance of nanomembranes, nanoadsorbents, and nano-photocatalysts in terms of selectivity, energy efficiency, and resistance to fouling. Qualitative analysis was used to evaluate the advantages and limitations of each technology, while quantitative data derived from existing studies were utilized to substantiate the findings [7].

Conclusion

The results of this study indicate that nanophysics is one of the most important fields of modern science and technology, and that the drastic changes in material properties occurring at the nanoscale are primarily attributed to quantum effects. In particular, phenomena such as quantum tunneling, size effects, and the quantization of energy levels fundamentally alter the optical, electrical, and mechanical properties of nanomaterials. From a practical standpoint, water purification technologies based on nanomaterials demonstrate high efficiency.

Research also indicates that while nanomembranes offer high selectivity and energy efficiency, they also face certain drawbacks, such as fouling and the requirement for high operating pressures. Technologies developed based on nanophysics provide significant solutions in the fields of ecology, energy, and medicine. Innovative systems based on nanomaterials are expected to play a pivotal role in addressing global water scarcity and environmental challenges in the future.

In conclusion, current trends in nanotechnology research promise a future marked by groundbreaking innovations. From healthcare to electronics, and from sustainability to quantum computing, the nanoscale continues to unlock new possibilities. However, with great power comes great responsibility; as we advance further into the nanoworld, prioritizing safety and ethics is crucial. The potential of nanotechnology is vast, and today's discoveries pave the way for a technologically advanced and sustainable tomorrow.

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ӘОК 372.853

ФИЗИКАНЫ ОҚЫТУ КЕЗІНДЕГІ БІЛІМДІ БАҚЫЛАУДЫҢ ЕРЕКШЕЛІКТЕРІ

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Аңдатпа: Мақалада жалпы білім беретін мектепте физиканы оқыту сапасын арттырудағы оқушылардың білімін бақылаудың рөлі қарастырылады. Білімді бақылаудың негізгі қызметтері, оның оқу жетістіктерін диагностикалаудағы, оқу барысында туындайтын қиындықтарды анықтаудағы және оқыту әдістемесін жетілдірудегі маңызы ашылған. Оқушылардың физикалық заңдылықтарды терең түсінуін, практикалық дағдылары мен зерттеушілік құзыреттерін қалыптастыру үшін дәстүрлі және инновациялық білімді тексеру әдістерін ұштастыру қажеттілігі негізделінген.

Түйін сөздер: білімді бақылау, білім беру сапасы, физиканы оқыту, оқу жетістіктерін бағалау, қалыптастырушы бағалау, кері байланыс, физикалық эксперимент, танымдық белсенділік, цифрлық технологиялар.

Кіріспе

Білім беру сапасын арттыру қазіргі мектептің басым міндеттерінің бірі болып табылады. Білім беру мазмұнының жаңаруына байланысты оқушылардың білімін тиімді бақылауды ұйымдастыру ерекше маңызға ие. Ол оқушылардың дайындық деңгейін анықтауға ғана емес, сонымен қатар оқу үдерісін жетілдіруге мүмкіндік береді. Білімді бақылау педагогикалық қызметтің маңызды құрамдас бөлігі ретінде білім беру мақсаттарының орындалуы, пәндік білімдердің меңгерілуі және практикалық дағдылардың қалыптасуы туралы ақпарат алуды қамтамасыз етеді.

Физиканы оқыту барысында бақылаудың маңызы ерекше, өйткені бұл пән теориялық қағидаларды меңгеруді, физикалық құбылыстар мен заңдарды түсінуді, математикалық аппаратты қолдануды, эксперименттер жүргізуді және алынған нәтижелерді түсіндіруді талап етеді. Анықтамалар мен формулаларды жай ғана қайталау оқушының тақырыпты терең түсінетінін әрдайым көрсете бермейді. Сондықтан оқушылардың физикалық үдерістерді түсіндіру, себеп-салдарлық байланыстарды анықтау және алған білімдерін теориялық әрі практикалық есептерді шешуде қолдану қабілеттерін бағалау қажет.Қарастырылып отырған мәселенің өзектілігі оқушылардың жеке ерекшеліктерін ескеретін, білімдегі олқылықтарды уақтылы анықтайтын және оқу нәтижелерін жақсартуға ықпал ететін бағалау әдістерін жетілдіру қажеттілігімен байланысты.

Негізгі бөлім – физиканы оқыту сапасын арттырудағы білімді бақылаудың педагогикалық мүмкіндіктерін анықтау және оқушылардың оқу жетістіктерін бағалауды ұйымдастырудың тиімді тәсілдерін негіздеу. Қойылған мақсатқа жету үшін келесі міндеттер белгіленді:

-оқу үдерісіндегі білімді бақылаудың мазмұны мен негізгі қызметтерін ашып көрсету;
-физиканы оқыту барысында оқушылардың білімін тексерудің ерекшеліктерін анықтау;
-оқу жетістіктерін бағалаудың заманауи әдістерін қарастыру;

-кері байланыс пен цифрлық технологияларды қолданудың оқу нәтижелілігін арттырудағы мүмкіндіктерін айқындау;

Қазіргі білім беру жүйесіндегі білімді бақылау

. Қазіргі педагогикада бақылау тек білімді тексеру құралы ретінде ғана емес, оқу үдерісін реттеу тетігі ретінде де қарастырылады. Оның нәтижелері мұғалімге сабақ мазмұнын уақытылы түзетуге, материалды түсіндірудің тиімді әдістерін таңдауға және оқушылармен жеке жұмыс ұйымдастыруға көмектеседі.Білімді бақылау бірнеше өзара байланысты қызметті атқарады.

Диагностикалық қызмет оқушылардың дайындық деңгейін анықтауға, білімдегі олқылықтарды табуға және оқу қиындықтарының туындау себептерін белгілеуге бағытталған.

Оқыту қызметі бақылау барысында оқу материалын қайталау, жүйелеу және бекіту арқылы жүзеге асырылады.

Дамытушылық қызмет логикалық ойлауды, ақпаратты талдау, қорытындыларды дәлелдеу және өз бетінше шешім қабылдау қабілеттерін қалыптастыруға ықпал етеді.

Тәрбиелік қызмет жауапкершілікті, тәртіптілікті, дербестікті және өз оқу нәтижелеріне саналы көзқарасты дамытуға бағытталады.

Түзетушілік қызмет алынған нәтижелер негізінде оқу үдерісіне өзгерістер енгізуді көздейді. Мұғалім қандай тақырыптарды қосымша түсіндіру керектігін, қандай тапсырмаларды күрделендіру қажеттігін және қай оқушыларға қосымша қолдау көрсету керектігін анықтайды.Аталған қызметтердің өзара байланыста жүзеге асырылуы оқыту, бағалау және оқушылардың әрі қарай дамуы арасындағы сабақтастықты қамтамасыз етеді.

Физиканы оқыту кезіндегі білімді бақылаудың ерекшеліктері

Физика оқу пәні ретінде білімді бақылау әдістерін таңдауда ескерілуі тиіс өзіндік ерекшеліктерге ие. Физикалық білімдерді меңгеру теориялық қағидаларды есте сақтаумен шектелмейді. Ол табиғат құбылыстарының заңдылықтарын түсінуді, математикалық тәуелділіктерді пайдалануды және бақылаулар мен эксперименттердің нәтижелерін түсіндіруді қамтиды.

Мысалы, «Электр тогы» тақырыбын меңгерген оқушы электр тогының күші ұғымын және оны есептеу формуласын біліп қана қоймай, осы физикалық шаманың мағынасын түсінуі, оны тәжірибе жүзінде анықтай алуы және алған білімін есептер шығаруда қолдануы керек.

Ом заңын оқыту кезінде оқушылардың ток күші, кернеу және өткізгіштің кедергісі арасындағы байланысты анықтау қабілетін бағалау қажет. Егер оқушы формулаға сандық мәндерді механикалық түрде қойып, есепті шығарғанымен, шамалар арасындағы тәуелділіктің физикалық мағынасын түсінбесе, оның білімін толық қалыптасқан деп есептеуге болмайды.

Осындай жағдай электролиз құбылысын оқыту кезінде де байқалады. Оқушылар электродтардың орналасуын және зарядталған бөлшектердің қозғалыс бағыттарын жаттап алуы мүмкін. Алайда иондардың рөлін, тотығу-тотықсыздану үдерістерін және электролиз кезінде бөлінетін зат массасының ток күші мен уақытқа тәуелділігін түсіндіруде қиындықтарға тап болады.

Осыған байланысты физика пәні бойынша білімді бақылауды бірнеше бағытта ұйымдастырған жөн:

- негізгі ұғымдарды, заңдарды және физикалық шамаларды түсінуін тексеру;
- есептеу есептерін шығаруда формулаларды қолдану қабілетін бағалау;
- физикалық құбылыстар мен үдерістерді түсіндіру дағдыларын анықтау;
- өлшеу құралдарымен жұмыс істеу дағдыларын тексеру;
- экспериментті жоспарлау және өлшеу нәтижелерін талдау қабілеттерін бағалау;

- алынған деректер негізінде негізделген қорытынды жасау дағдыларын анықтау.

Осы бағыттар бойынша кешенді бағалау оқушылардың дайындық деңгейі туралы толық түсінік қалыптастыруға және олардың физикалық білімдерді әртүрлі оқу жағдайларында қаншалықты тиімді қолдана алатынын анықтауға мүмкіндік береді.

Білімді бақылау мен бағалаудың заманауи әдістері

Оқыту сапасын арттыру білімді тексерудің әртүрлі әдістерін қолдануды талап етеді. Белгілі бір әдісті таңдау оқытылатын тақырыптың мазмұнына, сабақтың мақсатына, оқушылардың жас ерекшеліктеріне және жоспарланған оқу нәтижелеріне байланысты болады.

Білімді тексерудің кең таралған тәсілдерінің бірі – ***ауызша сұрау***. Бұл әдіс теориялық материалды түсіну деңгейін, физикалық заңдылықтарды түсіндіру және өз пікірін дәлелдеу қабілетін бағалауға мүмкіндік береді. Ауызша сұраудың тиімділігі оқушылардан ақпаратты жай қайталауды емес, өз бетінше ойлануды талап ететін проблемалық сұрақтарды қолдану арқылы артады.

Жазбаша бақылау жұмыстары теориялық білімді меңгеру деңгейін, есептеу есептерін шығару дағдыларын және физикалық шамалар арасындағы байланысты анықтау үшін қолданылады. Мұндай тапсырмаларды құрастыру кезінде әртүрлі күрделілік деңгейіндегі сұрақтарды қарастырған жөн. Бұл оқушылардың базалық білімін де, стандартты емес есептерді шығару қабілетін де анықтауға мүмкіндік береді.

Тестілеу қысқа уақыт ішінде оқу материалының едәуір бөлігін тексеруге және оқушылар жиі жіберетін қателерді анықтауға мүмкіндік береді. Тест тапсырмалары тек есте сақтауды тексерумен шектелмей, білімді қолдануға, графиктерді талдауға, эксперименттік деректерді түсіндіруге және физикалық құбылыстарды негіздеуге бағытталуы керек.

Зертханалық жұмыстар физика пәні бойынша білімді бақылау жүйесінде ерекше орын алады. Олар оқушылардың практикалық дағдыларын, өлшеулерді өз бетінше жүргізу қабілетін, қауіпсіздік ережелерін сақтауын, нәтижелерді өңдеуін және қорытынды жасауын бағалауға мүмкіндік береді.

Мысалы, ток күшінің кернеуге тәуелділігін зерттеу барысында оқушылар электр тізбегін құрастырады, өлшеулер жүргізеді, график салады және алынған тәуелділікті талдайды. Мұғалім тек соңғы нәтижені ғана емес, эксперименттік әрекеттердің дұрыс орындалуын, деректердің өңделу сапасын және қорытындылардың негізділігін де бағалайды.

Жобалық және зерттеушілік әрекет күрделі құзыреттердің қалыптасу деңгейін анықтауға мүмкіндік береді. Жобаларды орындау барысында оқушылар мәселені өз бетінше тұжырымдауға, болжам ұсынуға, ақпарат іздеуге, зерттеу жүргізуге және алынған нәтижелерді ұсынуға үйренеді.

Қорытынды

Физикалық білім берудің ерекшелігі білімді кешенді бағалауды талап етеді. Ол теориялық білімді тексеруді, есептеу есептерін шығаруды, зертханалық жұмыстарды орындауды және эксперименттік деректерді талдауды қамтуы керек. Бақылаудың әртүрлі формаларын қолдану оқушылардың меңгерген ақпарат көлемін ғана емес, физикалық білімдерін табиғат құбылыстарын түсіндіру және практикалық мәселелерді шешу барысында саналы түрде қолдану қабілетін де анықтауға мүмкіндік береді.

Қалыптастырушы бағалау, уақтылы кері байланыс, өзін-өзі бағалау және цифрлық білім беру ресурстарын пайдалану ерекше маңызға ие. Оларды оқу үдерісіне енгізу танымдық дербестікті дамытуға, оқу мотивациясын арттыруға және зерттеушілік дағдыларды қалыптастыруға ықпал етеді.

Осылайша, бақылаудың тиімділігі жүргізілген тексерулер мен қойылған бағалардың санымен емес, алынған нәтижелердің оқыту сапасын жақсарту үшін қаншалықты пайдаланылатынымен анықталады.

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ӘОК 37.001.895

БІЛІМ БЕРУДІҢ ИННОВАЦИЯЛЫҚ ЖҮЙЕСІН ЖЕТІЛДІРУ ӘДІСТЕРІ

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Аннотация: Мақалада оқушылардың зияткерлік қызметін дамыту қажеттілігі ерекше өзекті, өйткені соңғы жылдары мектепте оқуға деген қызығушылықтың төмендеуі байқалатыны көрсетілген. Сонымен қатар, бүгінгі таңда оқу процесі тиімді және тұлғаның интеллектуалды болуына мақсатты түрде жұмыс істеп, қолдан келгеннің бәрін жасау маңызды екені негізделінген.

Кілт сөздер: Мемлекет, бейінді, мамандар, білім, физика, дағдылар, құзыреттілік, дамыту, инновация, проблема, мотивация.

Білім берудің инновациялық жүйесінде оқыту жүйесі ғана жетілдіріліп қоймай, білім беру процесінің сапасын бақылау құралдары, әдістері мен жүйелері де өзгеруде. Сондықтан қазіргі жағдайда білім беру процесіне инновациялық технологияларды енгізу қажеттілігі туындайды.

Біздің мектептің жоғары сынып оқушылары техникалық оқу орындарына түсуге бағытталған арнайы сыныптарда оқитындықтан, олар математика, физика және информатика пәндерін табиғи түрде тереңірек оқып-үйренеді. Жұмысымда оқу процесін тиімді ұйымдастыруға және жоғары нәтижелерге қол жеткізуге мүмкіндік беретін заманауи білім беру технологияларын қолданамын.

Олардың қатарына мыналар кіреді: мамандандырылған оқыту (10–11-сыныптар); зерттеу және жобалық қызмет; ақпараттық технологиялар; желілік ынтымақтастық; мәселелерді шығар-машылық жолмен шешу; проблемалық оқыту; сондай-ақ сараланған және жекелендірілген оқыту. Физиканы оқыту процесінде озық және инновациялық педагогикалық технологияларды қолдану сөзсіз ішкі мотивацияны белсендіруге және әр оқушының оқу материалын игеруге деген шынайы қызығушылығын қалыптастыруға әкелетін негізгі элемент болып табылады. Бұл тәсіл танымдық белсенділіктің едәуір артуын ынталандырады, білімді тәуелсіз іздеуге және физикалық құбылыстарды терең түсінуге итермелейді.

Физика-жаратылыстану ғылымдарының (астрономия, химия, биология, география) арасындағы қазіргі заманғы дүниетаным мен адамның ғылыми ойлау стилін қалыптастыруға қабілетті жалғыз іргелі ғылым. Бұл күрделі процестермен, қарапайым объектілермен, әртүрлі құбылыстармен және табиғат әлемімен айналысатын физика, онда тиісті шындықтарды, қатаң дәл ұғымдарды құруға, идеалды модельдер құруға, принциптер мен сандық заңдарды қалыптастыруға, теорияларды дамытуға мүмкіндік туды. Физика базасында білім алушылардың дербес зерттеу қызметінің дағдылары мен дағдыларын дамытуға ықпал ететін кешенді проблемаларды қарастыру ұйымдастырылуы мүмкін [1].

Физика курсының мазмұнын өзгерту қазіргі педагогикалық зерттеулерде анықталған мектептегі білім беру мазмұны туралы идеяларды дамытудың негізгі тенденцияларын ескере отырып, физиканы оқытудың жеке әдістемесі саласында үлкен жүйелі ғылыми-зерттеу жұмыстарын қажет етеді. Атап айтқанда, қазіргі уақытта білім мазмұнын ғылым

негіздерінің Пәндік білім жүйесі ретінде түсінуден оны әлеуметтік және жеке тәжірибені сипаттайтын өзара байланысты әр түрлі білім түрлерінің (ақпараттық, процедуралық, бағалау, рефлексивті) тұтас жүйесі ретінде түсінуге көшу жүріп жатыр. Физика сабақтарын өткізудің инновациялық тәсілдерін қолдану әр оқушының оқу процесіне қызығушылығын қамтамасыз етеді, оқушылардың танымдық белсенділігін, шығармашылық белсенділігін арттыруға ықпал етеді, олардың ойлауы мен интеллектін дамытады.

Қазіргі уақытта жоғары білімді, интеллектуалды дамыған тұлғаны даярлауды жетілдіру бағыттарын іздеу мәселесі өткір тұр.

Механикаландырудың жоғары деңгейі бар заманауи өндіріс инженерлік-техникалық білімді, ойлаудың жоғары деңгейін, шығармашылық қабілеттерін талап етеді. Бұл қасиеттерді дамытуды бастау мектептегі оқу кезеңінде, оның көзқарастары, сенімдері, білімдері мен қабілеттері бар тұлға қалыптасқан кезде бастау маңызды [2]. Оқушылардың танымдық белсенділігін ұйымдастырудағы басым міндеттердің бірі білім алушылардың ғылыми әлеуетін толықтыру мүддесінде оларды дербес шығармашылық, оқу-зерттеу, тәжірибелік-конструкторлық жұмысқа тарту үшін оңтайлы жағдайлар жасау болып табылады.

Физика-мектепте оқытылатын негізгі пәндердің бірі. Алайда, тәжірибе көрсеткендей, оқушылардың үлкен пайызы осы пәннің маңыздылығы мен жан-жақтылығын түсінбейді, студенттер бұл күрделі, түсініксіз және қызықсыз пән деген қате пікірге ие. Оқушылардың назарын физиканы сапалы зерттеуге аудару үшін әр тақырып бойынша көрнекі және практикалық негіздеме бере алатын дәстүрлі емес сабақ форматтарына жүгіну керек. Сонда студенттер физиканың" айналамыздағы әлем " екенін түсінеді, бұл оқулықтағы күрделі формулалар емес, қызықты тәжірибелер мен құбылыстар.

Оқу процесінде орталық орын физикалық құбылыстар әлемін білу процесін өзінің қабілеттері мен жаңа нәрселерді білу қажеттіліктеріне сүйене отырып құратын оқушыға беріледі. Мұғалім көмекші, кеңесші ретінде жақын, танымдық белсенділікке назар аударады, бастама мен тәуелсіздікке шақырады, оқушыны табиғаттың түсініксіз құбылыстарын зерттеуге бағыттайды. Нәтижесінде толыққанды тұлға қалыптасады, ол жаңа жаңалықтардың ғылыми әлемінде оңай бағдарланады.

Физиканы оқу процесінде ақпараттық технологияларды қолданудың негізгі формалары: электронды оқулықтар, компьютерлік демонстрациялар, виртуалды эксперименттер мен зерттеулер, жобалар құру, аспаптарды көрсету және олардың жұмыс принципі, сынақ машиналары және тағы басқалар.

Сандық білім беру ресурстарының үлкен таңдауы келесі технологияларды пайдалануға мүмкіндік береді:

1.динамикалық слайд дәрістері. Бейне және аудио файлдарды, суреттер мен анимацияларды, кестелер мен формулаларды, диаграммалар мен графиктерді қоса алғанда, Power Point бағдарламасында орындалған презентация арқылы теориялық материалды көрсету;

2.оқыту және бақылау бағдарламалары. Заманауи ақпараттық кеңістік мұғалімнің таңдауы үшін физика бойынша әртүрлі электронды оқулықтарды ұсынады. Бүкіл мектеп бағдарламасы тек егжей-тегжейлі дәріс материалдарымен ғана емес, сонымен қатар тәжірибелер, иллюстрациялар, графиктер, формулалар, схемалар мен тест тапсырмаларының демонстрацияларымен ұсынылған. Тест тапсырмалары оқу материалын меңгеру деңгейін тексереді, автоматты түрде баға қояды және белгілі бір тапсырмалардағы қателерді қосымша талдауға назар аударады. Интернет желісінде материалды бекіту үшін интерактивті тренингтерді қолдануға болады – суреттің таңдалған құбылысқа белгілі бір сипаттамалармен және өзара тексерумен сәйкестігі;

3.Виртуалды физикалық зертханалар [3]. Ол виртуалды эксперимент негізінде физикалық құбылысты, заңдылықтарды, заңдылықтарды зерттеу үшін қолданылады. Виртуалды зертханалық жұмыстарды жүргізу кезінде оқушылар эксперименттер жүргізу дағдыларын игереді, аспаптардың құрылымын үйренеді. Алайда, егер физика кабинетінде тиісті жабдық болса, нақты экспериментті виртуалды экспериментке ауыстыру мүмкін емес, тек теориялық материалды тереңірек зерттеу үшін толықтыруға болатындығын атап өткім келеді.

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Medical Sciences

ТЕОРЕТИКО-МЕТОДОЛОГИЧЕСКИЙ ОБЗОР ПРИМЕНЕНИЯ ПРИКЛАДНОГО АНАЛИЗА ПОВЕДЕНИЯ (ABA-ТЕРАПИИ) В КОМПЛЕКСНОЙ РЕАБИЛИТАЦИИ ДЕТЕЙ С РАССТРОЙСТВОМ АУТИСТИЧЕСКОГО СПЕКТРА

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Аннотация.

В статье представлен комплексный теоретико-методологический обзор применения прикладного анализа поведения (ABA-терапии) как одного из наиболее доказательных подходов в системе комплексной реабилитации детей с расстройством аутистического спектра (РАС). Авторы анализируют эволюцию поведенческого подхода от фундаментальных принципов бихевиоризма до современных модифицированных протоколов вмешательства (ESDM). Особое внимание уделяется методологическим основаниям ABA-терапии, включая принципы функциональной оценки поведения, подкрепления и генерализации навыков. В работе критически осмысливается роль поведенческого анализа в формировании коммуникативных, социальных и адаптивных компетенций у детей с РАС, а также уделяется внимание важности обучения родителей элементам ABA и рассматриваются аспекты совмещения поведенческой терапии с другими реабилитационными практиками.

Ключевые слова: расстройство аутистического спектра, прикладной анализ поведения, реабилитация, социальная интеграция, развитие навыков.

Расстройство аутистического спектра (РАС) — это комплексное нарушение нейроразвития, характеризующееся дефицитом в сфере коммуникации и социальной адаптации, а также склонностью к узкому кругу интересов. У людей с РАС часто бывают специфические, глубокие интересы и повторяющиеся модели поведения. Нередко данная патология манифестирует совместно с коморбидными состояниями, такими как синдром дефицита внимания и гиперактивности, что делает общую картину развития еще более индивидуальной [1]. В более широком контексте охраны психического здоровья психические расстройства охватывают примерно 12,5% мирового населения, прочно удерживая позиции в первой десятке распространенных заболеваний. Примечательно, что с 1990 года уровень данной заболеваемости не демонстрирует тенденции к спаду. Спектр этих состояний крайне широк: от расстройства аутистического спектра, шизофрении, депрессии и биполярного расстройства до нарушений пищевого поведения и различных расстройств личности [2]. Согласно эпидемиологическим данным Всемирной организации здравоохранения (ВОЗ) и Центров по контролю и профилактике заболеваний (CDC), основанным на обзоре глобальных исследований, распространенность непосредственно РАС в детской популяции продолжает неуклонно расти. С учетом влияния географических, этнических и социально-экономических факторов она составляет примерно 1 случай на 100 детей, что ставит глобальный вызов перед мировой системой здравоохранения [3]. Многообразие клинических проявлений аутизма требует разработки и внедрения комплексных программ реабилитации, способных не просто купировать отдельные симптомы, а системно повышать уровень адаптации ребенка и улучшать качество жизни всей его семьи [4].

В современном научно-практическом пространстве особое место занимает терапия, основанная на доказательном подходе. Среди множества существующих систем помощи наиболее глубокую и верифицированную эмпирическую базу имеет прикладной анализ поведения (АВА-терапия). На сегодняшний день она признана международным научным сообществом, включая Американскую академию педиатрии (AAP) и экспертные институты, одним из золотых стандартов в структуре комплексной реабилитации детей с расстройством аутистического спектра. Поведенческие интервенции демонстрируют высокую эффективность в коррекции дезадаптивного поведения и формировании базовых жизненных навыков. Научно-доказательная база этого подхода подтверждается фундаментальным количественным метаанализом Х. Вируэс-Ортеги (2010), в котором были обобщены результаты долгосрочных программ прикладного анализа поведения. Исследование продемонстрировало, что интенсивное поведенческое вмешательство в объеме от 20 до 40 часов еженедельно на протяжении 1–2 лет обеспечивает выраженный положительный эффект, варьирующийся от среднего до крупного в зависимости от целевого домена. Систематический анализ данных показал значительное улучшение показателей общего интеллектуального функционирования и интенсивное развитие языковых компетенций, охватывающее как экспрессивную, так и импрессивную речь. Важнейшим вектором долгосрочной АВА-терапии выступает качественное преобразование адаптивного поведения: метаанализ фиксирует статистически значимый прогресс в освоении повседневных жизненных навыков и социализации. Автор подчеркивают прямую зависимость терапевтического эффекта от своевременности вмешательства, доказывая, что ранний старт поведенческих интервенций в возрасте до 4–5 лет позволяет максимально сгладить проявления дезадаптивных паттернов и заложить прочный фундамент для последующей интеграции ребенка в инклюзивную образовательную среду [5].

Понимание механизмов эффективности данных интервенций требует обращения к их генезису. Историко-теоретический фундамент АВА-терапии восходит к классическому бихевиоризму и фундаментальным принципам оперантного обуславливания,

сформулированным Б. Ф. Скиннером. За десятилетия своего развития поведенческий подход претерпел значительную эволюцию: от строго структурированного, подчас директивного обучения отдельными блоками (DTT) до современных модифицированных протоколов ранних и естественных поведенческих вмешательств (NDBI). Ярким примером такой эволюции является Денверская модель раннего вмешательства (Early Start Denver Model, ESDM), которая органично сочетает поведенческие принципы ABA с подходами психологии развития, делая процесс реабилитации максимально естественным, игровым и ориентированным на внутреннюю мотивацию ребенка [6]. Согласно теоретической парадигме NDBI (Naturalistic Developmental Behavioral Interventions), описанной консенсусной группой экспертов, данная эволюция представляет собой не просто модификацию техник, а глубокий синтез двух изначально независимых научных традиций - прикладного анализа поведения и психологии развития. Традиционный метод обучения отдельными блоками, несмотря на свою доказанную эффективность в формировании базовых навыков, часто критиковался за искусственность среды, жесткий контроль со стороны терапевта и слабую генерализацию усвоенных реакций. В противовес этому, протоколы NDBI переносят терапевтическое воздействие в естественный контекст повседневной жизни ребенка, где учебным стимулом становится не искусственное поощрение, а сам предмет или деятельность, выбранные им в процессе свободной активности. Денверская модель воплощает в себе фундаментальные операциональные характеристики этого класса методов. Вместо директивного предъявления задач терапевт использует разделенное внимание и взаимное вовлечение в структуре игровой сессии, превращая обучающие эпизоды в естественные интерактивные рутины. Процесс строится вокруг внутренней мотивации ребенка: подкреплением служат функциональные и социальные последствия, например, продолжение совместной игровой деятельности или получение желаемого предмета, что напрямую соответствует закономерностям нормативного онтогенеза. Метод NDBI гармонизирует поведенческие техники такие как подсказки, формирование реакций и моделирование с развивающими целями, фокусируясь на критически важных сферах: совместном внимании, имитации, прагматике коммуникации и эмоциональной взаимности. Это позволяет не просто развивать изолированные когнитивные функции, но и обеспечивать устойчивый перенос сформированных адаптивных навыков в реальную жизненную среду [7].

Методологическая сила прикладного анализа поведения заключается в его строгой технологичности и объективности. В основе любого вмешательства лежат три фундаментальных столпа: функциональная оценка поведения, позволяющая выявить истинные причины и триггеры дезадаптивных реакций; научно обоснованная система подкрепления для формирования новых форм поведения; и обязательное планирование генерализации навыков. Без целенаправленного переноса освоенных умений из кабинета терапевта в повседневную жизнь (домашнюю среду, детские сады, школы) реабилитационный процесс не может считаться завершенным. Таким образом, ABA выступает не как набор изолированных техник, а как гибкая, индивидуализированная методологическая система [8].

Современный этап развития комплексной реабилитации диктует отказ от изолированного применения одного метода в пользу междисциплинарного взаимодействия. Научный интерес исследователей сегодня сфокусирован на критическом осмыслении роли ABA-терапии в целостном развитии ребенка: от изолированного тренинга навыков к формированию глобальных коммуникативных, социальных и адаптивных компетенций. Более того, парадигма помощи сместилась в сторону семейно-центрированного подхода. Доказано, что обучение родителей базовым элементам ABA и их активное включение в терапевтический процесс кратно повышают долгосрочную

эффективность интервенции. Параллельно с этим актуальным остается вопрос синергии: как экологично совместить поведенческую терапию с другими востребованными реабилитационными практиками — логопедической помощью, сенсорной интеграцией и нейропсихологической коррекцией [9, 10].

Проведенный комплексный теоретико-методологический обзор позволяет сформулировать ряд существенных выводов относительно применения прикладного анализа поведения (ABA-терапии) в системе комплексной реабилитации детей с расстройствами аутистического спектра (РАС). Анализ научной литературы подтверждает, что на современном этапе поведенческий подход обоснованно занимает позиции одного из наиболее верифицированных направлений с высоким уровнем доказательности. Историческая эволюция метода от жестко структурированных классических концепций бихевиоризма до современных гибких протоколов естественного вмешательства, таких как Денверская модель раннего вмешательства (ESDM), свидетельствует о гуманизации и адаптации поведенческих инструментов под онтогенетические и психологические особенности детского возраста. При этом эффективность вмешательства напрямую зависит от строгого соблюдения его методологических оснований. Системное сочетание функциональной оценки поведения, научно обоснованных процедур подкрепления и целенаправленной работы над генерализацией навыков обеспечивает не просто механическое заучивание реакций, а формирование гибкого, адаптивного поведения, устойчивого к смене внешних условий и социальной среды.

Прикладной анализ поведения выступает эффективным инструментом преодоления ядерных дефицитов при РАС, внося фундаментальный вклад в развитие речевой деятельности, коммуникативных стратегий, социальных навыков и навыков самообслуживания, что создает прочную основу для успешной социальной интеграции ребенка. Важнейшим вектором современной реабилитации является семейно-центрированный подход, в рамках которого обучение родителей базовым элементам ABA позволяет перенести терапевтическую среду в повседневную жизнь семьи, обеспечивая непрерывность коррекционного процесса и повышая долгосрочную стабильность результатов. В заключение следует отметить, что перспективы развития комплексной реабилитации лежат в плоскости междисциплинарной синергии. Поведенческий анализ не должен противопоставляться другим подходам, а, напротив, его интеграция со смежными практиками: логопедической помощью, дефектологией и сенсорной интеграцией — позволяет выстроить максимально эффективный, гибкий и персонализированный адаптационно-реабилитационный маршрут ребенка с расстройством аутистического спектра.

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BARIATRIC SURGERY AND FATTY LIVER DISEASE IN PATIENTS WITH OBESITY AND METABOLIC SYNDROME: EFFECT ON STEATOSIS AND FIBROSIS, RISKS, AND PREVENTION OF CIRRHOSIS (A LITERATURE REVIEW)

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Abstract. Fatty liver disease associated with metabolic dysfunction accompanies most cases of obesity and metabolic syndrome and in a proportion of patients progresses to cirrhosis. This narrative review summarises evidence on the effect of bariatric surgery on hepatic steatosis, steatohepatitis and fibrosis, on its limitations and risks, and on approaches to the prevention of cirrhosis after surgery. Publications from PubMed, Google Scholar and SciSpace, mainly from 2015–2026, were analysed. Bariatric surgery resolves steatohepatitis in about 84% of patients at five years and reduces the ten-year incidence of major adverse liver outcomes from 9.6% to 2.3%; in a randomised trial, steatohepatitis resolved in 56–57% of operated patients versus 16% with lifestyle intervention. Regression of fibrosis is less frequent (25–70%), advanced fibrosis persists in nearly half of the patients who had it at baseline, and new or worsening liver lesions occur in about 12%. Liver enzymes normalise in most but not all patients. Rapid weight loss, malnutrition, alcohol use and pre-existing cirrhosis are the main sources of risk. Recommendations on liver follow-up after surgery are based on expert opinion, and no data are available for Central Asian populations. Studies combining routine clinical and laboratory data with an assessment of patients' lifestyle and adherence are needed.

Keywords: bariatric surgery, obesity, metabolic syndrome, non-alcoholic fatty liver disease, MASLD, steatohepatitis, liver fibrosis, cirrhosis, prevention.

1. Introduction

Obesity has become one of the main determinants of morbidity and mortality worldwide. According to the Global Burden of Disease study, 603.7 million adults and 107.7 million children were obese in 2015, the prevalence of obesity had doubled since 1980 in more than 70 countries, and a high body-mass index accounted for 4.0 million deaths, nearly 40% of which occurred in persons who were not obese [1]. Obesity rarely occurs in isolation: the cluster of abdominal obesity, hypertension, atherogenic dyslipidaemia and impaired glucose metabolism known as the metabolic syndrome affects between 12.5% and 31.4% of adults globally, depending on the definition applied [2].

The liver is both a target and an active participant in these disturbances. Non-alcoholic fatty liver disease (NAFLD), renamed metabolic dysfunction-associated steatotic liver disease (MASLD) in 2023 [3], is now regarded as the hepatic manifestation of the metabolic syndrome. Its global prevalence rose from 25.3% in 1990–2006 to 38.0% in 2016–2019 [4]; an independent meta-analysis reported an overall prevalence of 32.4% and an incidence of 46.9 cases per 1000 person-years, both higher in men [5]. Among people with obesity, NAFLD is found in 75.3%, steatohepatitis in about one third, and clinically significant fibrosis (F2–F4) in 21.6% of those with NAFLD [6]; in patients with type 2 diabetes the prevalence of NAFLD reaches 55.5%, and advanced fibrosis is present in 17.0% of those with both conditions [7].

These trends are fully relevant to Kazakhstan. In a cross-sectional survey of 4800 adults in four regions of West Kazakhstan, obesity was found in 22.3% of participants and was more frequent in women [8]. In a ten-year follow-up of a cohort in Turkestan, 40.3% of participants developed the metabolic syndrome, with elevated blood pressure and increased waist circumference as the strongest predictors [9]. Meanwhile, national registry data for 2014–2023 show that liver cancer mortality increased from 3.75 to 4.75 per 100,000 population and that a history of cirrhosis was associated with worse survival [10].

Bariatric (metabolic) surgery produces greater and more durable weight loss than any conservative approach and is increasingly viewed as a treatment for obesity-related liver disease. At the same time, its hepatic effects are not uniformly favourable, and the organisation of liver follow-up after surgery remains poorly defined. The aim of this review is to summarise current evidence on the effect of bariatric surgery on fatty liver disease in patients with obesity and metabolic syndrome, to describe its limitations and risks, and to outline approaches to the prevention of cirrhosis in operated patients.

2. Materials and methods

2.1. Study design

This work is a narrative literature review carried out as part of a master's dissertation on the prevention of cirrhosis and correction of hepatic steatosis after bariatric surgery in patients with obesity and metabolic syndrome. The review question was formulated according to the PICO framework: population – adults with obesity and metabolic syndrome who have fatty liver disease; intervention – bariatric (metabolic) surgery; comparison – the pre-operative state or non-surgical treatment; outcomes – changes in steatosis, steatohepatitis and fibrosis, liver enzymes, incidence of cirrhosis and other major liver events, and hepatic complications of surgery.

2.2. Information sources and search strategy

The search was performed in October 2026. Publications were identified through PubMed, Google Scholar and the SciSpace literature review tool; reference lists of key articles and clinical guidelines were additionally screened by hand. The following terms and their combinations were used: "bariatric surgery", "metabolic surgery", "sleeve gastrectomy", "Roux-en-Y gastric bypass",

"one-anastomosis gastric bypass", "non-alcoholic fatty liver disease", "NAFLD", "MASLD", "steatohepatitis", "NASH", "liver fibrosis", "cirrhosis", "alanine aminotransferase", "metabolic syndrome", "obesity" and "Kazakhstan". In SciSpace the structured query was: "effect of bariatric surgery (sleeve gastrectomy, Roux-en-Y gastric bypass, one-anastomosis gastric bypass) on NAFLD/MASLD in adults with obesity and metabolic syndrome", limited to 2015–2026; it returned 504 records, which were ranked by relevance. Searches for epidemiological data on Kazakhstan and Central Asia were conducted separately in English and Russian.

2.3. Eligibility criteria

Included were publications in English or Russian that involved adults (18 years and older) and belonged to one of the following types: meta-analyses and systematic reviews, randomised controlled trials, cohort and other observational studies, clinical practice guidelines and consensus statements. The main time frame was 2015–2026; earlier publications were admitted when they were landmark studies still cited in current guidelines. Excluded were animal and paediatric studies, single case reports, conference abstracts without full text, and publications whose bibliographic data or key results could not be confirmed in the original source.

2.4. Selection and data verification

Titles and abstracts were screened for relevance to the review question, after which the publications most informative for each of its components were selected; preference was given to studies with histological end points, long follow-up and higher levels of evidence. For every included source the bibliographic record was checked against bibliographic databases (OpenAlex, Crossref) or the publisher's website, and the quantitative results cited in this review were compared with the abstract or full text of the original article; statements that could not be confirmed were removed. Because the review is narrative, a PRISMA flow diagram and a formal assessment of the risk of bias were not applied.

2.5. Included sources

In total, 48 sources were included: 12 meta-analyses and systematic reviews, 6 randomised controlled trials, 17 cohort and other observational studies, 6 clinical guidelines, consensus and position statements, 3 narrative reviews and 4 publications of other types (a global burden of disease analysis, a modelling study, an international registry survey and a case series). Forty-five sources were published in 2015–2025 and three in 2011–2013; 45 are in English and three in Russian. The findings were synthesised qualitatively and grouped by topic.

3. Results

3.1. Natural history of fatty liver disease and the prognostic role of fibrosis

Simple steatosis is not a harmless finding. In a meta-analysis of paired-biopsy studies, fibrosis progressed by one stage over 14.3 years in patients with simple steatosis and over 7.1 years in those with steatohepatitis; during follow-up fibrosis progressed in 33.6% of patients and improved in 22.3% [11]. Prognosis is determined primarily by the stage of fibrosis: compared with stage 0, the liver-related mortality rate ratio is 1.41 for stage 1, 9.57 for stage 2, 16.69 for stage 3 and 42.30 for stage 4 [12]. In a prospective cohort of 1773 adults, all-cause mortality rose from 0.32 deaths per 100 person-years in stages F0–F2 to 0.89 in F3 and 1.76 in F4 [13]. A nationwide Swedish cohort of 10,568 biopsied patients showed that excess mortality is already present in simple steatosis (adjusted hazard ratio 1.71) and increases with each histological stage up to cirrhosis (3.79) [14].

Modelling for the United States predicts that by 2030 the incidence of decompensated cirrhosis related to NAFLD will increase by 168% and that of hepatocellular carcinoma by 137% compared with 2015 [15]. The main task of follow-up is therefore the timely detection and prevention of fibrosis rather than of steatosis itself.

3.2. Non-surgical treatment

Histological improvement is proportional to the degree of weight loss. In a prospective study of 293 patients, a weight loss of 5% or more was associated with resolution of steatohepatitis in 58% of cases, and a loss of 10% or more with resolution in 90% and regression of fibrosis in 45%; overall, however, steatohepatitis resolved in only 25% of participants after one year [16]. Pharmacotherapy has only recently emerged. Resmetirom achieved resolution of steatohepatitis in 25.9–29.9% of patients versus 9.7% with placebo and improvement of fibrosis in 24.2–25.9% versus 14.2% [17]; semaglutide 2.4 mg led to resolution of steatohepatitis in 62.9% versus 34.3% and improvement of fibrosis in 36.8% versus 22.4% [18]. For patients with severe obesity, surgery remains the most effective way to achieve substantial and lasting weight loss, and current guidelines list it among the treatment options for steatohepatitis in this group [19].

3.3. Bariatric surgery: indications and general outcomes

According to the 2018 survey of the International Federation for the Surgery of Obesity, 696,191 procedures were performed worldwide; sleeve gastrectomy accounted for 55.4%, followed by Roux-en-Y gastric bypass and one-anastomosis gastric bypass, the popularity of which continues to rise [20]. The same procedures are used in Kazakhstan, where a randomised trial has compared stapled and stapleless one-anastomosis gastric bypass in patients with the metabolic syndrome [21]. The 2022 ASMBS/IFSO statement recommends surgery for individuals with a body-mass index of 35 kg/m² or more regardless of comorbidities and suggests considering it at 30–34.9 kg/m² in the presence of metabolic disease [22].

Long-term efficacy is well documented. Seven years after gastric bypass, patients maintained a mean loss of 28.4% of baseline weight, with a regain of 3.9% between years 3 and 7 [23]. In the SLEEVEPASS trial both procedures gave sustained weight loss at ten years, somewhat greater after bypass (median excess weight loss 50.7% versus 43.5%), whereas oesophagitis was more frequent after sleeve gastrectomy (31% versus 7%) [24]. A pooled analysis of 174,772 participants found a 49.2% lower hazard of death after surgery and a median gain in life expectancy of 6.1 years [25].

3.4. Effect of surgery on liver histology

The most complete data come from the Lille cohort. One year after surgery, steatohepatitis had disappeared in 85% of 109 patients with biopsy-proven disease, and fibrosis had decreased in 33.8% [26]. At five years, steatohepatitis was resolved without worsening of fibrosis in 84% of patients; fibrosis had decreased in 70.2% and disappeared in 56%, including 45.5% of those with baseline bridging fibrosis. Persistence of steatohepatitis was associated with less weight loss, and the regression of fibrosis continued between the first and the fifth year [27].

Meta-analyses give more modest and heterogeneous estimates. In a pooled analysis of 32 cohort studies (3093 biopsies), complete resolution was recorded for steatosis in 66%, inflammation in 50%, ballooning in 76% and fibrosis in 40% of patients, while new or worsening features of NAFLD appeared in 12% [28]. Another meta-analysis of 21 studies (2374 patients) found improvement of steatosis in 88%, of steatohepatitis in 59% and of fibrosis in 30% [29]; a third, covering 37 studies, reported resolution of steatosis in 56% and of fibrosis in 25%, with better results in Asian countries [30]. A recent synthesis of 30 studies (3134 patients), which also included intragastric balloon and gastric banding, showed a 72% reduction of liver fat on magnetic resonance imaging six months after surgery; the proportion of patients with steatosis fell by 44% at 3–6 months and by 29% at 3–5 years, whereas the proportion with significant fibrosis (F2 or higher) fell by only 18% and 17% at 1–2 and 3–5 years, respectively [31]. Across all sources, regression of fibrosis is consistently less frequent than regression of steatosis and varies from 25% to 70%.

3.5. Clinical liver outcomes

Whether histological improvement translates into fewer clinical events was clarified by the SPLENDOR cohort of 1158 patients with biopsy-proven fibrotic steatohepatitis: the ten-year cumulative incidence of major adverse liver outcomes was 2.3% after surgery and 9.6% with non-surgical care (adjusted hazard ratio 0.12), and that of major cardiovascular events 8.5% versus 15.7% (0.30) [32]. In a matched analysis of insurance data, surgery was associated with a 69% lower risk of cirrhosis (hazard ratio 0.31) [33]. The first randomised trial, BRAVES, confirmed the superiority of surgery over lifestyle intervention plus best medical care: resolution of steatohepatitis without worsening of fibrosis at one year was achieved in 56% of patients after gastric bypass, 57% after sleeve gastrectomy and 16% in the control group [34].

3.6. Liver enzymes after surgery

Biochemical dynamics are of particular practical interest because aminotransferases and ultrasound remain the basis of routine follow-up in most clinics. In the Lille cohort the mean alanine aminotransferase (ALT) level decreased from 52.1 to 25.1 IU/L within one year [26]. Among 310 patients with biopsy-proven NAFLD and elevated baseline enzymes (median follow-up four years), liver tests normalised in 84%, usually by the end of the first year; mean ALT fell from about 60 to 26–27 IU/L and aspartate aminotransferase (AST) from 49 to 27–28 IU/L [35]. Pooled estimates are less optimistic: ALT improved in 62% and AST in only 32% of operated patients in one meta-analysis [29], and the mean reductions in another were 11.95 U/L for ALT and 6.44 U/L for AST [30]. A considerable proportion of patients therefore do not achieve biochemical normalisation. During the first months, when weight loss is most rapid, liver enzymes may rise, reflecting hepatic injury; they are expected to return to normal within a year [36]. Quantitative criteria that distinguish this transient rise from clinically significant damage have not been established.

3.7. Comparison of surgical procedures

For steatosis the two main procedures appear equivalent. BRAVES found no difference between them [34]; in a randomised comparison in patients with type 2 diabetes, 94% of patients after sleeve gastrectomy and all patients after gastric bypass had no or low-grade steatosis at one year, although the serum fibrosis marker ELF worsened in 18% of participants [37]. Normalisation of liver tests was equally frequent after sleeve gastrectomy and gastric bypass (82% versus 84%) [35]. For fibrosis the data are contradictory: one meta-analysis reported greater histological benefit after gastric bypass [29], another found that steatosis improved more after bypass and fibrosis more after sleeve gastrectomy [30], and in a long-term biopsy study sleeve gastrectomy was an independent predictor of persistent advanced fibrosis [38]. Evidence on one-anastomosis gastric bypass is scarce: in a prospective study of 67 patients, steatohepatitis disappeared in 42% and the fibrosis stage regressed in 79.1% fifteen months after the operation [39].

3.8. Hepatic risks and limitations of surgery

First, fibrosis does not regress in all patients. In 66 patients re-biopsied on average six years after surgery, fibrosis decreased by at least one stage in 70%, yet advanced fibrosis persisted in 47% of those who had it at baseline despite resolution of steatohepatitis; older age and sleeve gastrectomy were independent predictors, and persistence was associated with lesser weight loss [38]. Patients with advanced fibrosis therefore continue to need hepatological surveillance after surgery, including screening for hepatocellular carcinoma [36].

Second, the liver may deteriorate. Apart from the 12% of patients with new or worsening histological features [28], severe injury has been described after rapid weight loss or malnutrition: in a series of six such patients, four of whom had undergone gastric bypass and had lost 18 to 91 kg, four died or required urgent liver transplantation [40]. Liver failure is rare after sleeve gastrectomy and Roux-en-Y bypass, whereas after jejunoileal bypass and biliopancreatic diversion

its frequency reached 10% [36]. In SPLENDOR, four patients (0.6%) died within the first year from surgical complications [32].

Third, alcohol. The prevalence of alcohol use disorder did not change in the first year after surgery (7.3% versus 7.6% before) but rose to 9.6% in the second year, gastric bypass being an independent risk factor [41]. In insurance data, the short-term risk of alcohol-related cirrhosis was lower after sleeve gastrectomy and banding and higher after gastric bypass (hazard ratio 1.86), while women operated in an earlier period had about a twofold higher risk of alcohol-related cirrhosis and alcohol misuse [42]. Having removed the metabolic cause of liver disease, surgery may thus favour a toxic one if alcohol use is not monitored.

Fourth, pre-existing cirrhosis. In a nationwide sample, in-hospital mortality after bariatric surgery was 0.3% in patients without cirrhosis, 0.9% in compensated and 16.3% in decompensated cirrhosis [43]. An expert review of the American Gastroenterological Association considers surgery acceptable in selected patients with compensated cirrhosis at high-volume centres, with sleeve gastrectomy as the most likely optimal procedure, and regards surgery concurrent with or after liver transplantation as the only option in decompensated disease [44]. The stage of fibrosis should therefore be established before the operation.

Finally, bariatric procedures are followed by disturbances of vitamin, mineral and protein metabolism that require timely correction [45]; nutritional support and post-operative management are addressed in dedicated international guidelines [46, 47], and non-adherence to dietary recommendations compromises the result of the operation [48].

3.9. Post-operative liver follow-up and prevention of cirrhosis

The hepatological part of post-operative follow-up is far less developed than the nutritional one. The most specific proposals are contained in an expert review: liver tests (bilirubin, aminotransferases, gamma-glutamyltransferase, INR and albumin) at 3, 6 and 12 months and every 1–2 years thereafter if normal; referral of patients with significant fibrosis or cirrhosis found at surgery to a liver specialist for close monitoring and hepatocellular carcinoma screening; careful pre-operative assessment, in which a liver stiffness below 8 kPa reliably excludes advanced fibrosis; and education of patients about the risks of alcohol [36]. These recommendations reflect expert opinion and have not been tested in studies comparing different follow-up regimens.

Taken together, the available publications suggest the following directions for preventing progression of liver disease in operated patients: staging of fibrosis before surgery and choice of the procedure with regard to it [44]; avoidance of excessively rapid weight loss and protein deficiency in the first months [40]; continuous correction of vitamin and micronutrient deficiencies [45, 47]; abstinence from alcohol and active detection of its use [41, 42]; long-term maintenance of the achieved weight; and regular monitoring of liver tests with continued hepatological surveillance in patients with baseline advanced fibrosis [36, 38]. Because persistence of steatohepatitis is linked to insufficient weight loss [27], measures aimed at weight maintenance are at the same time measures of liver protection.

4. Discussion

The reviewed evidence is consistent in its main message: weight loss achieved by bariatric surgery reverses steatosis and steatohepatitis in the majority of patients, and this histological effect is accompanied by a lower incidence of cirrhosis and other major liver events. The effect on fibrosis is slower, less frequent and more variable across studies, which is explained by differences in baseline severity, duration of follow-up, type of procedure and definitions of response. Since fibrosis is the main determinant of prognosis, the hepatic benefit of surgery should be judged by fibrosis rather than by steatosis, and patients with advanced fibrosis cannot be considered cured after the operation. The data on liver enzymes point in the same direction: normalisation is frequent but not universal, so persistently abnormal tests after surgery deserve attention rather than reassurance.

Several gaps follow from this analysis. Almost all evidence originates from specialised centres in Western Europe and North America and relies on paired biopsies, which are rarely repeated in everyday practice; we found no studies that specifically assessed liver outcomes after bariatric surgery in Kazakhstan or other Central Asian countries. It remains unclear how to interpret the absence of enzyme normalisation or a repeated rise, when the ultrasound signs of steatosis should be expected to regress, and whether the thresholds of non-invasive fibrosis tests established for the general NAFLD population apply to operated patients. The contribution of patient behaviour – diet, physical activity, adherence to follow-up and alcohol use – to long-term hepatic results is seldom analysed together with clinical and laboratory data. Data on one-anastomosis gastric bypass are limited to small series.

This review has limitations. It is narrative rather than systematic, no formal assessment of the risk of bias was performed, and most of the included studies are observational, with only one randomised trial addressing liver histology. The conclusions on the comparative effect of different procedures and on post-operative follow-up should therefore be regarded as preliminary.

5. Conclusion

Bariatric surgery leads to resolution of steatosis and steatohepatitis in most patients with obesity and markedly reduces the incidence of cirrhosis and other major liver outcomes, which makes it the most effective available method of preventing cirrhosis in severe obesity. However, fibrosis regresses in a smaller proportion of patients and may persist for years, a minority of patients experience hepatic deterioration, and the long-term result depends on the rate of weight loss, nutritional status, alcohol use and adherence to recommendations. A generally accepted, prospectively validated algorithm of liver follow-up after bariatric surgery does not exist. Studies that combine routine clinical, biochemical and ultrasound data with an assessment of patients' lifestyle and adherence, particularly in populations not yet represented in the literature, are needed to develop such an algorithm.

Funding: This work was supported by the Ministry of Healthcare of the Republic of Kazakhstan through programme-targeted funding (Programme No. BR27310319, "Development of preventive and rehabilitation programmes to improve the population's quality of life in the post-COVID period").

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UDC: 616-006-071(574)

NATIONAL CANCER SCREENING PROGRAMS IN KAZAKHSTAN: IMPLEMENTATION RESULTS AND PRIORITIES

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Annotation: This scientific and analytical study examines the epidemiological patterns of cervical, breast, and colorectal cancer in the regions of the country, with particular emphasis on incidence and mortality rates and their regional variation. The study provides a comprehensive assessment of the current state of cancer screening and prevention, including the screening approaches used for the early detection of these malignancies in clinically asymptomatic populations. Particular attention is given to the organization and implementation of population-based screening programs, the target populations, screening intervals, diagnostic methods, and the subsequent management of individuals with abnormal screening results. The analysis also considers the role of screening in reducing the burden of malignant neoplasms through early detection and timely referral for further diagnostic evaluation and treatment. The study presents detailed, step-by-step algorithms for the organization and implementation of screening for cervical, breast, and colorectal cancer, outlining the principal stages from identification and invitation of eligible individuals to primary screening, additional diagnostic procedures, confirmation of the diagnosis, and appropriate follow-up. The diagnostic capabilities and practical significance of the screening methods currently applied are described, with particular emphasis

on their potential for detecting precancerous conditions and early-stage malignancies before the onset of clinical symptoms. The findings highlight the importance of a systematic, evidence-based approach to cancer screening and demonstrate the potential of well-organized preventive programs to improve early detection, facilitate timely treatment, and ultimately contribute to reductions in cancer-related incidence and mortality.

Key words: oncology, primary care, early diagnosis, cancer screening, cervical cancer, breast cancer, colorectal cancer, epidemiology, incidence, mortality, HPV, Pap test, smear for oncocytology, ultrasound examination, mammography, hemocult test, fecal occult blood test - FOBT, total colonoscopy.

Early detection of malignant neoplasms remains one of the fundamental priorities of modern oncology and an essential component of effective cancer control. The clinical outcomes of many malignant diseases are strongly influenced by the stage at which the tumor is diagnosed, with earlier-stage detection generally associated with a greater range of therapeutic options, improved treatment outcomes, and more favorable long-term prognosis. Consequently, the development and implementation of effective strategies for identifying malignant and premalignant conditions before the appearance of clinical manifestations represent an important direction in contemporary preventive medicine. Cancer screening is an established approach to secondary prevention aimed at detecting disease in individuals who do not yet exhibit symptoms or clinical signs suggestive of malignancy. Unlike diagnostic procedures performed in patients with suspected disease, screening is conducted among predefined target populations according to established age, sex, and risk-based criteria. Its primary objective is to identify cancer at a preclinical or early stage, when the pathological process may be more amenable to curative treatment. In addition, screening may facilitate the detection of premalignant lesions and other pathological changes that have the potential to progress to invasive cancer, thereby creating an opportunity for timely intervention and prevention of malignant transformation [1].

The effectiveness of a screening program depends not only on the diagnostic performance of individual screening methods but also on the quality of its overall organization and implementation. A well-functioning screening system requires clearly defined target populations, standardized procedures for participant recruitment and examination, appropriately trained healthcare professionals, and consistent criteria for interpreting and managing screening results. Equally important is the availability of an established pathway for the subsequent evaluation of individuals with abnormal findings, including confirmatory diagnostic procedures, specialist referral, treatment, and follow-up. Without adequate coordination between these stages, the potential benefits of screening may be substantially reduced [1,2].

Screening technologies and diagnostic approaches should meet several fundamental requirements to ensure their applicability at the population level. Ideally, screening procedures should be sufficiently simple, safe, accessible, reproducible, and acceptable to the target population, while demonstrating adequate sensitivity and specificity. High sensitivity is essential for minimizing the number of clinically significant cases that remain undetected, whereas adequate specificity helps to reduce false-positive results and unnecessary diagnostic interventions. Therefore, the development of standardized, evidence-based screening algorithms and their systematic implementation are critical for improving the early detection of cancer and precancerous conditions and, ultimately, for reducing cancer-related incidence and mortality [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 cancer 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 [6].

CC screening is a population-based preventive intervention aimed at detecting cervical precancerous lesions and CC at an early stage, when timely diagnostic assessment and treatment can prevent progression to invasive disease. In Kazakhstan, CC screening is organized within the national population screening program and is conducted among predefined target groups according to age and clinical eligibility criteria [7,8,9].

According to the current national screening framework, women who reach the ages of 30, 34, 38, 42, 46, 50, 54, 58, 62, 66, 70 and 74 years and who are not under dynamic follow-up for cervical malignancy constitute the target population for CC screening. Screening is performed once every four years, with the screening episode expected to be completed within 60 days.

The age-specific schedule represents a population-based strategy in which eligible women are identified through the primary healthcare system. Recent data from Kazakhstan confirm the use of a four-year screening interval and cytological examination for CC screening within the national program.

The preparatory stage is performed within the primary healthcare organization. It includes:

- identification and annual formation of the target population;
- verification and monthly updating of the list of eligible women;
- informing women about the purpose and benefits of CC screening;
- invitation to participate in screening;
- registration of screening attendance and organization of timely completion of the screening pathway.

The national regulations require primary healthcare organizations to form target groups from the population attached to the healthcare organization and to establish a sequential pathway for the provision of screening services. The target population is initially compiled annually, with subsequent monthly correction.

The primary screening examination is performed in the primary healthcare setting by an appropriately trained healthcare professional. The screening procedure includes collection of a cervical specimen for cytological examination.

Under the current Kazakhstan program, cervical screening is based on cytological examination of a cervical smear using the Papanicolaou (Pap) test, with liquid-based cytology used within the national screening program. The collected specimen is submitted to a cytology laboratory for standardized evaluation.

Before specimen collection, the woman should receive appropriate instructions concerning factors that may interfere with specimen quality. The collected material must be properly identified, documented and transported according to laboratory requirements.

Cytological examination should be reported using standardized terminology, preferably the Bethesda System, which provides a reproducible framework for classifying cervical cytological findings [10].

The cytological result may be classified as:

- NILM (Negative for Intraepithelial Lesion or Malignancy) – no evidence of intraepithelial lesion or malignancy;
- ASC-US (Atypical Squamous Cells of Undetermined Significance);

- ASC-H (Atypical Squamous Cells, cannot exclude HSIL);
- LSIL (Low-Grade Squamous Intraepithelial Lesion);
- HSIL (High-Grade Squamous Intraepithelial Lesion);
- AGC (Atypical Glandular Cells) and other glandular abnormalities;
- cytological findings suspicious for or diagnostic of invasive carcinoma.

The Bethesda terminology is widely used in contemporary cervical screening and abnormal-result management. Current evidence-based guidelines emphasize that management should depend not only on the cytological category but also, where available, on Human papillomavirus (HPV) status, previous screening history and the estimated risk of clinically significant cervical intraepithelial neoplasia.

A woman with an abnormal cytological result should not simply return to routine screening. She should enter a diagnostic pathway according to the severity of the abnormality and the applicable national clinical recommendations.

The diagnostic pathway may include: abnormal cytology → clinical assessment → HPV testing where indicated → colposcopy → directed cervical biopsy when indicated → histological examination → definitive diagnosis → treatment or surveillance.

Risk-based management is preferable to management based exclusively on a single cytological result. The 2019 American Society for Colposcopy and Cervical Pathology consensus guidelines, published in 2020 and subsequently updated, incorporate current screening results together with previous results and clinical history when determining the need for surveillance, colposcopy or treatment.

For example, high-grade cytological abnormalities generally require prompt diagnostic evaluation, while selected low-grade abnormalities may be managed with HPV-based triage and/or surveillance depending on the patient's estimated risk. Unsatisfactory cytology requires repeat testing or further evaluation according to the applicable guideline.

The second stage of the national screening pathway is intended to determine the cause of an abnormal screening result and establish a definitive diagnosis. Under the Kazakhstan regulations, women with abnormal screening findings are referred by the primary healthcare physician for further examination. Depending on the screening result, this may include consultation with an obstetrician-gynecologist, colposcopy or videocolposcopy, cervical biopsy when indicated, histological examination and consultation with an oncologist or gynecologic oncologist.

Thus, the screening process should be regarded as a continuum extending from population identification and primary testing to diagnostic confirmation and subsequent treatment or surveillance, rather than as an isolated cytological examination.

At the final stage, the screening results and the established clinical diagnosis are documented in the healthcare information system. The woman is informed of the results and receives recommendations regarding further diagnostic evaluation, treatment, surveillance or return to routine screening.

The national regulations specifically require screening organizations to record screening results, final diagnoses and recommendations for further examination and follow-up. The screening episode is considered complete when the appropriate endpoint of the clinical pathway has been documented.

The contemporary population-based cervical cancer screening algorithm can therefore be summarized as follows:

Identification of the target population → invitation and information → cervical specimen collection → primary cytological screening → cytological classification → assessment of abnormal results → HPV testing/triage where indicated → colposcopy and biopsy when indicated → histological confirmation → treatment or surveillance → documentation and return to routine

screening.

This approach combines the organizational framework of the national screening program in Kazakhstan with contemporary principles of risk-based management of abnormal cervical cancer screening results.

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 [11,12].

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 [13].

Preventive screening for early detection of BC in the Republic of Kazakhstan includes [7]:

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 [14].

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 [15].

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 [7]. 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 [16].

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 CC, BC and CRC clearly reflect the epidemiological situation with this pathology in the regions of our country.

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Historical Sciences

Ерлігімен үлгі болған қазақ қызы

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Аңдатпа

Ұлы Отан соғысы жылдары халқымыз үшін аса ауыр әрі сындарлы кезең болды. Майдан даласына елін, жерін қорғау үшін аттанған ер азаматтармен қатар, қазақтың қайсар қыздары да Отан алдындағы борышын өтеуге бел буды. Солардың қатарында ерлігімен ел жадында мәңгі қалған қазақтың батыр қызы – Әлия Молдағұлова бар. Жастық шағын соғыс өрті шарпыған Әлия небәрі он сегіз жасында майданға аттанып, мерген ретінде жауынгерлік міндетін абыроймен атқарды. Оның қайсарлығы, батылдығы мен Отанға деген адалдығы қазақ қыздарының рухының мықтылығын танытты. Әлияның қысқа ғұмыры мен ерлікке толы жауынгерлік жолы – бүгінгі ұрпақ үшін өшпес өнеге.

Бұл мақалада Әлия Молдағұлованың өмір жолы, майдандағы әскери қызметі мен ерлігі қарастырылады. Сонымен қатар оның қаһармандық тағдырының тарихи маңызы және кейінгі ұрпаққа берер тағылымы сараланады. Әлия Молдағұлованың ерлігі – соғыс жылдарындағы қазақ қыздарының қайсарлығы мен Отанға деген шексіз сүйіспеншілігінің жарқын көрінісі.

Кілт сөздер: Әлия Молдағұлова, қазақ қызы, Ұлы Отан соғысы, ерлік, батырлық, қаһармандық, тарихи жады.

Аннотация

Годы Великой Отечественной войны стали для нашего народа одним из самых тяжелых и судьбоносных периодов. Наряду с мужчинами, ушедшими на фронт защищать свою Родину и родную землю, мужественные казахские девушки также стремились выполнить свой долг перед Отечеством. Среди них была отважная казахская девушка Алия Молдагулова, чье имя навсегда осталось в памяти народа благодаря ее героизму. Война пришлась на годы ее юности, и в возрасте всего восемнадцати лет Алия отправилась на фронт, где служила снайпером и доблестно выполняла свой воинский долг. Ее стойкость, мужество и преданность Родине стали ярким свидетельством силы духа казахских девушек. Короткая жизнь Алии и ее наполненный героизмом боевой путь являются незабываемым примером для современного поколения.

В данной статье рассматриваются жизненный путь Алии Молдагуловой, ее военная служба на фронте и героический подвиг. Особое внимание уделяется историческому значению ее судьбы и нравственному наследию, которое она оставила последующим поколениям. Подвиг Алии Молдагуловой является ярким примером мужества казахских девушек в годы войны и их безграничной любви к Родине.

Ключевые слова: Алия Молдагулова, казахская девушка, Великая Отечественная война, подвиг, мужество, героизм, историческая память.

Abstract

The years of the Great Patriotic War became one of the most difficult and fateful periods in the history of our people. Alongside the men who went to the front to defend their homeland and native land, courageous Kazakh women and girls also sought to fulfill their duty to their country. Among them was Aliya Moldagulova, a brave Kazakh girl whose name has remained

forever in the memory of her people because of her heroic deeds. The war coincided with the years of her youth, and at the age of only eighteen, Aliya went to the front, where she served as a sniper and honorably fulfilled her military duty. Her resilience, courage, and devotion to her homeland demonstrated the strength of spirit of Kazakh women. The short life of Aliya and her heroic military journey remain an unforgettable example for younger generations.

This article examines the life of Aliya Moldagulova, her military service at the front, and her heroic contribution during the war. Particular attention is paid to the historical significance of her life and the moral legacy she left for future generations. The heroic deed of Aliya Moldagulova represents a remarkable example of the courage of Kazakh women during the war and their profound devotion to their homeland.

Keywords: Aliya Moldagulova, Kazakh girl, Great Patriotic War, heroic deed, courage, heroism, historical memory.

Кіріспе

Ұлы Отан соғысы – адамзат тарихындағы ең қасіретті әрі ауыр кезеңдердің бірі. 1941 жылы басталған соғыс миллиондаған адамның тағдырын өзгертіп, талай шаңырақты қара жамылдырды. Майдан даласында қаншама жауынгер Отан үшін жанын қиса, тылда қалған халық та Жеңіс үшін бар күшін жұмсады. Бұл жылдар – ерлік пен қайсарлықтың, төзім мен үміттің сынға түскен шағы болды.

Сол бір сұрапыл жылдары елін қорғау тек ер азаматтардың ғана міндеті болған жоқ. Қазақтың өр мінезді, жүрегі батыл қыздары да майданға аттанып, қолдарына қару алды. Олар туған жерінен жырақта жүріп, Отан үшін күресті, жаралыларға көмек көрсетті, байланыс қызметін атқарды, ал кейбірі тікелей ұрыс даласында жаумен шайқасты.

Солардың арасынан есімі ел жүрегінде мәңгі сақталған қазақтың батыр қызы – Әлия Молдағұлованың орны ерекше. Кеше ғана бейбіт өмір сүріп жүрген жас қыздың тағдырын соғыс күрт өзгертті. Ол жастық шағын соғыс жылдарына арнап, Отан қорғау жолын таңдады. Бар болғаны он сегіз жасында майданға аттанып, мерген ретінде жауынгерлік борышын атқарды.

Әлияның ғұмыры қысқа болғанымен, оның артында қалдырған ерлігі ғасырларға жетерлік. Ол өз өмірін елінің азаттығы мен бейбіт болашағы үшін құрбан етті. Оның есімі – қазақ қызының қайсарлығының, батылдығының және Отанға деген шексіз сүйіспеншілігінің символына айналды.

2. Негізгі бөлім

2.1 Әлияның балалық шағы мен майданға бастар жолы

Әлия Молдағұлованың тағдыры соғыс басталмай тұрып-ақ өмірдің талай сынағымен астасты. Ол 1925 жылғы 25 қазанда Ақтөбе облысы Қобда ауданының Бұлақ ауылында дүниеге келген. Жеті жасында анасынан айырылып, бала Әлияны нағашы ағасы Әубәкір қамқорлығына алады. Осылайша оның балалық шағы туған ауылынан жырақта, ағасының жанында өтеді.

1935 жылы Әубәкір әскери-көлік академиясына оқуға түсіп, отбасымен бірге басқа қалаға көшеді. Әлия да ағасының қасында жүріп, елдің бірнеше қаласында тұрады. Бұл көшіп-қону оның өмірге деген көзқарасының қалыптасуына, түрлі ортаға бейімделуіне ықпал етті. Кейін он төрт жасында ол Ленинградтағы Охта ауданындағы балалар үйіне тәрбиеленуге жіберіледі.

Әлияның жасөспірімдік шағы Ленинград қаласының тағдырымен тығыз байланыста өтті. 1941 жылдың қыркүйегінде қала қоршауға алынып, тұрғындар үшін аса ауыр күндер басталды. Жас Әлия да сол қиындықты қатарынан көрді. Ол өзімен бірге тәрбиеленіп жатқан балалармен бірге қала маңындағы қорғаныс бекіністерін салу жұмыстарына қатысты. Ауыр

еңбек пен аштыққа, қорқыныш пен белгісіздікке қарамастан, Әлия өз міндетіне адал болды. Ол тек өзі ғана қажымай еңбек етіп қоймай, айналасындағы балаларға да жігер беріп, қиындыққа мойымауға шақырды.

Оның қайсар мінезі мен белсенділігі сол кезеңдегі жастар ұйымы – комсомол мүшелігіне қабылдануымен де көрініс тапты. 1941 жылдың қарашасында Әлия комсомол қатарына қабылданды. Бұл жас қыздың ел басына түскен ауыр кезеңге бейжай қарамай, қоғам өміріне белсенді араласқанын көрсетеді.

1942 жылдың көктемінде балалар үйі Ярославль облысына көшірілді. Әлия мектепті сонда аяқтап, сол жылы Рыбинск авиациялық техникумына оқуға түсті. Алайда оның ойында бір ғана мақсат болды – ел басына күн туған кезде майданнан тыс қалмау. Ол бірнеше рет әскери қызметке сұранып, майданға жіберуді өтінді. Бірақ алғашқы өтініштері қабылданбады.

Әлияның жүрегінде туған елін қорғауға деген ұмтылыс барған сайын күшейе түсті. Он жеті жасқа толғаннан кейін көп ұзамай, 1942 жылдың қарашасында ол техникумнан «майданға аттануына байланысты» деген негізбен шығарылды. Осы сәт оның өміріндегі жаңа кезеңнің басталуын білдірді.

2.2 Әлия Молдағұлованың әскери қызметі

Әлия Молдағұлова Мәскеу түбіндегі Вешняки елді мекенінде орналасқан мергендер даярлайтын Орталық әйелдер мергендер мектебіне қабылданды. Әскери дайындықтан өткеннен кейін, 1943 жылдың шілде айында 22-армия құрамындағы 54-ші жеке атқыштар бригадасына мерген ретінде жіберілді.

Әлияның майдандағы қызметі туралы мәліметтер оның майдандастарының естеліктерінде де сақталған. Бригада жауынгері Я.К. Прокопенкованың естелігінде Әлияның Қазақстаннан келгені және он сегіз жаста болғаны айтылады. Оның айтуынша, 1943 жылдың қазан айына дейін Әлияның жауынгерлік есебінде 32 жау әскері болған.

Әлиямен бірге бір бөлімде қызмет еткен Н.А. Матвеева да оның жауынгерлік тапсырмалары туралы естелік қалдырған. Оның айтуынша, мергендер тапсырманы көбіне жұп болып орындаған және алдын ала белгіленген позицияларға орналасқан. Ұрыс кезінде Әлия өзіне жүктелген міндетті орындаумен қатар, жараланған жауынгерлерге де көмек көрсеткен.

2.3. Әлия Молдағұлованың соңғы шайқасы

1944 жылдың қаңтар айының басында 54-ші жеке атқыштар бригадасы Ленинград-Новгород операциясы барысында Псков облысындағы Новосокольники бағытына қарай жылжыды. Әлия Молдағұлова қызмет еткен 4-ші батальонға Насва станциясы маңындағы Новосокольники–Дно теміржолын кесіп өтіп, Казачиха елді мекеніне шабуыл жасау міндеті қойылды.

1944 жылғы 14 қаңтардың таңында кеңес әскері шабуылға шықты. Алғашқы кезеңде қорғаныстың алдыңғы шебі бұзылғанымен, кейін неміс әскерлерінің қарсылығы күшейді. Осы шайқаста Әлия Молдағұлова жауынгерлермен бірге шабуылға қатысты.

Шайқас барысында Әлия жауынгерлерді алға ұмтылуға шақырып, шабуылды жалғастырды. Ұрыс кезінде оның қолына мина жарықшағы тиіп, жараланды. Соған қарамастан, ол шайқасты тоқтатпай, жаумен қоян-қолтық ұрысқа қатысты. Осы ұрыста Әлия тағы да жараланып, алған жарақаты салдарынан қаза тапты.

Әлия Молдағұлова 1944 жылғы 14 қаңтарда небәрі он сегіз жасында майдан даласында қаза тапты. Оның соңғы шайқасы жас қазақ қызының әскери жолындағы ең маңызды оқиғалардың бірі болды.

Әлия Молдағұлованың ерлігі мемлекет тарапынан жоғары бағаланды. КСРО Жоғарғы Кеңесі Президиумының 1944 жылғы 4 маусымдағы Жарлығымен оған қайтыс болғаннан кейін Кеңес Одағының Батыры атағы беріліп, Ленин орденімен марапатталды.

Осылайша, Әлия Молдағұлованың қысқа, бірақ ерлікке толы өмір жолы 1944 жылдың қаңтарындағы соңғы шайқасында аяқталды. Оның есімі соғыс жылдарында Отан қорғаған қазақ қыздарының ерлігінің символына айналды.

Қорытынды

Әлия Молдағұлованың өмір жолы – бір адамның тағдыры ғана емес, ел басына күн туған кезеңде Отан үшін отқа түскен тұтас бір ұрпақтың тарихы. Соғыс жылдарында қазақтың талай қызы туған жерінен жыраққа аттанып, қолына қару алып, Жеңіс үшін күресті. Солардың ішінде Әлияның есімі өзінің қайсарлығы мен ерлігі арқылы ерекше орын алады.

Әлия небәрі он сегіз жыл ғұмыр кешті. Бірақ осы қысқа өмірінің әрбір кезеңі елге деген сүйіспеншілікпен, табандылықпен және жауапкершілікпен өрілді. Ол соғыс басталғанда қиындықтан бойын аулақ салмай, өз еркімен майданға аттанды. Мерген ретінде жауынгерлік міндетін атқарып, соңғы деміне дейін шайқас даласында болды. Оның 1944 жылғы 14 қаңтардағы соңғы шайқастағы ерлігі – Отан алдындағы адалдықтың айқын көрінісі.

Бүгін біз бейбіт аспан астында өмір сүріп отырмыз. Бұл бейбітшіліктің артында қаншама адамның төгілген қаны, үзілген арманы мен құрбан болған ғұмыры жатыр. Әлияның өмірін еске алу – сол құрбандықтарды ұмытпау, өткен тарихқа құрметпен қарау деген сөз.

Әлия Молдағұлова өмірден ерте кеткенімен, оның есімі халық жадынан өшкен жоқ. Оның ерлігі жылдар өткен сайын кейінгі ұрпаққа өнеге болып қала береді. Ол бізге туған жерді сүюдің, елге адал болудың, қиындыққа мойымаудың және өз міндетіңді соңына дейін атқарудың мәнін көрсетеді.

Әлияның ғұмыры қысқа болды, бірақ ерлігі мәңгілікке жетті. Оның есімі – қазақ қызының қайсарлығының, батылдығының және Отанға деген шексіз сүйіспеншілігінің символы. Әлияның ерлігі – тарихта қалған бір күннің оқиғасы емес, ұрпақтан ұрпаққа жалғасатын мәңгілік аманат.

Қазақстандағы халық ағарту ісінің эволюциясы және ұлттық кадрлардың қалыптасуы

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Аңдатпа. Мақалада Ресей империясы кезінде қазақ даласында алғашқы білім ордаларының салынып, кеңес үкіметінің алғашқы жылдарындағы өзгерісі талданады. Қазақ жерінде салынған алғашқы мектеп-медреселер, кітапханалар мен әдеби ұйымдардың тарихи маңыздылығымен қатар, оқиғалардың басында жүрген зиялылардың білім саласының дамуына қосқан үлестері сараланды. Мақалада Қазан төңкерісінің білім жүйесіне әкелген өзгерістері жан-жақты талданады. Жүйелілік, жинақтау және салыстырмалы әдіс жинақталған ақпараттарды бір жүйеге салып, нақты қорытынды жасауға мүмкіндік берді.

Тірек сөздер: зиялылар, білім жүйесі, мектеп, газет, журнал, сауаттылық, Халық Ағарту Комиссарлары.

Ресей Империясы қазақ жерінде бірнеше білім ордаларын ашқан еді. Бұны олар жергілікті халық арасында Ресейге қызмет ететін топты қалыптастыру үшін жасаған еді. «Азиялық училище» 1789 жылы Омбыда ашылса, 1813 жылы әскери училище Омбыда, ал 1825 жылы тура сондай училище Орынборда ашылған. 1831 жылы орысша білім беретін училище Семейде, 1836 жылы интернаты бар училище Өскеменде, 1841 жылы Жәңгір хан құрған мектеп Бөкейде, 1850 жылы шекаралық комиссиясы жанынан қазақтарға орысша білім беретін мектеп Орынборда, 1861 жылы орыс-қазақ мектебі Троицкте ашылды. Одан басқа ақысыз қоғамдық кітапханалар Торғай мен Орынборда, қоғамдық кітапхана 1883 жылы Семейде ашылды. Орал, Омбы мен Орынбор қалаларында кітап шығару қолға алынып, бірнеше кітаптар жарыққа шыққан еді. 19 ғасырдың соңына таман көпшілік қоғамдық кітапханалар Верныйда да пайда болды.

Бұл уақытта қазақтар медреседе сауаттарын ашқан еді. Олар жастайынан араб тілін меңгеріп, тарих, хикмет, пайғамбарлар тарихы сынды пәндерді оқыған еді. 1870 жылы білім беру жүйесіне өзгерістер енгізіліп, оқушылар мамыр-тамыз айларында оқып, оқуды бітірген жағдайда әдетте Бұқар мен Ташкентте оқуларын жалғастырған [1].

Бірінші орыс төңкерісі және одан кейін болған Ақпан төңкерісі мен Қазан төңкерісі қоғамды түбегейлі өзгертуге мүмкіндік ашты. Білім беру жүйесін өзгерту мәселесі Қарқаралы петициясы арқылы және Мемлекеттік Думада мінберде қазақ депутаттары сөйлеген сөздер арқылы көтерілсе де, кадрларды қайта даярлау және елдегі оқыту ісін қайтадан қарау туралы ойлар алаш зиялылары жариялаған газет пен журналдардан көрініс тапты. 1913-1918 жылдары Орынборда шыққан, әртүрлі уақытта Ахмет Байтұрсынұлы, Міржақып Дулатұлы және Жанұзақ Жәнібекұлы редакторлық еткен «Қазақ» газеті, 1917-1919 жылдары Семейде шығып тұрған, Имам Әлімбек, Халел Ғаббас, Райымжан Мәрсекұлы редакторлық еткен «Сарыарқа» газеті, 1918 жылы Семейде шығып тұрған, Жүсіпбек Аймауытұлы мен Мұхтар Әуез редакторлық еткен «Абай» журналы, 1917 жылы Қызылжарда шығып тұрған, Біләл

Малдыбайұлы жауапты болған «Жаңа заман» журналы, 1917-1918 жылдары Ташкентте Мұстафа Шоқай, Хайретдин Болғанбай, Сұлтанбек Қожанұлы атты азаматтардың редакторлығымен жарияланған «Бірлік туы» газеті жас кадрлардың қалыптасуына айтарлықтай үлес қосты деп айтуға болады [2].

«Сарыарқа» газетінің белгілі редакторлары Райымжан Мәрсекұлы мен Халел Ғаббас болды [3]. Бұл газеттің жаңа кадрлардың қалыптастырып, білім саласындағы өзекті мәселелерді көтеруіне қосқан үлесін атап өткен дұрыс. Бұл газет азамат соғысы кезінде халықты дер кезінде біріктіріп, ортақ игілік үшін ұйымдастыруға жағдай жасаған «Қазақ» газетінің тарихи миссиясын атқарған бірден-бір ерекше газет болды.

Бұл газетте «Шәкірт ойы», «Жас жүрек» деген Сұлтанмахмұт Торайғырдың өлеңдері шықты. Мұхтар Әуездің әйел мәселесін көтерген мақалалары шықты. Сәбит Дөнентайұлының «Жамилә қыз» және «Қаулы» деген өлеңдері жарық көрді. Ғұмар Қараштың «Алаштың ұлдарына» атты үндеуі де жарияланды [4, 44 б.].

«Мұғалімдердің ұйымынан» және «Мұғалім курстары туралы» мақалаларының авторы оқуды ұйымдастыруды түбегейлі өзгертуді шақырды. Автор диплом үшін емес, адам кемелденуі үшін оқу қажеттілігін айтып қана қоймай, догматизм мен қорқыныштан арылып, ғылымға сыни көзқараспен қараудың маңыздылығына тоқталды. Автор мұғалімдердің біліктілігіне де тоқталды. Көбісінің жеткілікті білімі болмаса да, пән оқытушысы болатыны, ал оқушылардың ғылымға қызыққандықтан емес, әкелері жібергендіктен ғана оқитындығын айта келе, тек оқушының санасы ашылып, көкірегі оянғанда ғана ғылым дамитынын атап өтті [4, 46 б.].

«Курсқа Мұғалімдер қажет» атты мақалада Көкшетауда екі айлық мұғалімдер даярлайтын курс ашылғандығы, оны мемлекет қаржыландырылатыны баяндалды [4, 48 б.].
«Әдеби кеш» атты мақалада Зайсанда әдеби кеш ұйымдастырылғаны, оның ұйымдастырушысы әйел екені мәлімделді. Әдеби кешті «Халық жәрдемі» атты ұйым ұйымдастырған. Бұл алғашқы рет қазақ тілінде ұйымдастырылған қоғамдық кеш болды. Әйелдердің бұл кешке белсене араласуы кештің тарихи маңыздылығын арттыра түсті. Тура сол сияқты Павлодар уезіндегі Басқұдық ауданында тура сондай кешті «Өрнек» ұйымы ұйымдастырған [4, 49 б.]. Осылайша, алаш зиялылары болашақ жастарды тәрбиелейтін мұғалімдерді даярлайтын оқу орындары мен әдеби ұйымдарды ашып, қабілетті білім берушілер мектебінің іргетасын қалаған еді.

Кеңес билігі кезінде сауатсыздықпен күрес одан да жылдамырақ өткен. РКФСР Халық Комиссарлар Кеңесі тарапынан 1919 жылдың 26 желтоқсанында сауатсыздықты жою туралы Декретке қол қойылды. 1939 жылы сауаттылық деңгейі 76 пайызға жетіп, кеңес билігі қойған мақсаттарына жете алған [5].

Қазақстанда білім беру жүйесі қағидаттары Қазақ КСР БОАҚ «Бірыңғай еңбек мектебі» туралы Ережесінде бекітілді. Бұл ереже 1918 жылдың 16 қазанында жарияланып, ақысыз білім беру, ер балалар мен қыз балаларды бірге оқыту, мектептің өзін-өзі басқаруы, білім алушыларды жазалауды тоқтату туралы сол заман үшін ілгері оймен қатар, мектепті екі сатыға бөлу арқылы білім беруді оңтайландыру идеясы көтерілді. Бірінші сатыда 8-13 жасар балалар, екінші сатыда 13-17 жасар балалар оқитын болды. Медреселер, орыс-қазақ мектептері және басқа да орындарды кеңестік мектепке айналдыру жұмыстары белсендірілді. Бір және екі жылдық мектептердің орнына төрт сыныптық мектептерді ұйымдастыру көзделді. 1926 жылдың мамырындағы «Қазақ АКСР бірыңғай еңбек мектебінің Жарғысы» нәтижесінде біржылдық және екіжылдық мектептердің үлес салмағы азайып, үшжылдық және төртжылдық мектептердің саны әлдеқайда арттыруға қадамдар жасалды [6, 65 б.].

Білім саласының дамуына бірінші қазақ-қырғыз білімпаздарының рөлі зор болды. Олар 1924 жылы 12 маусым күні құрылтай өткізген. Бұл топқа сол кездегі алдыңғы қатарлы

зиялылар мүше болды. Әсіресе, Нәзір Төреқұлұлы мен Әлихан Бөкейханның рөлін атап өткен дұрыс. Нәзір Төреқұлұлы мен Әлихан Бөкейхан 1923 жылы Күншығыс баспасынан Ахмет Байтұрсынұлы өңдеуімен «Ер Сайын» дастанын, одан өзге «Ер Тарғын», «Қозы Көрпеш – Баян Сұлу», «23 жоқтау» сынды қазақ әдебиеті үлгілерін басып шығарды [6, 63 б.].

Қазақстанда халық ағарту ісінің дамуына, әрине, Қазақ КСР Халық Ағарту Комиссарларының рөлі зор. Қазіргі тілмен айтқанда алғашқы білім министрі Ахмет Байтұрсынұлы (1920-1921 жж.) болды. Бұл кезде оның орынбасары қызметін Жүсіпбек Аймауытұлы атқарды. Оның орнын Аспандияр Кенжин (1921-1922 жж.) басты. Аталған азаматтар Алашорда үкіметінің мүшелері болған еді. Одан кейін аттары көпшілік халыққа белгісіз Нұғыман Залиев пен Ж. Талғат (1922-1924 жж.), Ілияс Темірбеков (1924-1925 жж.) бұл қызметті атқарған еді [7]. Аталған азаматтар туралы деректер көп емес. 1920-1925 жылдар аралығында Кеңестік Қазақстанда кадрлық өзгерістер көп болып, бұл азаматтар елдің дамуына жеткілікті деңгейде үлес қоса алмады.

1925 жылы Халық Ағарту Комиссары қызметіне Смағұл Сәдуақасұлы келеді. Ол Еңбекшіл қазақ газетінің редакторы қызметін де қоса атқарған. Саясат, тіл, экономика мәселелерін көтеріп, елде білім ордалары мен театрлардың салынуына жағдай жасаған болатын. 1926 жылы Қызылордада Қазақ ұлттық драма театрын ашқан еді. Театрдың директоры сол кезде Дінше Әділ болатын. Театрдың шымылдығын Қошке Кемеңгердің «Алтын сақина» пьесасы ашқан еді. Ф.Голощекиннің Кіші Қазан төңкерісі идеясына қарсылық танытқандықтан, Смағұл Сәдуақасұлы қуғын-сүргін көріп, қызметін әрі елін де тастап кетеді. Оның орнын 1927 жылы Кәрім Тоқтыбай басып, ал ол өз кезегінде өз орнын тура сол жылы сол кездегі белгілі саяси қайраткер, жер-су реформасын жүргізген Ораз Жандосқа қалдырған еді. Алматыдағы белгілі қазіргі Абай атындағы Қазақ Ұлттық Педагогикалық Университет 1928 жылы, ал малдәрігерлік университет 1929 жылы Ораз Жандостың белсенділігінің арқасында салынған еді. Кейін Нұғман Манаев (1929-1930 жж.), ал одан кейін Сейітқали Меңдешұлы (1930-1933 жж.) білім саласын дамытқан еді. Сейітқали Меңдешұлы бұрын 1920-1925 жылдар аралығында Қазақ КСР ОАК төрағасы қызметін атқарған еді. Сондықтан бұндай жауапты қызметті атқару оған айтарлықтай қиындыққа соқпаған деп айтуға болады. 1930 жылы ауыл шаруашылығы және медицина институттары Алматыда ашылса, 1931 жылы қазіргі Алматыдағы белгілі Ұлттық кітапхана ашылған еді. 1932 жылы Ілияс Жансүгіруұлы төрағалық еткен Қазақстан Жазушылар Одағы және КСРО Ғылым академиясының Қазақ филиалы ашылған еді. 1930 жылы кәсіптік-техникалық мектептер мен фабрика-зауыт оқу (ФЗО) орнындары және міндетті жеті жылдық білім беру жүйесі енгізілді. 1930 жылы М.Ю. Лермонтов атындағы Мемлекеттік академиялық орыс драма театрының да Сейітқали Меңдешұлының арқасында іргетасы қаланды [2].

Одан кейін 1933-1937 жылдары Темірбек Жүрген, 1937 жылы Біржан Манкин, 1937-1938 жылдары Сұлтан Сүйіншәлин, 1938-1941 жылдары Мұхамеджан Әбдіхалықов, 1941 жылы Төлеген Тәжібайұлы және 1941-1946 жылдары Әбдіхамит Сембай Халық Ағарту саласына жауапты болған еді. Бұл азаматтардың ішінен Темірбек Қараұлы Жүргенді ерекше атап өтуге болады. Ол Халық Ағарту Комиссары болған кезде 1934 жылы әл-Фараби атындағы Қазақ Ұлттық Университет, Абай атындағы Қазақ мемлекеттік академиялық опера және балет театры, ұйғыр мемлекеттік музыкалық комедия театры, 1935 жылы Жамбыл атындағы Қазақ мемлекеттік филармониясы және Құрманғазы атындағы халық аспаптар оркестрі салынған еді. Соғыс кезінде 1944 жылы Құрманғазы атындағы Қазақ ұлттық консерваториясы және Қазақ мемлекеттік қыздар педагогикалық институты ашылған еді [7].

Қорытындылай келе, Ресей империясы кезінде Қазақстанда мектептер жан-жақта салынып, көбіне орыс шенеуніктеріне қызмет ететін тілмәштарды даярлайтын мектептер салуға тырысса, кеңес үкіметі кезінде нақты бір жүйеге негізделген міндетті оқыту жүйесі

пайда болды. Қазақстанда алғашқы жоғарғы оқу орындары салынып, жас ұрпақты тәрбиелейтін кадрлар қалыптасты.

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Sociological Sciences

SOCIAL NETWORKS AS A MEANS OF INTERCULTURAL DIALOGUE AMONG YOUNG AI SPECIALISTS FROM DIFFERENT COUNTRIES

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Abstract. This article examines social networks and professional digital platforms as environments of socialization and intercultural dialogue among young artificial intelligence (AI) specialists from different countries. The target group includes students preparing for AI-related careers, junior developers and researchers, and early-career professionals. A structured narrative review and comparative secondary analysis of 13 verified sources from 2020-2026 is used to identify five social dimensions: participation, intercultural competence, bridging social capital, professional identity, and trust. The findings indicate that networked professional communication can widen access to international peers, mentoring, culturally diverse norms and professional opportunities. At the same time, language differences, regional clustering, unequal visibility and the need to verify AI-generated information can limit inclusive interaction. The proposed model shows how reciprocal participation, inclusive language, cultural sensitivity and verification practices can convert online contact into sustainable intercultural ties and professional development.

Keywords: youth; young AI specialists; artificial intelligence; social networks; intercultural dialogue; social capital; professional identity; digital communities.

Introduction

For young people entering AI-related professions, social networks are not only technical information channels but also spaces of participation, identity formation and entry into professional communities. Evidence from Kazakhstan shows that meaningful public participation in social networks can be associated with stronger involvement of young people in real social activity [1]. In AI-related communities, active participation may similarly support a transition from individual learning toward visible membership in wider expert networks.

Intercultural competence is therefore a social resource as well as a communication skill. Research on students in multilingual environments emphasizes the ability to interpret unfamiliar perspectives, adapt interaction and participate constructively across cultural boundaries [2]. These competencies matter for young AI specialists because learning, collaborative coding, peer review and career networking increasingly occur in international digital environments.

Social media can create direct intercultural exposure at an early stage of professional formation. Research with university students shows that interaction with culturally diverse users can support openness, curiosity, empathy and critical cultural awareness [3]. For future and early-

career AI specialists, such interaction may expand weak ties beyond national or institutional circles and build bridging social capital through access to new knowledge and opportunities.

Language remains a major social filter. Analysis of bilingual communication in Kazakhstan documents active switching between languages and mixed written practices online [4]. In global AI communities, English often serves as a shared technical language, while local languages remain important for identity and inclusion. Social networks can therefore broaden intercultural contact while reproducing inequalities when participation depends on linguistic confidence or visibility in a limited set of languages.

Materials and Methods

The study applies a structured narrative review and comparative secondary analysis of 13 verified sources published between 2020 and 2026. Sources address youth and social-media participation, intercultural communication, developer networks, AI-mediated professional interaction or cross-border collaboration. Five dimensions were coded: social participation and peer support, intercultural openness, bridging social capital, professional identity and inclusion, and trust and verification. Youth-specific evidence is distinguished from broader developer evidence; findings from general professional samples are treated as contextual rather than direct measurements of youth.

Results and Discussion

The social dimension of AI communication extends beyond ordinary platform use. The concept of “artificial sociality” describes situations in which AI agents become participants or active mediators of social interaction [5]. For young specialists, professional socialization may therefore involve both human peers and AI systems, changing patterns of authority, trust, learning and knowledge validation.

Professional discussion of AI governance also shows that technical communities participate in creating norms around responsibility, transparency and acceptable use [6]. Young specialists encounter these norms while building professional identity: peer reactions and community moderation communicate what is considered credible, ethical and professionally acceptable. Social networks thus operate as informal institutions of professional socialization.

Changes in work practices reinforce this effect. Research on freelancers using AI identifies prompt formulation, output assessment and error minimization as increasingly important competencies [7]. For early-career specialists, online communities can provide peer support and rapid skill diffusion, while also requiring users to learn when to trust automated assistance and when human verification is necessary.

Developer social networks provide an empirical basis for examining these processes at community level. A systematic mapping study identified 255 primary studies and showed that community structure, collaboration behavior and developer roles are major research themes [8]. GitHub, Stack Overflow and related spaces can therefore be understood as social systems where young specialists build reputation, observe norms, find mentors and establish professional ties.

Intercultural contact within these networks is not socially neutral. Comparison of Stack Overflow contributors from the United States, China and Russia found differences in task focus, pronoun use, information exchange and reflective behavior consistent with different cultural profiles [9]. For young AI specialists, cultural sensitivity can reduce misinterpretation when directness, collective orientation and socio-emotional expression differ across communities.

Cross-border collaboration remains extensive but incomplete. Analysis of approximately 144,000 European GitHub developers estimated that national borders reduced online collaboration by 16.4%, with shared language and cultural proximity explaining part of the effect [10]. Social platforms can create bridging ties that would be difficult to form offline, yet language, cultural familiarity and existing connections still shape who collaborates with whom.

Professional identity is also negotiated through visible expert discourse. Analysis of tens of thousands of AI-related LinkedIn posts found that adoption is shaped by performance expectations, social influence, cognitive efficiency and ecosystem conditions, with cultural context recalibrating these factors [11]. For young specialists, such discourse creates reference groups that signal valued skills and legitimate ways of framing uncertainty.

A cross-continental analysis of Stack Overflow contributors similarly found that regional context, workforce diversity, technology-ecosystem maturity and cultural cues shape knowledge-sharing behavior [12]. Professional networks can connect young specialists across borders, but regional differences may influence visibility, topic selection and styles of participation, producing unequal pathways into global communities.

Age-specific evidence from the 2025 Stack Overflow Developer Survey strengthens the youth focus of this analysis. Among Gen Z developers aged 18-24 seeking relevant developer content, 37% reported using human chat compared with 27% overall, while 39% used coding challenges compared with 30% overall [13]. These differences suggest that younger developers rely relatively more on interactive and socially embedded learning channels. For young AI specialists, intercultural dialogue may therefore develop through repeated peer contact, joint problem-solving and community participation rather than through passive content consumption alone.

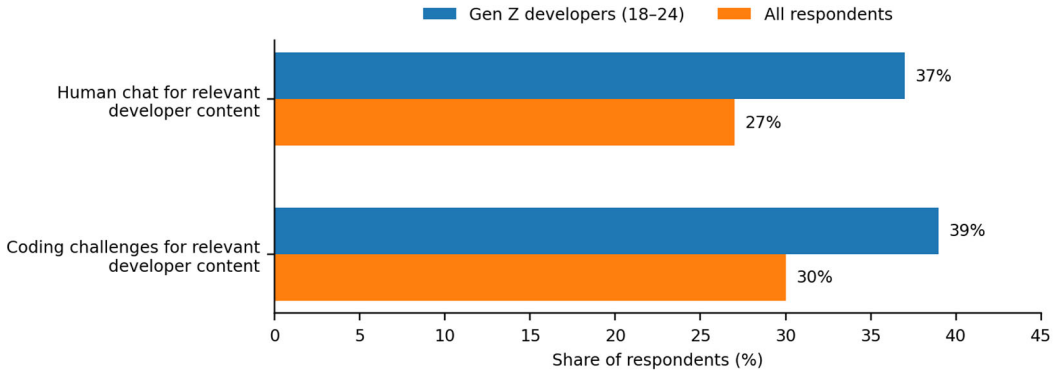


Figure 1. Social learning channels used by Gen Z developers and all respondents, 2025 (%)

Note: Stack Overflow 2025 age-specific data; the survey covers developers generally, so the values are contextual evidence for young AI specialists.

The synthesis indicates a dual social effect. Networked participation can build bridging social capital, peer support, intercultural competence, professional identity and access to opportunities. However, language barriers, regional clustering, communication differences and uncertainty about AI-generated information can weaken inclusion and trust. The social value of a platform therefore depends on whether international contact becomes reciprocal, culturally intelligible and professionally meaningful.

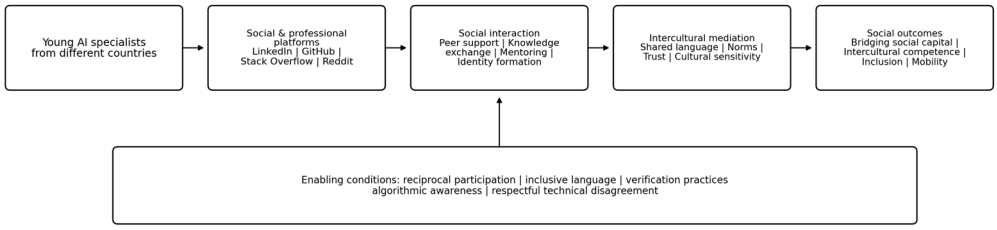


Figure 2. Social-intercultural model of networked interaction among young AI specialists

Conclusion

Social networks and professional digital platforms can function as an infrastructure of intercultural dialogue among young AI specialists from different countries. Their social significance lies in combining technical learning with peer recognition, identity formation and access to culturally diverse professional ties. Active discussion, mentoring and collaborative problem-solving can expand bridging social capital and intercultural competence while supporting professional mobility and innovation.

Online contact, however, does not automatically produce inclusive relations. Language barriers, cultural differences, regional segmentation and the need to verify AI-generated information remain important constraints. Universities, professional associations and technology communities can strengthen positive effects through multilingual mentoring, cross-cultural project teams, international junior-developer communities, peer review of AI outputs, and norms for respectful technical disagreement. Under these conditions, social networks become social environments in which young specialists learn to cooperate across cultural boundaries.

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Philological Sciences

LINGUISTIC FACTORS SHAPING READING COMPREHENSION IN ARABIC AS A FOREIGN LANGUAGE: VOCABULARY, MORPHOLOGICAL AWARENESS AND DIACRITICS

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Abstract. Reading comprehension in Arabic as a foreign language requires more than accurate decoding of the Arabic script. Learners must coordinate lexical knowledge, morphological information and orthographic cues while constructing meaning from connected text. This theoretical article examines three language-specific factors that are particularly relevant to this process: receptive vocabulary knowledge, morphological awareness and the processing of Arabic diacritics. A descriptive-analytical review of eight sources in second-language reading, Arabic language pedagogy and Arabic literacy research is used to distinguish evidence obtained directly from learners of Arabic as a second or foreign language from findings based on native Arabic readers. The reviewed literature indicates that receptive vocabulary is closely associated with comprehension, that morphological structure can provide an additional route to lexical access, and that vowelization may support word recognition and comprehension, especially for less experienced L2 readers. At the same time, these findings do not justify permanent reliance on fully vowelized texts or the treatment of morphology as an isolated grammar exercise. The article argues for integrated reading instruction in which vocabulary development, morphological analysis and gradual adaptation to unvowelized orthography support one another within meaningful text work.

Keywords: Arabic as a foreign language; reading comprehension; receptive vocabulary; morphological awareness; Arabic diacritics; word recognition

Introduction

Reading comprehension is a central component of foreign-language literacy because it connects knowledge of the language system with the ability to obtain, interpret and evaluate information from written texts. In second-language reading, accurate pronunciation alone is not sufficient. A learner may read a sentence aloud with acceptable phonological accuracy and still fail to construct its meaning. Reading therefore involves the coordinated operation of word recognition, lexical access, grammatical processing, integration across clauses and sentences, and the use of background and contextual knowledge. Grabe and Stoller describe reading as a complex, purposeful process in which lower-level linguistic processing supports higher-level comprehension [1]. This distinction is particularly important in language courses where oral reading is sometimes treated as evidence that a text has been understood.

Arabic as a foreign language adds a set of language-specific demands to this general picture. The learner encounters a writing system in which short vowels are usually omitted from

ordinary adult texts, a lexicon strongly organized by derivational morphology, and word forms that often require the reader to combine orthographic, morphological, syntactic and contextual information. Ryding treats reading comprehension as a distinct area of Arabic pedagogy rather than as an automatic consequence of learning the alphabet or pronunciation [2]. For this reason, a theoretically sound approach to Arabic reading must distinguish between decoding the written form and using linguistic information to construct textual meaning.

Research on Arabic literacy provides a useful account of the structural characteristics that make this coordination necessary. Saiegh-Haddad's MAWRID model identifies vowelization, morphological structure and diglossia as three prominent features shaping Arabic word-reading development [3]. The model was developed primarily to explain reading among Arabic-speaking children, so its claims cannot simply be transferred to adult foreign-language learners. Nevertheless, it clarifies two features that are directly relevant to L2 reading: the transparent representation of much derivational morphology and the variable availability of short-vowel information in the orthography. A scoping review by Bin Sawad, Law, Tibi and Boese likewise found that morphological awareness, phonological awareness and orthographic knowledge are associated with reading comprehension among Arabic-speaking school-age readers, while also warning that the evidence base remains limited and heterogeneous [4].

The present article therefore focuses on three linguistic factors that can be discussed with reasonable support from both Arabic L2 research and the broader Arabic literacy literature: receptive vocabulary knowledge, morphological awareness and diacritics. These factors are not claimed to exhaust the determinants of reading comprehension. Motivation, background knowledge, reading strategies, working memory, text difficulty and instructional quality also matter. The narrower aim is to clarify how lexical, morphological and orthographic information contributes to the transition from recognizing written Arabic words to understanding connected text. The guiding question is: what role do vocabulary knowledge, morphological awareness and Arabic diacritics play in reading comprehension among learners of Arabic as a foreign language?

Methodology and Scope

This study is theoretical and uses a descriptive-analytical review rather than an experimental design. Eight sources were selected because they address one or more of the following areas: general second-language reading, the pedagogy of Arabic as a foreign language, receptive vocabulary in Arabic L2, attention to Arabic morphology in L2 reading, Arabic diacritics in L2 reading, and metalinguistic or morphological factors in native Arabic literacy. Priority is given to research that directly involves learners of Arabic as a second or foreign language. Studies of native Arabic readers are used only to explain structural properties of Arabic literacy or to identify hypotheses that may be pedagogically relevant to L2 contexts.

This distinction is methodologically important. Evidence that a particular variable predicts reading among Arabic-speaking children does not prove that the same variable has the same effect size or developmental function among university students learning Arabic as an additional language. Accordingly, the discussion separates direct L2 evidence from supporting L1 evidence and avoids causal claims when the underlying studies are correlational, descriptive or based on small samples. The objective is not to rank the three factors statistically, but to synthesize what the literature allows us to say about their contribution and to derive cautious implications for classroom reading instruction.

1. Arabic Reading as a Language-Specific Processing Task

Arabic words often encode meaning through the interaction of consonantal roots and morphological patterns. The root ك ت ب(k-t-b), for example, appears in forms such as كَتَبَ(kataba, 'he wrote'), كِتَاب(kitab, 'book'), كَاتِب(katib, 'writer'), مَكْتُوب(maktub, 'written') and مَكْتَبَة(maktaba,

'library'). These words are not semantically identical, and their meanings cannot be mechanically derived from the root alone. Yet the recurring root and the patterns surrounding it provide structural information that can help a reader relate an unfamiliar item to known lexical material. Arabic reading therefore rewards sensitivity to internal word structure in a way that is pedagogically significant for vocabulary growth and lexical inference.

Orthography adds another layer. In fully vowelized Arabic, short vowels and certain other phonological features are represented by diacritical marks. In most ordinary adult prose, however, short-vowel diacritics are absent. A consonantal sequence such as كتب can correspond to forms including كَتَبَ(kataba, 'he wrote'), كُتِبَ(kutiba, 'it was written') or كُتُب(kutub, 'books'), with the intended reading resolved through lexical, morphological, syntactic and semantic context. Skilled readers perform much of this resolution rapidly. Foreign-language learners, by contrast, may still be developing the vocabulary and grammatical knowledge needed to recover the missing phonological information efficiently.

Saiegh-Haddad's model is useful here because it treats morphology and vowelization as interacting components of Arabic word reading rather than as unrelated classroom topics [3]. For L2 pedagogy, the practical implication is not that every learner should consciously analyse every word. Rather, instruction should develop sufficient lexical and morphological sensitivity for word recognition to become progressively more automatic, while exposing learners to the orthographic conditions they will encounter in authentic texts. The following sections examine the three factors separately before returning to their interaction.

2. Receptive Vocabulary and Access to Textual Meaning

Vocabulary knowledge is one of the clearest linguistic constraints on reading comprehension. A reader who cannot access the meanings of a substantial proportion of the words in a passage must devote considerable attention to local lexical problems, leaving fewer resources available for integrating propositions across the text. In a foreign-language context, this often appears as slow word-by-word reading, repeated dictionary consultation and difficulty maintaining the overall line of meaning. Receptive vocabulary is particularly relevant because reading primarily requires learners to recognize and understand words encountered in input, even when they cannot yet produce all of those words accurately in speech or writing.

Direct evidence from Arabic as a foreign language is provided by Messouab, who investigated receptive vocabulary knowledge and reading comprehension among 125 Arabic L2 learners [5]. Using a receptive vocabulary measure and a reading-comprehension test, the study reported a significant relationship between the two and concluded that vocabulary knowledge is a fundamental factor in comprehension. Because the design is quantitative and correlational, the result should be interpreted as evidence of association rather than proof that vocabulary alone causes better reading. Nevertheless, the study is valuable precisely because it examines Arabic L2 learners rather than inferring from English or from native Arabic literacy.

The pedagogical meaning of this relationship is more nuanced than simply increasing the number of memorized words. Useful receptive knowledge includes rapid recognition of written forms, access to core meanings, sensitivity to common collocations and awareness of related morphological forms. If each familiar word is accessed slowly, comprehension may still be disrupted. Conversely, readers do not need complete knowledge of every item in a text. Strategic tolerance of lexical uncertainty is part of mature reading: some unknown words can be ignored, while others can be interpreted from context or from their internal structure. The goal is therefore to raise lexical coverage while also reducing dependence on immediate translation.

Arabic morphology offers an opportunity to connect vocabulary learning with structural knowledge. A learner who already knows عِلْم('knowledge') may more easily process عَالِم('scholar'), تَعْلِيم('education/teaching') or مُعَلِّم('teacher') when the shared root and the derivational patterns

are made salient. Such relationships do not eliminate the need to learn individual meanings, but they can organize the lexicon into families rather than isolated lists. For reading instruction, this means that vocabulary selection should be planned together with recurring roots and high-frequency patterns. Repeated exposure across texts is likely to be more useful than presenting large numbers of disconnected words before each reading passage.

3. Morphological Awareness and Arabic Word Recognition

Morphological awareness refers to the ability to notice and analyse meaningful units within words and to understand how changes in word structure relate to changes in meaning or grammatical function. In Arabic this includes sensitivity to roots, derivational patterns, prefixes, suffixes and inflectional markers. The relevance of morphology is especially clear in unvowelized text, where readers cannot rely on complete short-vowel information and may use structural expectations to narrow possible interpretations.

Research on native Arabic literacy provides strong evidence that morphology is related to reading comprehension, although this evidence must be applied cautiously to foreign-language learners. Mahfoudhi, Elbeheri, Al-Rashidi and Everatt examined morphological awareness among typically developing and learning-disabled native Arabic-speaking children [6]. For the typically developing group, morphological measures explained unique variation in comprehension beyond phonological skills and nonverbal ability. A later scoping review of 16 studies involving students in grades 1-12 concluded that morphological awareness was the strongest metalinguistic predictor of reading comprehension in the reviewed Arabic literacy literature, while phonological awareness and phonemic diacritics were particularly relevant in earlier grades [4]. The review also explicitly cautioned against broad generalization because of differences in dialect and the limited number of studies.

The value of these L1 findings for Arabic L2 research lies in the linguistic mechanism they highlight, not in a direct transfer of developmental conclusions. Foreign-language learners typically approach Standard Arabic with different oral-language histories, literacy experience and metalinguistic knowledge from Arabic-speaking children. Nonetheless, Arabic morphology remains the same structural system, and learners can potentially use it as an additional route to lexical access. Recognizing that a form contains a familiar root or pattern can constrain interpretation and connect new input to stored lexical knowledge.

More direct L2 evidence comes from Nassif, Huntley and Mohamed, who used eye tracking to investigate how eleven fourth-semester learners of Arabic attended to sound and geminate verb morphology while reading sentence pairs [7]. The study did not demonstrate a broad causal effect of morphology on reading comprehension; its sample was small and its primary focus was attention and learning. It did, however, show that verbal morphology becomes an object of visual processing during L2 Arabic reading and that learners can notice structural contrasts in written input. This matters pedagogically because it supports treating morphology not only as a paradigm to memorize but also as information encountered and processed during meaningful reading.

A reasonable instructional approach is therefore to teach morphological analysis selectively. Learners can be trained to identify common roots and high-frequency patterns when these genuinely aid interpretation, without turning every text into a full parsing exercise. For example, a reader meeting an unfamiliar derived form can first identify a familiar root, inspect the pattern and affixes, and then test a tentative interpretation against sentence context. This sequence keeps morphology subordinate to comprehension. It also reduces the risk of a common instructional problem in which students can recite morphological rules but cannot use them when reading connected prose.

4. Diacritics, Vowelization and Orthographic Processing

Arabic diacritics provide phonological and, in some cases, morphosyntactic information that is absent from the consonantal skeleton of an unvowelized word. For beginning foreign-language learners, these marks can reduce ambiguity by making pronunciation and word form more explicit. Their role is therefore not merely decorative. Vowelization changes the amount of information directly available in the written input and can alter the cognitive demands placed on the reader.

The clearest L2 evidence comes from Al Midhwah and Alhawary, who investigated 54 English-speaking learners of Arabic at beginner, intermediate and advanced levels [8]. Participants came from instructional backgrounds using either vowelized or unvowelized textbooks and completed word-list reading, text reading and comprehension tasks. The groups with experience of vowelized materials generally performed better across measures of reading speed, accuracy and comprehension. Because the study compares learners with different instructional histories rather than randomly assigning a single homogeneous group to long-term conditions, the findings should not be reduced to a simple causal formula. They nevertheless provide substantial evidence that systematic exposure to diacritics can facilitate L2 Arabic word recognition and reading performance.

This finding is compatible with the broader Arabic literacy literature. Saiegh-Haddad identifies vowelization as one of the defining dimensions of Arabic word-reading development [3], while Bin Sawad et al. report associations between phonemic diacritics and comprehension in early native reading [4]. At the same time, fully vowelized text is not the normal endpoint of adult Arabic literacy. Newspapers, academic prose, general nonfiction and most contemporary literary texts are largely unvowelized. An instructional system that never reduces diacritic support may therefore produce dependence on a form of text that learners will not consistently encounter outside the classroom.

The more defensible pedagogical principle is gradual removal of support. At early stages, full or substantial vowelization can stabilize grapheme-phoneme mapping, reinforce known vocabulary and reduce unnecessary ambiguity. As lexical and grammatical knowledge grows, materials can shift toward partial vowelization, reserving diacritics for new, ambiguous or pedagogically important forms. More advanced learners should regularly read predominantly unvowelized texts and learn to resolve word forms through morphology, syntax and context. Such progression treats diacritics as scaffolding rather than as either a permanent requirement or an obstacle to authentic reading.

5. Pedagogical Implications and Limits of the Evidence

Taken together, the literature suggests that vocabulary, morphology and orthography should be coordinated within reading instruction rather than taught as three independent modules. A text that contains too many unknown words, unfamiliar patterns and reduced vowel information may overload a learner at several levels simultaneously. Conversely, a carefully sequenced text can recycle known vocabulary, introduce a limited number of morphologically transparent new items and provide diacritics where they genuinely support interpretation. The same passage can therefore become a site where lexical growth, structural awareness and reading comprehension reinforce one another.

For vocabulary, the priority should be repeated recognition in meaningful contexts. Pre-teaching every unfamiliar word risks turning reading into translation preparation; introducing no lexical support can make the text inaccessible. A middle position is preferable: teach a small set of high-value items before reading, recycle them across later passages, and require learners to infer or tolerate less important unknown words. For morphology, instruction should emphasize productive reading heuristics rather than exhaustive terminology. Roots and patterns are useful

when they help identify a lexical family, distinguish a grammatical form or infer a plausible meaning. They are less useful when analysis becomes an end in itself.

For vowelization, instructional decisions should reflect proficiency and task purpose. A pronunciation-focused beginner activity may require more diacritics than a comprehension-focused intermediate activity. Partial vowelization can be used strategically to highlight forms whose interpretation would otherwise depend on grammatical knowledge not yet acquired. Over time, reducing diacritics encourages learners to integrate lexical, morphological and syntactic information in the way ordinary Arabic reading requires. Ryding's broader pedagogical account of Arabic comprehension supports this principle of developing comprehension as a skill in its own right rather than assuming it will emerge automatically from formal knowledge [2].

The evidence base also imposes limits on the conclusions. Direct Arabic L2 studies remain fewer than studies of native Arabic literacy, and some influential findings come from small or specialized samples. The three factors discussed here are interdependent and are also affected by proficiency, first-language literacy, task type and text genre. Future research would benefit from larger longitudinal studies that track how vocabulary growth, morphological sensitivity and tolerance of unvowelized text develop together across proficiency levels. These limitations make an integrated but cautious pedagogical interpretation more appropriate than claims that one factor alone determines successful Arabic reading.

Conclusion

Reading comprehension in Arabic as a foreign language is best understood as an interaction between general comprehension processes and the specific linguistic organization of Arabic. This article has examined three factors that are especially relevant to the transition from word recognition to text understanding: receptive vocabulary knowledge, morphological awareness and diacritics. The available evidence does not permit a simple ranking of these variables, but it does show that each contributes a distinct form of information to the reading process.

Receptive vocabulary provides rapid access to meanings needed for building a coherent representation of the text, and direct research with Arabic L2 learners shows a clear association between vocabulary knowledge and comprehension [5]. Morphological awareness can help readers relate derived forms to known lexical material and use structural information when processing partially unfamiliar words; evidence from native Arabic literacy is strong, while L2 eye-movement research confirms that learners attend to morphological contrasts during reading [4, 6, 7]. Diacritics provide explicit phonological cues that can facilitate recognition and comprehension, particularly for less experienced readers, but long-term instruction must also prepare learners for the predominantly unvowelized texts of normal adult Arabic literacy [3, 8].

The main pedagogical conclusion is therefore one of integration and progression. Arabic reading courses should build lexical coverage, teach morphology as a resource for interpretation, and use vowelization strategically rather than absolutely. As proficiency develops, support should be reduced in a controlled way so that learners increasingly resolve meaning through the combined use of vocabulary, morphological structure, syntax and context. This approach moves reading instruction beyond oral decoding and toward the development of independent comprehension - the central goal of reading in a foreign language.

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ИСТОРИКО-ПОЗНАВАТЕЛЬНЫЕ ПЛАСТЫ ЭТНОКУЛЬТУРНОЙ ЛЕКСИКИ

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Аннотация
В целом, проблема, которая привлекает внимание исследователей языка-это структура национального языка, его составные части. Главным признаком наций является - язык, у языка своеобразный характер развития и структура, или язык каждой нации имеет свои пути развития, формирования. Национальный язык- понятие очень широкое, очень сложное посвоему историческому развитию, поэтому они по своему составу не однозначны. Язык Казахского народа, обитающего в бескрайнем пространстве от Европы до Азии- язык монолитный, язык единства народа, языкконтрастный. Единство языка выражается в свободном взаимопонимании народа одной крови живущих в этом и за пределами этого пространства, использующий этот же язык, имея региональные особенности.
В статье излагается занимаемое местов рядах комуникационных единиц региональной лексикологии в процессе синтаксических взаимоотношении с единицами других языков, потому как региональная лексика является частью национального языкового богатства, и региональная культура не может быть иной. Региональная лексикология-этнокультурно - содержательные единицы, отражающие казахскую традиционную культуру.

Ключевые слова: национальный язык, диалект, говор, культура, этнолингвистика, этнокультура, этнодиалектизм.

Современнное языкознание наряду с функцией «важного инструмента взаимоотношении», большое внимание обращает на познавательную функцию и функцию отражения культуры [Бисенбаева *et.al.*2017]. Издавна внимание исследователей языка привлекает на себя проблемы как национальный язык, его составные части. Если главным признаком нации является – язык, то он имеет самостоятельный характер развития, каждый национальный язык имеет свой особенный, уникальный путь формирования и развития. Национальный язык- понятие очень широкое, и языки с точки зрения истории не одинаковы по развитию. И национальный язык казахского народа по своему формированию и развитию состоит из:разговорного и литературного языков, из местных особенностей регионов, которые служат всей нации. [Калиев, 2005, 373]
Диалект – язык населения, живущих в отдельновзятом регионе, определить диалект можно сопоставив его с языком жителей другого региона. Диалект, это когда слова имеют отличия от литературного языка, понятного всему народу, всей национальности . Во многих случаях

эти отличия имеют общенародный вариант. Каждый носитель языка может пользоваться и литературным языком и диалектом региона, где он живёт. Противоположность диалекта и литературного языка нужно понять с точки зрения диалектических особенностей, так как литературный язык и народный язык- его особенности взаимосвязаны. Эту проблему Р.И.Аванесов объясняет тем, что диалекты в составе национального языка – явление противоположное и друг другу, и литературному языку, нет диалекта без противоположностей [Аванесов, 1949, 9-10].

Язык через слово передает все культурные богатства созданные человечестом: духовные и материальные. Содержательный признак слова- позиционирование названия как самостоятельную смысловую лексему. Диалектное слово, региональное слово-лексикологическая единица испольняющая функцию названия. Главное характер слова, как лексикологическая единица – определить, изложить понятие формировавщегося в определенный исторический период, передать его от поколения к поколению [Атабаева, 2006,16]. По осмыслению А. Салкынбая, при выборе названия любому понятию появившегося в сознании народа не зря обращали большое внимание на его внутреннюю убедительность, на основу. При изучении казахского лексикологического фонда и состава можно легко убедиться в том, что образование личностного и смыслового структур-результат ювелирности, мастерства, главное, мудрости и гениальности. Названия определяющие денотатных и сигнификатных значении отличаются логической убедительностью, смысловой и содержательной глубизной, звуковой гармонией. Даже каждое слово даёт информацию о познании, понятиях, состоянии чувств, духовной сущности, материальном богатстве народа, о дыхании времени [Салкынбай, 2008,328].

Это человеческое познавательное действие направлено на познание истинной сущности, понять окружающую среду, понять место в мире на основе полученного и собранного образования. Человек всегда стремится познать мир и своё место в нём. Язык – инструмент изображения мировоззрения говорящего, показатель самобытности нации, основа культуры. Язык в результате когнитивной деятельности человека не только собирает эффекты окружающей среды, так же передает исследовательские мысли, сохраняет образ мира сформировавщего в народной, коллективной, этнокультурной сознании [Жубаева, 2014,12-13]. Это качество языка В.Гумбольдт обьясняет следующим образом: “Язык есть орган, образующий мысль (Die Sprache ist das bildende Organ des Gedanken). Интеллектуальная деятельность, совершенно духовная, глубоко внутренняя и проходящая в известном смысле бесследно, посредством звука материализуется в речи и становится доступной для чувственного восприятия. Интеллектуальная деятельность и язык представляют собой поэтому единое целое. В силу необходимости мышление всегда связано со звуками языка; иначе мысль не сможет достичь отчетливости и ясности, представление не сможет понятием” [Гумбольдт, 2000,74].

Региональная лексика не только группа слов, обозначающие название предмета, явлений. Неодинаковы частота присутствия и применения местных особенностей, по этой причине наряду со своеобразной системой словообразования региональной лексики, ей присущи разнообразные изменения и развитие значении слов.

Сущность этноса – понятие широкого и глубокого содержания. Сущность этноса отражается в его материальном и духовном богатстве, созданных им самим, а эти богатства сохраняет и передает язык. Народ, потерявший свой язык, теряет свою корень, историю, национальную самобытность. Есть мнения, что идеи осмысления сущности этноса берут начало от трудов И.Г. Гердера (XVIII в) и В.Гумбольдта (XIX в), исследователи придерживаются этими идеями. А знаменитый Казахстанский ученый М.М.Копыленко считает, что история этнолигвистических взглядов начинается с трудов М.Кашкари, например, «Диуану лугат ат-

турк» («Словарь тюркских языков»). Разбирая историю возникновения слов «йалма», «дағ»., он определяет роль этимологического анализа в познании этнолингвистического значения: “Эти комментарии мало отличаются от тех, которыми снабдил бы слова *йалма* и *дағ*” отмечает современный этнолингвист. Доказывая тюркское происхождение того или иного слова, Махмуд учитывает степень распространенности его среди тюркских народов и мотивированность их бытом” [Копыленко, 1997, 4]. Это не просто синтез этнолигвистического языкознания и этнологии, а плод разума и сознании народа, раздел языкознания, которая познает и передает духовную и материальную культуру народа через языковые данные, через традиции и обряды, присущих этносу, это отдельное направление языкознания. В связи с этим, появляются самостоятельные объекты изучения научного направления, каналы- источники информации, принципы и методы его исследования.

Этнос формируется культурой, историей, культура- плод познания этноса. Поэтому, этнолингвистика, как отдельная синкретная наука тесно связана с разными направлениями языкознания и гуманитарных наук, одна из них – лингвокультурология. Все это требует необходимости исследования диалектической лексики с точки зрения этнолингвистикипотому что, диалектическая лингвистика- не только отражение древности, старого, но и направление этнолингвистики, сохранившее богатые красочные данные народного языка. А.Кайдар связывает цель исследования с переемственностьюэтнолингвистики и диалектологии, цель которой - расследовать все, что связано с этносом – глубоко, обширно, всеобъемливающе, всесторонне всех пластов языкового богатства. А диалектология является источником, началом всех начал этнолингвистики, которая обхватывает, познает и передает все древние слова, используемые местным населением, понятия и слова заимствованные у соседних народов, касательно их жизнедеятельности. *Тайтұяқ* – в общенародном языке название самородка золота, серебра объемом с копыта жеребёнка. В Жанкелдинском районе Костанайской области, это слово означает«ледоруб» - инструмент из копыта жеребца или жеребёнка. (Раньше, зимой лед рубили с помощью *“майтуяк”),* это приводит нас на древнее время, потому что такой инструмент после освоения обработки металла изготовливали из железа, стали, «тайтұяқ» - название того инструмента, современем приобрело другое понятие. Здесь основой словообразования служит- действие коня копытом, образовалось слово из двух компонентов(тай ₊ тұяқ), обозначающее название инструмента, как подарочный или хранящее, как богатство, *“майтуяк”* -понятие, передающее объем предмета. Тайтұяқ – инструмент, название носящее информацию о времени до эпохи обработки металла, поэтому наука этнолингвистики выделяет внимание на просвещение диалектических древних материалов [Атабаева, 2006, 12]. Источников, дающих информацию о сущности этноса, дополняющих “основных и производных смысловых единиц” количественно, и по смыслу, увеличивающих их обьем ирасширяющих сферу применения называют “этнолингвистическими каналами” : альтернативы, фразеологизмы, пословицы, поговорки, загадки, образцы устной литературы. Их А.Т.Кайдар называет этнолингвизами, которые появились в жизни этноса, и сверкают свойственными этносу , духовными, культурно-познавательными красками и узорами, как бисеры в мире языка [Кайдар, 1998, 24-26], и эти каналы являются этнолингвистическими каналами речевой лексики. Судя по обьему, этих каналов следует изучать не разделяя языковых данных казахстанской этнолингвистики в едином языковом мире- в«зеркале языка».Такие особенности этнолингвистики определяют принципы исследований: 1) принцип познания сущности этноса через языковые данные, по мнению А.Кайдара, национальную сущность этноса определяет только богатство его языка, языковой мир; 2) наука- переемлемая с другими общественными предметами, но не «подручная» им, сохранившая свои принципы-универсальная наука ; 3) принцип полного раскрытия содержания лексического богатства, дать возможность данным (словари,

образные слова и орнаментальные образцы художественного слова, не входящие в словари, шутки – прибаутки и т.д.), имеющимотношение к сущности этноса- раскрыться полностью, описывать словесными красками, колоритом , узорами, свойственными языку; 4) принцип системности, лексика-системное явление, явление упорядочная по обьективным закономерностям, содержанию, логической тематикегде названия предметов и явлений в сущности этноса образуются друг от друга; 5) оттуда и принцип классификации [Кайдар ,17]. Казахстанские этнолингвистические исследования рассматривают применение названных выше принципов исследования переемственностью с источниками информации, опираются на национальные действия способа (метода) этимологического анализа. Это, в основном, познать казахский этнос не только через тюркский мир, в целом, а через возможности его языка.

В казахском мировоззрении у коней и верблюдов исходя из их внешних форм, данных и особенностей, возраста и т.д., определили их место в быту, и давали им разные характерные названия. Один из них-қазанат.

Қазанат- в общенародном языке это «крупного телосложения, терпеливый, мощный конь» [ҚТТС, 1980,5,503-504-бб]. По этой причине, во-первых, в фольклоре, поэзии акынов и жырау қазанат описывается как крылья, верный спутник батыра-богатыря. Во-вторых, народ такие качества қазанат, как крупность,надежность, терпимость, мощь переносят и на образ батыра. Название қазанат даёт значение как «красивое телосложение, мускулистость, терпеливый». Вместе с этим в региональной лексике название қазанат имеет разные смысловые значения: 1) қазанат - «конь-скакун с короткими и редкими гривой, хвостом». 2) қазанат означает «порода лошадей с красивым телосложением, широкой грудью, высокого роста, длинными ножками, легким весом». 3) словом қазанат характеризуют человека «гостеприимного, широкой души» [ҚТАС, 2005, стр 367]. Название из двух слов *қазан* и *ат* в системе всенародного языка и речевой системе, в разных регионах, относительно его применения можно заметить, оно название древнее, не является первой номинацией. Образ коня и образ батыра передает понятие о мощности, терпимости, широкости, душевности.

Для глубокого и основательного освоения языкового мира казахского этноса требуется:изучение «переносных, входящих фразеологических значении» в подтекстах языкового богатства и др., поиск культурного кода в содержании названия, оживив внутреннюю форму единиц превратившихся на «смысловой символ» из-за непонятного ныне значения, знание названия «этнокультурная семантика », семантика определяемая через культурный код, сосуществовать с национальной традиционной культурой.

По мнению А.Соломоника, истина вне языка обозначает, отражает предмет, явление. Истина-правда вне языка называется материальным и духовным миром. И так, слово-знак, обозначаемый понятие, связь в отражении человеческого сознания развивается в трёх направлениях: обозначаемый, его знак в слове-лингвистическая связь; отражение в сознании –психологическая связь; ознакомление положения в культуре своей эпохи-культурно-социальная связь. Это трехзначная связь, преемственность играет решающую роль в развитии человечества и его культуры (Соломоник, 2011,264-265). Его можно понять, разбирая пути вхождения в систему языка слов-наименовании. Например,қазан-общее название в тюркских языках. Возникновение названия *«казан»* можно связывать с древним бытом тюрков,в частности с кочевыми традициями казахского народа. В труде «Диуани луғат-ит-турк» М.Кашкари приводит словосочетания «Еч ачық қazdы» (Ер арық қазды. Адам арық қазды.Человек прорыл канал)» At қazdы» (Ат қазды. Лошадь упрямилась и копытами рыла землю). «Қazar-қazmақ» (қазар-қазбақ) (Кашкари, 2005, 491).

По мнению учёных исследователей корней в тюркских языках, **қаз**-исторический однослоговый корень. А.Т.Кайдар показывает четыре значениикорня **қаз.** Если значение

действия означают слова «қазу», «жерқазу», «қаз», в сочетании с вспомогательным глаголом «тұру» образуется сложный глагол-қаз тұру,что означает «стоймя нечто стоящее вертикально». Казахский народ попытку ребенка стоя делать первый шаг называет«қаз тұру». Е.Кажыбеков говорит,что общетюркский корень «қаз» в тюркских языках:**qaz- /gas-/ gaz**означает «рыть, копать, выкапывать,окапывать. С этим значением этот же корень в тюркских словарях встречается в трудах С.Малова (Малов 1951). Значение названия корня есть только в гагаузском языке, qaz- означает «мотыга, который окапывают землю» [Кажыбеков 1985, с.162].

Корень “қаз ” берёт начало с давних времён древних тюрков, когда ониокапывая землю делали земляной очаг “ жер ошақ”. На казахском языке много комонентных фразеологизмов “қазан ”. Казахи “қазан ” считают священной посудой, слово “қазан- ошақ” означает семью, дом. Казах считает что “қазан” хранит в себе богатство, благо. Отсутствие “қазан ” считали как несущую голод, нищету так, как благо покидает семью. Қазан – для казахского этноса вещь священная, она имеет глубокое этнокультурное значение. (Камалашулы, 2006, 100-101).

Все информации о содержании названий **қазанат, қазан**являются этнопознавательными, чувственными, этнокультурными информациями, для их осмысления, познания требуется всесторонний этимологический анализ на основе народных традиции.

Этнокультурную лексику образуют система этнокультурных информационных единиц как **қазан, қазанат,** название **қазан** входит в состав наследственных ценностей. Модель словообразования названия **қазан**: **“қаз+(ғ)ан ”** синтетический (корень+словообразующий) метод, а название **қазанат “қаз+(ғ)ан+ат”** (корень+ словообразующий суффикс+корень) сложное слово образованное аналитическим методом по составу.

Основой двух названий служит корень“**қаз**”. Речевое значение“**қазанат**” как конь крупного телосложения, терпеливый, мощный дошло до нас, можно сказать, со времён войн и сражений. **Қазанат** и есть Тулпар, являясь спутником и крыльями богатырей- батыров , героев эпосов , с помощью которого легко преодолевали все препятствия.

Региональная лексика- составная часть национального языкового богатства, поэтому и региональная культура не может быть иной. Язык передает через слово духовные и материальные богатства человечества, созданных им. Содержательный признак слова-позиционирование названия как смысловой лексемой. В труде о проблемах региональной лексикологии О.И. Блинова указывает признаки диалектических слов:

Местная особенность, сложность регионального слова, лексика обьясняется средой обитания носителя слова, речи.

Таким образом, региональное слово- этнокультурные смысловые единицы, отражают казахскую традициональную культуру, поэтому по историко-познавательной структуре состоит из общетюркских самобытных производных и заимствованных пластов.

Бесконечно длительный период от забытых историей времён до отделения самобытного тюркского мира называется общетюрской эпохой. В трудах тюркологии термины *общетюркская эпоха, общетюрское состояние, тюркская знатность, тюркийататіл (язык предков), тюркский негізтіл (коренной)* применяются как эквивалент. По мнению Э.Р.Тенишева, если рассмотреть с точки зрения термина, можно понять смысловые подтексты этих слов, пока не понятна материальная смысловая сущность, это связано с отсутствием опыта по конкретному разделению в компартивистике тюркских языков [Тенишев, 76]. Э.Р.Тенишев считает, термин **общетюрское состояние** надо понимать как тюркское первое языковое обьединение, гипотетический (язык и диалекты)язык тюркских племён, иначе говоря,сборник языковых факторов свойственнные всем уровням языка, востановленные, условно считаемые старинными, которые могут быть основой

сравнительному изучению и как сохранившихся во многих современных тюркских языках или дошедших со времен старинных памятников. [Тенишев, 56].

Э.Р.Тенишев относительно мнения одного из сторонников алтайской гипотезы, Н.Н.Поппе, о том, что «разделяя общетюркское состояние на два периода-до тюркский и тюркский ататіл (язык предков), что до тюркский период ведет основу появления тюрко- монголский, тунгус-маньчжурского языков к общеалтайскому языковому обьединению, а в период ататюркского, языки отделились от алтайского основного языка и развивались самостоятельно», особое внимание уделяет на две проблемы: во-первых, между языками алтайской группы, хоть слабая, но есть родственная связь, это служит основой для Н.Н.Поппе делать заключение, что тюркский , монголский, тунгусо-манжурский языки сохранили реликт некоторых древних языков, во-вторых, разделение общетюрскую основу-языка на две эпохи – выгодно для исследования. Формирование общетюркского языка-основы долговременно, поэтому его формирование, развитие, общее строение неоднородны. Э.Р.Тенишев по хронологии делит на два периода: древний общетюркский,последующий общетюркский. (Тенишев,13), у каждого из них есть своя особенность, самобытность,первое отделившиеся от языков алтайской группы, характеризуется как очень древний, чем последующий общетюркский период. Последующий общетюркский период имеет некоторые новизны,например, трансформация падежей-именительный, родительный, дательный, винительный, творительный, предложный, звуки ғ, г в конце слов, потому как для некоторых тюркских языков этот период оказался переходным, в этот период образовалась основа для отделения многих языков. (Тенишев, 56).

А.М.Щербак [Щербак, 110] считает, что «общетюркский лексический пласт»тюркских языков надо принять условно, потому что для рассмотрения определенных названии как реликвию общетюркского периода необьязательно нахождение названии в лексике всех тюркских языков, достаточны данные, доказывающие существования этих слов.

Общетюркский характер ярко заметен в звуковых особенностях и грамматических, словообразующих формах, чем в лексических особенностях. Г.Калиев отмечая свойственность общетюркского характера многим словообразующим суффиксам, как присутствие диалектических явлений определенных тюркских языков в соседствующих тюркских языках, или наличие в общетюркском обьеме, как неоднократно отмечались в тюркологических литературах, генетическими, связь типологических признаков с родством тюркских языков, общетюркскими традициями в их развитии » [Калиев, 2026, 44],- связывает с общетюркскими тенденциями развития.

Главное в общетюркской тенденции развитии, по мнению Е.И.Убрятовой, не выходить из границ общетюркских соответствий -характер, свойственный диалектическим особенностям тюркских языков, потому что неразвита диалектическая система тюркских языков, образованных из родственных казахских племенных языков [Убрятова, 33], поэтому отражение в разной степени общетюркского характера слов присуще и другим тюркским языкам.

Н.З.Гаджиева делает вывод, что отсутствие ярких противоположностей в тюркских языках заключается в единой общетюркской тенденции развития, и так, «... сохранились ататілдік формы, инновации первичного состояния ататіл подчинены общетюркским тенденциям развития» [Гаджиева, 23].

При анализировании диалектических материалов казахского языка по сохранению общетюркской основы можно заметить, что они в соответствии названных выводов применяются в обьеме нескольких языков, в литературном языке других тюркских языков, считающихся в казахском языке диалектом.

Региональная лексика языка намного богаче, чем общетюркский лексический пласт языка, она отличается большей обьемностьюоснов, источников образующих его. Огромная часть

региональной лексики образовалась в период формирования отдельных этносов тюркских народностей, поэтому региональная лексика казахского языка считается как слова, характеризующие, отражающие быт, хозяйствование, духовное и культурное богатства казахского народа, она в соответствии с закономерностями лексики обогащается, развивается. В исследованиях говоров и проблем общей диалектической лексики отмечают, что диалектическая лексика казахского языка образовала сохраняющую племенных, родовых, по происхождению элементов свою самобытную лексику. С.Аманжолов говорит, что такие слова как **адақтау** и др. которые применяются в современном казахском языке являются древним элементом, они встречаются в Орхоно-Енисейских письменностях и слово **адақ** стало основой словообразования **адақ-лық** [Аманжолов, 85], надо отметить, название адақ получило развитие на местностях как адақ-қы (последний), адақ-тау (окончание, выполнение, обгонять, гулять), адақ арба (тележка для обучения ребенка ходить), ада қылу (закончить). Сабан-«соха, инструмент похоты земли для посева». Слово, с таким значением есть в словаре М.Кашкари «Диуани луғат-ит-түрк», встречается во всех тюркских языках, применяется и в казахском языке. В казахской речи образованы много производных от слова сабан: «сабаншы» (тянущий соху, пахарь), «сабан айдау» (пахать землю), «сабанға шығу» (выходить пахать). Самобытный пласт речевой лексики во-первых, дополнилась смысловым расширением древних слов и словами образованных синтетическо- аналитическим способом, во-вторых, и заимственные слова могут быть основой для словообразования. Эти данные показывают наличие своей системы словообразования казахской речевой лексики.
Большую часть речевой лексики казахского языка занимает явление, так называемыев языковом мире, заимственные слова. Переход слова от одного языка к другому-историческое явление которое происходит в результате общения.Заимственные словав любом языке имеют общенародный характер, среди них встречаются применяемые активно, так и пассивно, а некоторые могут остаться в региональном применении, могут и изменяться семантически, несмотря на это, пути образования заимственных слов в казахском языке для общенародного языка и диалектической лексики общее, потому как носитель языка – один, это – казахский этнос. Известно так же, что многие заимственные слова вошли в использование до формирования общенародного и национального литературного языков [Атабаева, 2016]. Он как и другие тюркские языки связан с этнолингвистическим состоянием среды, где жил казахский этнос. Процесс заимствования слов, явление происходящее вместе с началом общественной, политической, экономической взаимоотношений. В связи с этим И.Н.Шервашидзе в своей статье о заимственном пласте общетюркской лексики заимственных слов, относительно их происхождения, делит на: 1) заимственные слова из китайского языка; 2) слова из иранских языков, в основном, из согдианских или среднеперсидских (пехлеви) языков; 3) немногие слова из индоевропейских источников; 4) и других языков (окказионал) монгольские слова, слова на финн-угорской основе. Среди них самые древние-заимственные слова из китайского языка, время процесса заимствования ученый определяет III-IV в.в. По общетюркскому пласту лексики тюркских языков некоторые китайские заимственные слова (40слов; это не обхватывает всю лексику), которых указывает ученый, кроме общенародных языков встречаются и в диалектической лексике (Шервашидзе, 1989, 54-55). Заимственные слова в казахской речевой лексике по периодам вхождения в казахский язык характеризуются как: вошедшие из китайского, арабского и иранских языков; из монгольских, русских и соседних тюркских языков [Атабаева , 2015]. В этом ряду находятся такие слова, как: *алашы қ*(легкая юрта), *күп* (хранилище для воды), *мұрап* (человек, поливающий поле, профессиональный), *ауқат* (еда, пища), *тандыр* (печь для изготовления хлеба) и др. Во многом, заимственные слова с речевыми названиями и со словами общенародного пользования образуют вариантно-дублетный ряд, по применению делятся

на «литературные дублеты», «литературно –диалектические дублеты». Последний делится на «дублеты с определенным литературным вариантом» и «дублеты снеопределенным литературнымвариантом». Например: у названия «*нағашы*», означающегородство есть дублеты *дайы ~тағатейке/ тайеке.* Это- дублетный ряд с определенным литературным вариантом, его литературный вариант-*нағашы* означает родственник по линии матери. А в ряд неопределенного литературного варианта можно ввести «*шымшуыр- жіптік- қышқаш-мәстемір- әтешкір*» и др. означающие бытовое понятие«*шоқ қысқыш*».

Местные особенности казахского языка независимо от характерности говора, являются наиболее частовстречающимся направлениемв региональном слове, лексических особенностях, потому что слово – название обхватывает начиная от семейного быта до всего образа существования. С этой точки зрения, региональная лексика – сохранивший след разных периодов и событий,отношений, состояний в истории этноса, безценное богатство его быта, истории, культуры. У казахского языка , одного из тюркских языков, у которого мало письменных данных в оценке своей истории, в осмыслении духовно-материального богатства народа, в самопознании этноса, написании новой истории познавательным, определяющим, наследственным источником - региональная лексика является свидетельницей всех исторических, эпохальных событий.

Региональная лексика- часть национального языкового богатства, поэтому региональная культура не может быть иной. Региональная лексика –отражение казахской традиционной культуры и единицы этнокультурного содержания. Языковое богатство измеряется не только количеством слов-названий, но и качеством, смыслом, глубизной, обьемностью, это присуще не только общенародной лексике, есть семантические особенности развития диалектической лексики. Региональная лексика считается системой систем. Анализированные, выше данные показывают, что и система говоров, и значение слов в соответствии закономерностями развития подвергается разным смысловым изменениям, и это присуще всем пластам лексики говоров.

История диалектической лексики казахского языка взаимосвязана с историей казахского народа и историей тюркских языков. След Великого переселения от Алтая до Европы можно обнаружить в лексике говоров казахского языка и языке других тюркских народов. С этой целью казахские этнолингвисты определили осмысление сущности Казахского этноса в «зеркале языка», поэтому в рядах источников информации и каналов находится региональная лексика. Это показывает единство и монолитность казахского языка, существование некоторых региональных особенностей, которые вносят краски, колорит в единую казахскую культуру. Таким образом, данный исследовательский труд расскрывая региональные краски, колорит этой культуры, определяет его роль в формировании сущности казахского этноса.

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Sədi rübailərinin farscadan Azərbaycan dilinə maşın tərcüməsində üslub və ritmin qorunması

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Xülasə

Məqalədə Sədi Şirazinin üç rübaisinin farscadan Azərbaycan dilinə maşın tərcüməsində məna, üslub və ritmin ötürülməsi araşdırılır. Məqsəd poetik obrazların, idiomatik ifadələrin və lirik münasibətlərin tərcümədə hansı dəyişikliklərə məruz qaldığını müəyyənləşdirməkdir. Tədqiqat Ganjoor elektron toplusundan məqsədli seçilmiş üç orijinal mətnin və Google Translate, DeepL və ChatGPT adı ilə qeydə alınmış doqquz tərcümə variantının müqayisəli keyfiyyət təhlilinə əsaslanır. Qiymətləndirmə məna və məntiqi əlaqələr, obraz və üslub, ritmik təşkil, qafiyə və dil axıcılığı üzrə aparılır. Ritmik müşahidələr misra quruluşu və yazıda görünən saitlərin sayı ilə məhdudlaşdırılır. Təhlildə güzgü obrazının itməsi, oxun çiçəklə əvəzlənməsi, fədakarlıq ifadəsinin hərfi anlaşılması və sevgilidən dönməmək fikrinin istiqamətinin dəyişməsi aşkarlanır. ChatGPT variantlarında əsas məna münasibətləri daha ardıcıl saxlanılsa da, obraz detallarının ümumiləşdirilməsi, qeyri-təbii ifadələr, misra uzunluqlarının dəyişkənliyi və qafiyənin bərpa olunmaması müşahidə edilir. Nəticələr leksik uyğunluğun poetik bütövlüyü təmin etmədiyini və məna ilə formanın ayrı meyarlarla yoxlanmasının zəruriliyini göstərir. Məqalənin töhfəsi seçilmiş fars–Azərbaycan nümunələrində semantik dəyişmələri lirik məntiq və formal təşkil ilə əlaqələndirməsidir. Kiçik seçmə, tərcümələrin fərqli kontekstdə hazırlanması və müstəqil ekspert qiymətləndirməsinin olmaması səbəbindən nəticələr sistemlərin ümumi keyfiyyət sıralamasına kimi şərh edilmir.

Açar sözlər: Sədi Şirazi, rübai, fars–Azərbaycan tərcüməsi, maşın tərcüməsi, poetik üslub, ritm, qafiyə.

Preserving Style and Rhythm in Machine Translation of Saadi's Rubaiyat from Persian into Azerbaijani

Abstract

This article examines the transfer of meaning, style and rhythm in the machine translation of three rubais by Saadi Shirazi from Persian into Azerbaijani. It aims to identify changes in poetic imagery, idiomatic expressions and relationships expressed by the lyric speaker. The study provides a comparative qualitative analysis of three source poems purposefully selected from the Ganjoor digital collection and nine translation variants recorded under the labels Google Translate, DeepL and ChatGPT. The analysis addresses meaning and logical relations, imagery and style, rhythmic organization, rhyme, and target-language fluency. Observations on rhythm are restricted to line structure and counts of written vowel letters. The findings include the omission of the mirror image, the substitution of a flower for an arrow, literal interpretations of self-sacrifice, and a change in the direction of the speaker's pledge of fidelity. Although the ChatGPT variants retain the principal semantic relations more consistently, they generalize details of imagery, contain unnatural expressions, show variation in line length and do not reproduce the source rhyme patterns. The findings demonstrate that lexical correspondence does not ensure poetic coherence and that meaning and form require separate evaluation. The article contributes a reading of semantic shifts in selected Persian–Azerbaijani examples in relation to lyric logic and formal organization. The small sample, unequal translation contexts and absence of independent expert assessment preclude interpreting the results as an overall ranking of the systems.

Keywords: Saadi Shirazi, rubai, Persian–Azerbaijani translation, machine translation, poetic style, rhythm, rhyme.

Giriş

Poetik tərcümədə məna sözlərin lüğəvi qarşılığı ilə məhdudlaşmır. Obrazların qarşılıqlı əlaqəsi, danışanın sevgiliyə münasibəti və misraların səs quruluşu şeirin necə anlaşılmasına təsir göstərir. Buna görə leksik baxımdan tanınan bir tərcümə poetik baxımdan ciddi dəyişikliklər daşıya bilər. Jones (2011) şeir tərcüməsini tərcüməçinin qərarlarıvə iş prosesi daxilində araşdırır, qafiyə və ritmin ötürülməsini ayrıca nəzərdən keçirir. Bu yanaşma məna, üslub və formal təşkilin əlaqəli, lakin fərqli göstəricilər kimi qiymətləndirilməsinə əsas verir.

Sədinin rübailəri qısa mətn daxilində obraz və məntiqi münasibətlərin necə birləşdiyini izləməyə imkan verir. Güzgü, can damarı, ox, ətək və niyaz əli burada lirik fikrin qurulmasında iştirak edir. Məqalənin məqsədi üç rübainin farscadan Azərbaycan dilinə təqdim olunmuş tərcümələrində bu əlaqələrin və poetik formanın qorunmasınıaraşdırmaqdır. Tədqiqat iki suala cavab axtarır: məna dəyişiklikləri hansıifadə və münasibətlərdə yaranır; əsas fikrin saxlanması üslub, ritm və qafiyənin ötürülməsi ilə nə dərəcədə uzlaşır? İşin töhfəsi seçilmiş nümunələrdə leksik dəyişməni bütöv rübainin lirik məntiqi ilə əlaqələndirməsidir.

Nəzəri əsaslar

Maşın vasitəsilə şeir tərcüməsinə dair araşdırmalar janra uyğun materialın və tərcümə tapşırığının əhəmiyyətini göstərir. Chakrabarty və b. (2021) poetik mətnlərlə uyğunlaşdırılmış çoxdilli modellərin daha böyük qeyri-poetik materialla uyğunlaşdırılan modellərdən üstün nəticələr verdiyini müəyyənləşdirmişlər. Wang və b. (2024) ingilis–çin poeziya tərcüməsində izaha əsaslanan yanaşmanınsınaqdan keçirərək mətnin şərhinin tərcüməyə kömək edə bildiyini göstərmişlər. Bu tədqiqatlar hazırkı nümunələr üçün iki məsələni aktuallaşdırır: poetik ifadənin kontekstdə anlaşılmasıvə tərcümə variantlarının hazırlanma şəraitinin nəzərə alınması.

Formanın qorunmasıayrıca yoxlanmalıdır. Klumpp (2026) Şekspir sonetlərinin ingiliscədən almancaya tərcüməsində təkrar işləmənin qafiyə və vəzni yaxşılaşdıra bildiyini, bunun isə bəzən məna və qrammatik düzgünlük hesabına baş verdiyini göstərir. Walsh və b. (2024) modellərin ingilisdilli şeir formalarını tanımasını araşdırmışlar; formanın tanınması onun başqa dildə yaradılması haqqında birbaşa nəticə vermir. Resende və Hadley (2024) dil modellərinin tərcüməçiyə yaradıcıhəllər təklif edə bildiyini, çıxış mətnini nəşr olunmuş tərcümə səviyyəsinə çatdırmaq üçün isə böyük redaktə əməyinin tələb oluna biləcəyini qeyd edirlər. Bu nəticələr fərqli dil cütlərində əldə olunmuşdur və fars–Azərbaycan tərcüməsinə dair ümumi hökm kimi tətbiq edilmir.

Material və metod

Tədqiqat müqayisəli keyfiyyət təhlili əsasında qurulmuşdur. Material Ganjoorun Sədi divanı bölməsində 7, 81 və 100 nömrələri ilə verilən üç tam rübai və onların doqquz tərcümə variantıdır (Sədi, tarixsiz). Birinci rübai güzgü obrazıvə özünə heyranlıq münasibətinə, ikinci fədakarlıq idiomu və sədaqətə, üçüncü oxatma leksikasıvə çəkişmə–barışıq əlaqəsinə görə məqsədli seçilmişdir. Mətnlərin nömrələri elektron toplunun sıralanmasını bildirir. Təhlil farsca şeir mətninə əsaslanır; Ganjoordakıavtomatik şərhlər qiymətləndirmə mənbəyi kimi istifadə edilmir.

Google Translate və DeepL adıilə verilən mətnlər müəllifin təqdim etdiyi materiallardır; onların platforma mənşəyi təqdim olunmuş etiketlərə əsasən göstərilir. Doqquz variant 7 oktyabr 2026-cıildə təhlil korpusuna daxil edilmişdir. ChatGPT tərcümələri digər nəticələr təqdim olunmazdan əvvəl mənbələrin yoxlandığısöhbət kontekstində hazırlanmışdır. İlkin variantların söz tərkibi redaktə olunmadan saxlanılmışdır. Model versiyaları, tam təlimatlar, interfeys parametrləri və ilkin ekran görüntüləri sənədləşdirilmədiyi üçün müqayisə nəzarətli sistem sınağıkimi qurulmur. Əsas təhlil vahidi platformanın ümumi fəaliyyəti deyil, təqdim olunmuş tərcümə mətnidir.

Qiymətləndirmə beş meyar üzrə aparılır: məna və məntiqi əlaqələrin saxlanması, obraz və üslubun ötürülməsi, ritmik təşkil, qafiyə və Azərbaycan dilində axıcılıq. Məna üzrə əlavə, itki,

idiomun hərfi anlaşılmasıvə hərəkətin iştirakçılarının dəyişməsi yoxlanılır. Üslub üzrə müraciət forması, məcazın funksiyasıvə emosional ton nəzərə alınır. Ritmik müşahidələr misra quruluşu və yazılaksaitlərin sayına əsaslanır; bu sayın əruz vəzninin təqtii hesab edilmir. Müstəqil ekspertlər və nəşr olunmuş insan tərcüməsi ilə müqayisə olmadığından bal şkalasıvə ümumi keyfiyyət faizi tətbiq edilmir. ChatGPT variantlarınıhazırlayan köməkçi onların ilkin təhlilində də iştirak etdiyindən bu qiymətləndirmə müstəqil rəy statusu daşımır.

Nəticələrin təhlili

Birinci rübaidə güzgü obrazıvə lirik müraciət

صد بار بگفتم به غلامان درت
تا آینه دیگر نگذارند برت
ترسم که ببینی‌رخ همچون قمرت
کس باز نیاید دگر اندر نظرت

Birinci rübaidə danışan sevgilinin qapıçılarındakıqullara onun qarşısına güzgü qoymamağı tapşırır. Qorxunun səbəbi sevgilinin öz ayabənzər üzünü gördükdən sonra başqalarının nəzərində dəyərsizləşdirməsidir (Sədi, tarixsiz, rübai 7). Güzgü, öz üzünə baxış və başqalarına marağın azalmasıardıcıl məna əlaqəsi yaradır. Tərcümədə bu əlaqənin hər hansıhissəsinin itməsi mətnin lirik vəziyyətini dəyişir.

Google Translate:“ Qullara yüz dəfə sizə başqa güzgü qoymamağıdesəm belə, daha çox ay kimi üzünüzün bir daha gözlərinizə qayıtmayacağınıgörəcəyinizdən qorxuram.”

DeepL:“ Mən qullarımıza yüz dəfə demişəm ki, başqasının sizə yaxınlaşmasına imkan verməyin. Qorxuram ki, ay kimi bir üz görəcəksiniz və bir daha heç kim gözünüzə görünməyəcək.”

ChatGPT:

Qapıçılarıqullara yüz dəfə dedim:
Bir daha qarşıma güzgü qoymasınlar.
Qorxuram, ay kimi üzünü görəsən,
Daha heç kəs gözündə yer tutmasın.

Google variantında güzgü və ayabənzər üz saxlanılır, lakin son iki misranın məntiqi dəyişir: başqalarının sevgilinin nəzərində görünməməsi üzün gözlərə qayıtmamasıkimi verilir. “Desəm belə” qarşılığıdeyilmiş göstərişi güzəşt münasibətinə çevirir. DeepL variantında güzgü buraxılır, yerinə başqasının yaxınlaşmasına yol verilməməsi haqqında göstəriş əlavə olunur. Beləliklə, öz gözəlliyinə heyranlıq başqa bir şəxsin gözəlliyini görmək ehtimalıilə əvəzlənir. Hər iki variantdakı nəzakətli “siz” müraciəti də orijinalın tək şəxsə yönəlmiş lirik yaxınlığınıdəyişə bilər.

ChatGPT variantıgüzgü ilə özünə heyranlıq arasındakıəlaqəni və tək şəxs müraciətini saxlayır. Bununla belə, “gözündə yer tutmaq” ifadəsi son misranın şərhə əsaslanan qarşılığıdır; “görəsən… tutmasın” quruluşu qorxu ilə nəticə arasındakı sintaktik bağlılığı zəiflədir. Məna əlaqəsinin saxlanmasıqafiyənin bərpasıilə müşayiət olunmur. Bu variantın üstün cəhəti konkret lirik vəziyyətin ötürülməsidir; ifadə axıcılığıvə formal uyğunluq əlavə redaktə tələb edir.

İkinci rübaidə fədakarlıq idiomu və sədaqət

تا سر نکنم درسرت ای مایهٔ ناز
کوته نکنم ز دامنت دست نیاز
هر چند که‌راهم به تو دورست و دراز
در راه بمیرم و نگردم ز تو باز

İkinci rübainin سر“… درسرت” quruluşu sevgili uğrunda başınıfəda etmək mənasında oxunur. دست نیاز“” vدامن“ ə” ifadələri niyaz edən əlin sevgilinin ətəyindən çəkilməməsi obrazınıyaradır. Son beyt bu bağlılığıdavam etdirir: yol uzaq olsa da, danışan yolda ölməyə hazırdır və sevgilidən üz döndərmir (Sədi, tarixsiz, rübai 81). Tərcümə üçün əsas məsələ fədakarlıq ifadəsi ilə son misradakı sədaqətin əlaqəsini saxlamaqdır.

Google Translate:“ Ey zərif varlıq, ağlına girənə qədər, sənə gedən yolum uzaq və uzun olsa da, yolda ölsəm də, bir daha sənə baxmasam da, ehtiyac içində qucağına çatana qədər.”

DeepL:“ Səni başımda taxmadığımadək, ey mənim canım, ətəyindən, ehtiyac əlimdən əl çəkməyəcəyəm. Sənə gedən yolum uzun və uzaq olsa da, yolda öləcəyəm və sənə dönməyəcəyəm.”

ChatGPT:

Ey nazlı qaynağı, uğrunda başım verməyincə,
Niyaz əlimi ətəyindən çəkmərəm.
Sənə yolum nə qədər uzaq, uzun olsa da,
Yolda ölərəm, səndən geri dönmərəm.

Google variantında başın fəda etmək “ağlına girmək” şəklində anlaşılır; ətəkdən çəkilməyən əl isə mənbədə olmayan qucaq obrazı ilə əvəz edilir. “Bir daha sənə baxmasam da” hissəsi sədaqət mənasını ötürmür. Sonluqdakı “çatana qədər” quruluşunun əsas predikatla tamamlanmaması sintaktik bütövlüyü də pozur. DeepL variantı baş obrazını saxlayır, amma “səni başımda taxmaq” ifadəsi fədakarlıq idiomunu dəyişir. Ən mühüm fərq “sənə dönməyəcəyəm” qarşılığıdır: orijinalda sevgilidən geri dönməmək, tərcümədə isə sevgiliyə qayıtmamaq bildirilir. İstiqamətin dəyişməsi lirik münasibətin mənasını çevirir.

ChatGPT fədakarlıq, niyaz və sədaqət arasındakı əlaqəni daha ardıcıl ötürür. Lakin “nazlı qaynağı” müraciəti Azərbaycan dilində süni səslənə bilər; “niyaz əlimi” birləşməsi farsca quruluşun təsirini saxlayır və axıcılığı zəiflədir. Birinci misranın digər misralardan uzun olması ritmik tarazlığı pozur. “Çəkmərəm” v“ ədönmərəm” sonluqları səsləşsə də, bu yaxınlıq mənbədəki dörd misranın qafiyə birliyini bərpa etmir. İdiomun düzgün açılması bütöv poetik formanın saxlanması ilə nəticələnmir.

Üçüncü rübaidə oxatma leksikası və barışıq

گر بر رگ جان ز شستت آید تیرم
چه خوشتر از ان که پیش دستت میرم
دل با تو خصومت آرزو می‌کندم
تا صلح کنیم و در کنارت گیرم

Üçüncü rübainin ilk beyti sevgilinin atdığı oxun danışanın can damarına yönəlməsi və onun qarşısında ölməyin xoşluğu üzərində qurulur. Dehxodanın lüğətində “شست ə” baş barmaq və ox atmaq üçün işlədilən barmaq halqası mənalarında izah edilir (Dehxoda, tarixsiz). تیر“” ilə birlikdə bu söz oxatma kontekstini yaradır. İkinci beytdə çəkişmək istəyi barışmaq və sevgilini qucaqlamaq məqsədinə bağlanır (Sədi, tarixsiz, rübai 100). Mətnin mənası ölümə razılıq və yaxınlaşma arzusu arasındakı bu əlaqə ilə açılır.

Google Translate:Ə“ gər barmağımdan gözəl bir çiçək çıxsa, qarşımdan keçəndən daha gözəl bir çiçək çıxsa, səninlə düşmənçilik etmək istəyirəm ki, barışıb sənin yanında olaq.”

DeepL:Ə“ gər oxum həyatının kökünə dəyərsə, bu, gözlərinizin önündə ölməkdən nə qədər şirindir. Ürəyimin sənin ürəyinlə dalaşa-dalaşa düşməsinə can atıram ki, sonra barışıq edək və mən sənə daha da yaxın olum.”

ChatGPT:

Əlindən atılan ox can damarıma dəysə,
Qarşında ölməkdən daha xoş nə var?
Ürəyim səninlə çəkişmək istəyir,
Barışıb səni qucağıma almaq üçün.

Google variantında ox “gözəl bir çiçək”lə əvəz edilir, can damarı və ölüm məzmunu buraxılır. Çiçək obrazının təkrarı ilk beytin emosional quruluşunu dəyişir. “Düşmənçilik” və “barışmaq” sözləri ikinci beytdəki qarşılaşdırmanı qismən saxlayır, qucaqlamaq isə ümumi yaxınlığa çevrilir. DeepL variantında “oxum həyatının kökünə dəyərsə” ifadəsi oxu danışana, hədəfi qarşı tərəfə aid edir; orijinaldakı hərəkətin istiqaməti dəyişir. “Həyatın kökü” can damarı obrazını, ürəklərin dalaşması haqqında əlavə təsvir isə çəkişmə arzusunu dəyişdirir. “Həyatının” v“ əsənin” formalarının qarışması müraciətin ardıcıllığını pozur.

ChatGPT əsas məna əlaqəsini saxlayır, lakin “şəst”in konkret oxatma detalını “əl” ilə ümumiləşdirir. “Qarşında” qarşılığı “پیش دست” ifadəsindəki əl ilə bağlı çalarları azaldır; “çəkişmək” sözü “خصومت”in düşmənçilik mənasını yumşalda bilər. Barışmaq ilə qucaqlamaq arasında məqsəd əlaqəsi ötürülür, ancaq misra uzunluqları və qafiyə orijinalın formal təşkilini təkrarlamır. Burada semantik ardıcıllıqla obraz dəqiqliyi eyni səviyyədə qorunmamışdır.

Ritmik təşkil və qafiyə

Orijinal mətnlərin misra sonları birinci rübaidə darat, barat, qamarat, nazarat; ikincidə nāz, niyāz, derāz, bāz; üçüncüdə tīram, mīram, mīkonadam, gīram şəklində şərti transkripsiya edilə bilər. Birinci və ikinci rübai AAAA, üçüncü AABA qafiyə quruluşuna malikdir. Təqdim olunmuş variantlarda bu tam sxemlər bərpa edilmir. Google və DeepL mətnlərinin ilkin interfeysdəki misra sərhədləri sənədləşdirilmədiyindən onların təqdimat formasına əsasında ritm haqqında qəti nəticə çıxarmaq mümkün deyil. Dörd misra ilə saxlanılmış ChatGPT variantları üzrə isə misra uzunluqlarını ayrıca müşahidə etmək mümkündür.

Cədvəl 1. ChatGPT variantlarında yazılan saitlərin sayı

Rübai	Misralar üzrə saitlərin sayı
1-ci rübai	12 / 12 / 12 / 11
2-ci rübai	16 / 12 / 14 / 12
3-cü rübai	14 / 11 / 12 / 13

Birinci variantda üç misrada 12, son misrada isə 11 sait vardır. İkinci və üçüncü variantlarda misralar arasındakı fərqlər daha böyükdür. Bu sayın tələffüz variantlarını, eliziyanı və uzun–qısa heca münasibətlərini nəzərə almır; buna görə orijinalın əruz vəzninin qorunmasına kimi şərh edilmir. Cədvəl yalnız hədəf mətndə misra uzunluqlarının dəyişməsini göstərir. Dörd misralıq quruluşun saxlanması ardıcıl vəzn və qafiyənin yaradılması üçün yetərli deyil.

Müzakirə

Nümunələrdə məna dəyişiklikləri leksik əvəzlənmə, idiomatik yanlış anlama və münasibətin istiqamətinin dəyişməsi şəklində görünür. Güzgünün itməsi və oxun çiçəyə çevrilməsi obrazlar arasındakı əlaqəni pozur. Başını fəda etmək yerinə başda taxmaq ifadəsinin seçilməsi idiomu dəyişdirir. Sevgilidən dönməməyin sevgiliyə dönməmək kimi verilməsi isə sədaqət fikrini başqa məzmuna keçirir. Buna görə tərcümə qiymətləndirilərkən düzgün sözlərin mövcudluğu ilə yanaşı, hərəkətin kimə yönəldiyi və həmin obrazın lirik məntiqdəki funksiyası yoxlanmalıdır.

ChatGPT variantlarında əsas əlaqələrin daha ardıcıl ötürülməsi kontekstin faydasına haqqında ehtimal yaradır, lakin kontekst təsiri ayrıca ölçülməmişdir. Wang və b. (2024) tərəfindən izaha əsaslanan tərcümənin sınaqdan keçirilməsi bu məsələnin gələcəkdə eyni şərtlərlə araşdırılmasını əsaslandırır. Hazırkı nəticələr üç platformanın keyfiyyət sıralamasını müəyyən etmir. Kiçik seçmə, təkrar çıxışların olmaması, model versiyalarının qeydə alınmaması və müstəqil qiymətləndiricilərin iştirak etməməsi ümumiləşdirməni məhdudlaşdırır. Mətnlər həmçinin tənqidi çap nəşri və nəşr olunmuş insan tərcüməsi ilə tutuşdurulmamışdır. Tərcümə tədrisində bu nümunələr idiom, hərəkətin istiqaməti və qafiyə üzrə redaktə məşqlərinə çevrilə bilər; onların təlim nəticələrinə təsiri burada sınaqdan keçirilməyib.

Nəticə

Sədinin seçilmiş üç rübaisinin təhlili göstərir ki, maşın tərcüməsində ayrı-ayrı leksik vahidlərin saxlanması obraz, üslub və lirik məntiqin bütövlüyünü təmin etmir. Təqdim olunmuş Google Translate və DeepL variantlarında əsas məna münasibətlərinin dəyişməsi, ChatGPT variantlarında isə obraz detallarının ümumiləşdirilməsi və ifadə axıcılığının zəifləməsi müşahidə edilir. Dörd misralıq təqdimat formal uyğunluq üçün yetərli olmamış, mənbənin qafiyə sxemləri

bərpa edilməmişdir. Ritmə dair müşahidələr misra uzunluqlarının dəyişkənliyini göstərir; orijinal vəznin ötürülməsi haqqında tam nəticə vermir.

Bu material üzrə poetik tərcümənin redaktəsi əvvəlcə məna münasibətlərinin yoxlanmasını, sonra idiom və obrazların Azərbaycan dilində işlənməsini, ayrıca mərhələdə isə ritm və qafiyənin qiymətləndirilməsini tələb edir. Nəticələr məhz araşdırılan doqquz mətnə aiddir. Sonrakı tədqiqatda eyni təlimat və kontekstlə alınmış təkrar variantlar, nəşr olunmuş insan tərcümələri və bir neçə müstəqil qiymətləndirici ilə müqayisə daha əsaslı nəticə çıxarmağa imkan verər.

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Xarici dil tədrisində anaqram və panqramlardan istifadənin linqvodidaktik əsasları

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Xülasə
Məqalədə xarici dilin tədrisində anaqram və panqramlardan istifadənin nəzəri və praktik əsasları araşdırılmışdır. Müasir təhsil mühitində şagirdlərin və tələbələrin dil bacarıqlarının inkişaf etdirilməsi üçün interaktiv və yaradıcı metodlardan istifadə xüsusi əhəmiyyət daşıyır. Bu metodlar arasında anaqram və panqramlar həm lüğət ehtiyatının zənginləşdirilməsi, həm də oxu, yazı, tələffüz və tənqidi düşünmə bacarıqlarının inkişaf etdirilməsi baxımından mühüm vasitələr hesab olunur. Məqalədə anaqram və panqramların mahiyyəti açıqlanmış, onların xarici dil dərslərində tətbiq imkanları, üstünlükləri və pedaqoji əhəmiyyəti təhlil edilmişdir. Həmçinin müəllimlərin dərs prosesində bu dil oyunlarından istifadə etməsinin motivasiya və öyrənmə keyfiyyətinə müsbət təsiri elmi-pedaqoji baxımdan əsaslandırılmışdır. Xarici dilin mənimsənilməsi çoxşaxəli idrak prosesi olmaqla dinləmə, danışma, oxu və yazı kimi dörd əsas dil bacarığının paralel inkişafını tələb edir. Müasir linqvodidaktik yanaşmalara görə, bu bacarıqlar bir-birindən ayrılıqda deyil, qarşılıqlı əlaqədə formalaşdırılmalıdır. Bu baxımdan anaqram və panqramlar dilin müxtəlif səviyyələrini eyni vaxtda əhatə edən və inteqrativ öyrənməni dəstəkləyən metodik vasitələr kimi xüsusi əhəmiyyət daşıyır. Onların tədris prosesinə məqsədyönlü şəkildə daxil edilməsi öyrənənlərin həm dil materialını daha dərindən mənimsəməsinə, həm də yaradıcı düşünmə qabiliyyətinin inkişafına müsbət təsir göstərir. Müasir xarici dil tədrisi kommunikativ yanaşma, kompetensiya əsaslı təlim və tələbəyönümlü pedaqoji modellər üzərində qurulduğundan öyrənənlərin leksik ehtiyatının zənginləşdirilməsi, orfoqrafik savadlılığının artırılması, fonetik bacarıqlarının inkişaf etdirilməsi və yaradıcı təfəkkürünün stimullaşdırılması mühüm əhəmiyyət kəsb edir. Bu baxımdan anaqram və panqramlar yalnız dil oyunu deyil, həm də idrak fəallığını artıran, öyrənməyə motivasiya yaradan və dil vahidlərinin daha səmərəli mənimsənilməsini təmin edən didaktik vasitələr kimi çıxış edir. Məqalədə anaqram və panqramların nəzəri mahiyyəti, onların xarici dil dərslərində tətbiq formaları, ingilis və fransız dili nümunələri əsasında metodik xüsusiyyətləri, həmçinin müəllim hazırlığında və müasir tədris texnologiyalarında istifadə perspektivləri araşdırılır.
Açar sözlər: xarici dil, anaqram, panqram, linqvodidaktika, dil oyunları, lüğət ehtiyatı, kommunikativ təlim, interaktiv metodlar

Ключевые слова: иностранный язык, анаграмма, панграмма, лингводидактика, языковые игры, словарный запас, коммуникативное обучение, интерактивные методы.

Keywords: foreign language, anagram, pangram, language didactics, language games, vocabulary, communicative teaching, interactive methods.

Giriş

Qloballaşma dövründə xarici dillərin öyrənilməsi fərdin peşəkar və şəxsi inkişafının əsas şərtlərindən biri hesab olunur. İnformasiyanın sürətlə artdığı müasir cəmiyyətdə yalnız qrammatik

qaydaların öyrədilməsi kifayət etmir. Tədris prosesi şagirdlərin yaradıcı düşünməsini, nitq bacarıqlarını və dilə marağını inkişaf etdirən üsullarla zənginləşdirilməlidir. Buna görə də xarici dil müəllimləri ənənəvi metodlarla yanaşı, innovativ və interaktiv yanaşmalardan istifadə etməyə çalışırlar.

Dil oyunları bu baxımdan xüsusi əhəmiyyət kəsb edir. Onlar şagirdlərdə öyrənməyə maraq yaradır, emosional rahatlıq təmin edir və öyrənilən materialın uzunmüddətli yaddaşda saxlanılmasına kömək edir. Anaqram və panqramlar da məhz belə vasitələrdəndir. Bu üsullar sadəcə əyləncə elementi deyil, həm də söz ehtiyatının genişləndirilməsi, düzgün yazı vərdişlərinin formalaşdırılması, diqqətin, məntiqi və yaradıcı təfəkkürün inkişaf etdirilməsi üçün effektiv pedaqoji vasitədir.

Müasir linqvodidaktik yanaşmalar sübut edir ki, oyun elementlərinin tətbiqi öyrənənlərin motivasiyasını artırır, onların dərsdə fəallığını yüksəldir və kommunikativ bacarıqlarının inkişafına müsbət təsir göstərir. Xüsusilə ingilis, alman, fransız və digər xarici dillərin tədrisində anaqram və panqramlardan istifadə şagirdlərin yeni sözləri daha asan mənimsəməsinə, sözlərin yazılışını yadda saxlamasına və fonetik xüsusiyyətləri daha düzgün qavramasına şərait yaradır.

Bu məqalənin məqsədi xarici dil tədrisində anaqram və panqramlardan istifadənin nəzəri əsaslarını araşdırmaq, onların pedaqoji əhəmiyyətini müəyyənləşdirmək və praktik tətbiq imkanlarını elmi baxımdan təhlil etməkdir.

Xarici dilin tədrisində istifadə olunan dil oyunları öyrənənlərin idrak fəallığını artıran, öyrənmə prosesini maraqlı və səmərəli edən mühüm pedaqoji vasitələrdir. Bu oyunlar arasında anaqram və panqramlar həm linqvistik, həm də didaktik baxımdan xüsusi əhəmiyyətə malikdir.

Anaqram hər hansı sözün və ya söz birləşməsinin hərflərinin yerini dəyişdirməklə yeni sözün yaradılması üsuludur. Məsələn, ingilis dilində *listen* sözünün hərflərinin düzülüşünü dəyişdikdə *silent* sözü alınır. Bu cür tapşırıqlar öyrənənlərin diqqətini artırır, sözlərin quruluşunu daha dərindən dərk etməsinə kömək edir və lüğət ehtiyatını zənginləşdirir. Anaqramlar həm fərdi, həm də qrup şəklində təşkil olunan fəaliyyətlər üçün əlverişli vasitə hesab edilir. Anaqramlar öyrənənlərin leksik ehtiyatının zənginləşdirilməsi, sözlərin qrafik quruluşunun mənimsənilməsi və analitik düşünmə bacarıqlarının inkişaf etdirilməsi baxımından mühüm didaktik vasitə hesab olunur (Nation, 2013). Tədqiqatlar göstərir ki, sözlərlə manipulyasiya xarakterli tapşırıqlar uzunmüddətli yaddaşın formalaşmasına müsbət təsir göstərir (Ellis, 2008)Panqram isə əlifbanın bütün hərflərini özündə ehtiva edən cümlə və ya mətndir. Panqramlar xüsusilə yazı bacarıqlarının inkişafında, klaviatura vərdişlərinin formalaşdırılmasında, şriftlərin yoxlanılmasında və fonetik xüsusiyyətlərin mənimsənilməsində geniş tətbiq olunur.

Linqvodidaktik baxımdan hər iki metod öyrənənin passiv iştirakçı deyil, aktiv öyrənən olmasını təmin edir. Şagird söz üzərində düşünür, analiz aparır, müqayisə edir və nəticə çıxarır. Belə fəaliyyətlər yaddaşın möhkəmlənməsinə, analitik təfəkkürün inkişafına və sözlərin uzunmüddətli mənimsənilməsinə müsbət təsir göstərir.

Müasir təhsil yanaşmalarında oyun texnologiyalarının tətbiqi konstruktivist təlim nəzəriyyəsi ilə də uyğunluq təşkil edir. Bu yanaşmaya görə, şagird biliyi hazır şəkildə qəbul etmir, onu müstəqil fəaliyyət nəticəsində qurur. Anaqram və panqramlarla işləmək də məhz bu prinsipi dəstəkləyir. Öyrənən sözləri araşdırır, müxtəlif variantları yoxlayır və nəticədə yeni bilik əldə edir.

Anaqramlardan istifadə xarici dil dərslərində yeni sözlərin mənimsənilməsi prosesini asanlaşdırır. Müəllim yeni mövzuya aid sözləri qarışıq hərflərlə təqdim etdikdə şagirdlər həmin sözləri bərpa etməyə çalışırlar. Bu fəaliyyət onların diqqətini, məntiqi düşünməsini və sözlərin düzgün yazılışını yadda saxlamasını təmin edir.

Anaqram tapşırıqları aşağıdakı bacarıqların inkişafına xidmət edir:

- lüğət ehtiyatının zənginləşdirilməsi;
- düzgün yazı vərdişlərinin formalaşdırılması;
- vizual yaddaşın gücləndirilməsi;

- analitik və yaradıcı düşünmənin inkişafı;
- dərsə maraq və motivasiyanın artırılması.

Məsələn, müəllim ingilis dili dərsində **teacher**, **student**, **school**, **language**, **dictionary** kimi sözləri qarışıq formada təqdim edə bilər. Şagirdlər sözləri düzgün bərpa etdikdən sonra həmin sözlərlə cümlələr qurur, dialoqlar hazırlayır və beləliklə, yeni sözlər həm yazılı, həm də şifahi nitqdə aktiv istifadə olunur.

Belə tapşırıqlar xüsusilə ibtidai və orta məktəb şagirdləri üçün maraqlı olduğundan onların dərsə fəallığını artırır və öyrənməni daha səmərəli edir.

Bəs panqramların xarici dilin öyrənilməsində rolu və praktik tətbiqi nədən ibarətdir? Panqramlar xarici dil tədrisində şagirdlərin əlifba sistemini, hərflərin yazılışını və fonetik xüsusiyyətlərini mənimsəməsində mühüm rol oynayır. Bu cümlələrdə əlifbanın bütün hərfləri iştirak etdiyi üçün öyrənənlər həm yazı, həm də oxu zamanı müxtəlif hərf birləşmələri ilə tanış olur, sözlərin düzgün yazılışı və tələffüzü barədə daha dolğun təsəvvür əldə edirlər.

Müasir pedaqoji tədqiqatlar göstərir ki, oyun elementləri ilə zənginləşdirilmiş dərslər şagirdlərin motivasiyasını artırır, dərs prosesində fəallığını yüksəldir və öyrənilən materialın uzunmüddətli yaddaşda saxlanılmasına müsbət təsir göstərir. Anaqram və panqramlar da məhz bu xüsusiyyətlərinə görə kommunikativ yanaşmanın mühüm vasitələrindən biri hesab olunur.

Panqramlarla bağlı fəaliyyət zamanı şagirdlərdən verilmiş cümləni düzgün oxumaq, yazmaq və tərcümə etmək tələb olunur. Daha sonra onlar yeni öyrəndikləri sözlərdən istifadə etməklə öz panqramlarını hazırlamağa çalışırlar. Bu fəaliyyət yaradıcı təfəkkürün, əməkdaşlıq bacarıqlarının və dil materialının praktik şəkildə tətbiq etmək vərdişlərinin inkişafına şərait yaradır.

Bundan əlavə, rəqəmsal təhsil platformalarında və mobil tətbiqlərdə təqdim olunan anaqram oyunlarında dərs prosesinə inteqrasiya oluna bilər. Bu cür resurslar şagirdlərin müstəqil öyrənmə bacarıqlarını gücləndirir, onların informasiya-kommunikasiya texnologiyalarından səmərəli istifadə etməsinə imkan yaradır və təlim prosesini daha maraqlı edir.

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Daha sonra onlar yeni öyrəndikləri sözlərdən istifadə etməklə öz panqramlarını hazırlamağa çalışırlar. Bu fəaliyyət yaradıcı təfəkkürün, əməkdaşlıq bacarıqlarının və dil materialının praktik şəkildə tətbiq etmək vərdişlərinin inkişafına şərait yaradır. Rəqəmsal təlim mühiti öyrənənlərin motivasiyasını artırır və interaktiv fəaliyyətlər vasitəsilə dil bacarıqlarının daha səmərəli inkişafına imkan yaradır (UNESCO, 2023). Müasir kurikulumlarda oyun əsaslı öyrənmə metodlarının tətbiqi tələbəyönümlü təhsilin mühüm komponentlərindən biri hesab edilir (Richards, 2001).

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vasitə kimi çıxış edir. Bu metodlardan istifadə şagirdlərin lüğət ehtiyatının zənginləşməsinə, düzgün yazı və tələffüz bacarıqlarının formalaşmasına, diqqət, məntiqi təfəkkür və yaradıcı düşünmə qabiliyyətinin inkişafına müsbət təsir göstərir.Müəllimin bu üsullardan məqsədyönlü şəkildə istifadə etməsi tədrisin keyfiyyətini yüksəldir, şagirdlərin motivasiyasını artırır və xarici dil öyrənmə prosesini daha səmərəli edir. Xüsusilə kommunikativ yanaşmanın tətbiq olunduğu müasir dərslərdə anaqram və panqramlardan sistemli istifadə öyrənənlərin dil bacarıqlarının kompleks inkişafına xidmət edir.Nəticə etibarilə, anaqram və panqramlar xarici dil tədrisində innovativ və effektiv metodlardan biri kimi qiymətləndirilə bilər. Onların tədris prosesinə geniş şəkildə inteqrasiyası təhsilin keyfiyyətinin yüksəldilməsinə və öyrənənlərin xarici dili daha asan mənimsəməsinə mühüm töhfə verə bilər.Anaqram və panqramlar yalnız dil oyunu deyil, həm də leksik kompetensiyanın, fonoloji emalın və koqnitiv elastikliyin inkişafına xidmət edən inteqrativ linqvodidaktik vasitələrdir.

Anaqram tapşırıqları leksik vahidlərin semantik və morfoloji xüsusiyyətlərinin eyni vaxtda mənimsənilməsinə şərait yaratmaqla öyrənənlərin leksik kompetensiyasını inkişaf etdirir. Bu baxımdan anaqramlar konstruktivist təlim yanaşmasının əsas prinsiplərindən biri olan aktiv bilik quruculuğunu dəstəkləyən didaktik vasitə kimi qiymətləndirilə bilər.

Panqramlardan sistemli istifadə öyrənənlərin qrafik-fonetik uyğunluğu mənimsəməsinə, orfoqrafik savadlılığının formalaşmasına və vizual yaddaşın gücləndirilməsinə müsbət təsir göstərir. Bu xüsusiyyətlər xüsusilə xarici dilin başlanğıc mərhələsində mühüm metodik əhəmiyyət daşıyır.

Müəllim bu cümlədən istifadə etməklə şagirdlərə həm oxu, həm də yazmaşqları təşkil edə bilər. Şagirdlər cümləni yazır, tələffüz edir, sözlərin mənasını öyrənir və sonradan həmin sözlərdən istifadə etməklə yeni cümlələr qururlar. Bu fəaliyyət onların lüğət ehtiyatını aktivləşdirir, söz seçimi bacarığını inkişaf etdirir və dil materialından yaradıcı şəkildə istifadə etmələrinə şərait yaradır.

Qarışıq hərflər	Düzgün söz	Azərbaycan dilində mənası
LOECÉ	ÉCOLE	məktəb
EELVE	ÉLÈVE	şagird
ÇAANRSIF	FRANÇAIS	fransız dili
URTDEIÉ	ÉTUDIER	öyrənmək
IERVL	LIVRE	kitab

Xarici dil müəllimi dərsin müxtəlif mərhələlərində anaqram və panqramlardan istifadə edə bilər. Yeni mövzunun izahı zamanı anaqramlar vasitəsilə əsas sözlərin təqdim edilməsi şagirdlərin marağını artırır və onları fəal düşünməyə sövq edir. Möhkəmləndirmə mərhələsində isə panqramlardan istifadə etməklə yazı və oxu bacarıqlarını inkişaf etdirilə bilər.

Şagirdlər sözləri düzgün bərpa etdikdən sonra həmin sözlərlə dialoq qurur, alış-veriş mövzusunda kiçik rollu oyunlar təşkil edirlər. Belə fəaliyyət həm söz ehtiyatını artırır, həm də kommunikativ bacarıqların inkişafına xidmət edir.

Nəticə

Aparılan təhlillər göstərir ki, anaqram və panqramlar xarici dilin tədrisində yalnız əyləncəli dil oyunları deyil, həm də elmi cəhətdən əsaslandırılmış linqvodidaktik vasitələrdir. Onların məqsədyönlü tətbiqi öyrənənlərin leksik ehtiyatının zənginləşdirilməsinə, orfoqrafik və fonetik bacarıqlarının inkişafına, məntiqi və yaradıcı təfəkkürünün formalaşmasına, eləcə də kommunikativ kompetensiyalarının gücləndirilməsinə mühüm töhfə verir.

Araşdırma göstərir ki, anaqramlar söz ehtiyatının mənimsənilməsini asanlaşdırmaqla yanaşı, dil vahidlərinin strukturunun daha dərindən dərk edilməsinə, assosiativ yaddaşın inkişafına və öyrənənlərin analitik düşünmə bacarıqlarının güclənməsinə şərait yaradır. Panqramlar isə əlifbanın

bütün hərflərini əhatə etməklə fonetik, qrafik və orfoqrafik bacarıqların sistemli şəkildə inkişafına xidmət edir. Xüsusilə fransız dili kimi mürəkkəb fonetik və orfoqrafik sistemə malik dillərin tədrisində panqramlardan istifadə tələffüzün təkmilləşdirilməsi, yazı vərdişlərinin möhkəmləndirilməsi və hərf–səs uyğunluqlarının mənimsənilməsi baxımından yüksək metodik səmərəlilik nümayiş etdirir.

Müasir kompetensiya əsaslı təhsil modeli, kommunikativ yanaşma və rəqəmsal pedaqogika kontekstində anaqram və panqramlardan istifadə müəllimə interaktiv, tələbəyönümlü və motivasiyaedici təlim mühiti yaratmağa imkan verir. Bu vasitələr öyrənənlərin fəallığını artırır, əməkdaşlıq bacarıqlarını inkişaf etdirir və müstəqil öyrənmə vərdişlərinin formalaşmasına müsbət təsir göstərir.

Nəticə etibarilə, anaqram və panqramların xarici dil dərslərində sistemli və metodik cəhətdən əsaslandırılmış şəkildə tətbiqi tədrisin keyfiyyətinin yüksəldilməsinə, dil bacarıqlarının inteqrasiyalı inkişafına və öyrənənlərin kommunikativ kompetensiyalarının formalaşmasına xidmət edən mühüm didaktik vasitə kimi qiymətləndirilə bilər. Gələcək tədqiqatlarda bu metodların rəqəmsal təhsil platformalarında tətbiqinin səmərəliliyinin eksperimental yollarla araşdırılması məqsədəuyğun hesab olunur.

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Technical Sciences

UDC 664.681

DEVELOPMENT OF TECHNOLOGY OF FUNCTIONAL SHORTBREAD COOKIES ENRICHED WITH RASPBERRY POWDER

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The development of functional foods is a priority area in the modern food industry. One promising method for increasing the nutritional and biological value of baked goods is the use of fruit and berry powders containing dietary fiber, phenolic compounds, and natural antioxidants [1, 3, 4]. Raspberry powder is of practical interest due to its high content of biologically active substances and the potential for its use in baked goods recipes [2, 4]. Despite existing research, the optimal dosages of raspberry powder and their effect on the quality of shortbread cookies have not been sufficiently studied.

The aim of the study was to develop a technology for functional shortbread cookies using raspberry powder and to evaluate its impact on the quality of finished products.

The study involved raspberries from the 2025 harvest, grown in the Almaty region of the Republic of Kazakhstan. The powder was obtained by convective drying at 60°C until a residual moisture content of 8.4% was reached.

Shortbread cookies were produced according to GOST 24901–2014 with some of the wheat flour replaced with raspberry powder in amounts of 3, 5, and 7%.

The organoleptic properties, nutritional value and antioxidant activity of the obtained samples were assessed.

Convective drying produced a powder with good flowability, natural color, and a distinct aroma. Reducing moisture content to 8.4% resulted in a concentration of dry matter, leading to increased concentrations of protein, carbohydrates, and antioxidant compounds. These results are consistent with other studies showing that moisture removal promotes the concentration of biologically active substances in fruit and berry powders [2,4].

The content of fat-soluble antioxidants increased from 0.05 to 0.18 mg/g, and water-soluble antioxidants from 0.21 to 0.73 mg/g, which indicates the high biological value of the obtained powder and the prospects for its use in the production of functional flour products [2,3].

Adding raspberry powder improved the color, flavor, and aroma of the cookies, as well as increased the dough's water-holding capacity. At 7%, a firmer texture and increased crumbliness were observed. Similar changes in organoleptic properties when using berry powders in cookie technology are noted in the study [2].

Based on the results of a comprehensive assessment, a 5% raspberry powder dosage was found to be optimal, providing the best organoleptic and physicochemical properties. Table 1 presents the nutritional value of shortbread cookies using 5% raspberry powder.

Table 1 - Nutritional value of shortbread cookies using raspberry powder

Indicator	Control	Raspberry cookies
Mass fraction of protein, %	6.8	7.5
Mass fraction of fat, %	18.4	18.1
Mass fraction of carbohydrates, %	67.2	64.8
Energy value, kcal/100 g	468	452

The introduction of 5% raspberry powder resulted in an increase in protein content by 10.3%, a decrease in carbohydrate content by 3.6%, and a decrease in the energy value of the products by 3.4% compared to the control sample.

Thus, a technology for producing functional shortbread cookies using raspberry powder has been developed. It has been proven that the optimal dosage is 5% of the wheat flour weight, providing improved organoleptic characteristics, increased nutritional value, and antioxidant potential while reducing carbohydrate content and energy value. The obtained results confirm the feasibility of using raspberry powder in the development of functional flour confectionery products and the potential for implementing this technology in food processing enterprises in the Republic of Kazakhstan.

This work was carried out for the purpose of implementing the program-targeted financing project BR24993031 "Development of technology for the production of healthy food products for everyday consumption, enriched with natural antioxidants and biologically active compounds", within the framework of the topic "Development of technology for the production of confectionery products (cookies and gingerbread) based on dry powders of melons, fruits and berries"

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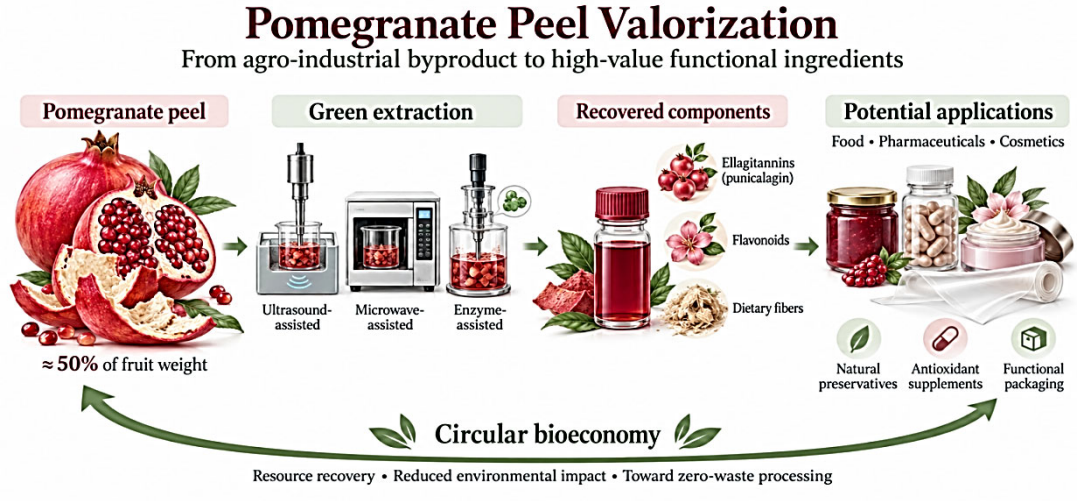
CONCEPTUAL FOUNDATIONS OF POMEGRANATE PEEL VALORIZATION: A BRIEF OVERVIEW

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Abstract
This mini-review examines the conceptual foundations of pomegranate peel valorization, focusing on transforming this agro-industrial byproduct into high-value functional ingredients. Pomegranate peel accounts for approximately 50% of the total fruit weight and represents a rich source of bioactive compounds, particularly ellagitannins (punicalagin), flavonoids, and dietary fibers. This paper synthesizes current circular economy frameworks, highlighting the transition from conventional waste management to advanced biorefinery strategies. We discuss innovative green extraction technologies-such as ultrasound, microwave, and enzyme-assisted methods-that maximize phytochemical recovery while minimizing environmental impact. Furthermore, the review outlines the diverse applications of extracted compounds in the food, pharmaceutical, and cosmetic industries, specifically as natural preservatives, antioxidant supplements, and functional packaging materials. Ultimately, this review underlines the economic and ecological potential of pomegranate peel valorization as a sustainable pathway toward zero-waste industrial processing.
Keywords: Pomegranate peel, Valorization, Bioactive compounds, Circular economy, Green extraction, Biorefinery.

Graphical abstract



1 Introduction

Global food production is inevitably accompanied by the formation of colossal amounts of biomass, most of which is disposed of as waste. In the pomegranate processing industry (Punica granatum L.), up to 50% of the total weight of the fruit is accounted for by the peel, which is traditionally considered as a by-product of low cost. However, from the standpoint of modern bioeconomics, this resource is a valuable raw material enriched with biologically active compounds, including polyphenols, tannins and pectin. The transition from simple utilization of pomegranate peel to its deep processing (valorization) opens up broad prospects for its integration into the pharmaceutical, cosmetic and food industries as functional ingredients.

In this context, the transition means abandoning the disposal of pomegranate peel as cheap waste ("simple processing", for example, drying for livestock feed) in favor of extracting high-tech and expensive components from it ("deep processing").

Deep processing reveals the value of the peel in three key areas:

• Bioactive value (for pharmacy and cosmetics): Pomegranate peel is rich in powerful antioxidants (such as punicalagin and ellagic acid). Deep processing allows these purified extracts to be isolated to create medicines, dietary supplements, and anti-aging cosmetics.

• Technological value (for the food industry): Natural preservatives, dyes and dietary fiber (pectin) are extracted from the peel, which replace synthetic additives in food.

• Commercial value (for business): The sale of highly refined extracts and functional ingredients generates tens of times more profit than the sale of raw or simply dried peel. In the raw materials market, this turns "garbage" into a valuable resource in demand.

In general, we are talking about added value (economic value) and biological value (functional value) raw materials.

The purpose of this review is to systematize modern scientific, theoretical and technological approaches to the valorization of pomegranate peel. The paper examines the key conceptual areas of extraction of valuable components, analyzes the mechanisms of their biological activity, and evaluates the economic and environmental feasibility of scaling these technologies. The formation of such a comprehensive theoretical framework is designed to identify the most promising vectors for creating waste-free industries and introducing the principles of circular economy into the agro-industrial sector.

2 Botanical and Anatomical Characteristics of Punica Granatum L. Fruit

2.1 Morphology and structure of the exocarp and mesocarp

Pomegranate peel comprises the exocarp and adjacent mesocarp, whose structural features critically determine its behavior during extraction and fermentation processes [1, 2]. When the peel is used as coarse, irregularly shaped fragments obtained from manual or mechanical cleaning, the tissue maintains its macrostructural integrity under ambient conditions. This intact architecture enables efficient gravita-tional phase separation after fermentation, since large fragments do not release excessive mucilaginous components into the medium and can be decanted and pressed without disintegration of the solid matrix [3]. Mechanical comminution and thermal aqueous treatment drastically alter this mor-phology. Intensive grinding increases the specific surface area but also disrupts cell wall continuity, whereas high temperature promotes hydrolytic degradation of the pectin rich matrix. As a result, the exocarp and mesocarp transform from a structured tissue into a viscous colloidal suspension, charac-terized by turbidity, elevated viscosity, and dispersed hydrolyzed particulates. This rheological shift severely impairs solid liquid separation and favors co extraction of non target saccharides and biocol-loids, illustrating how loss of structural integrity in these layers translates directly into technological drawbacks [4]. Thermal

and hydrothermal treatments not only modify texture, but also provoke substantial leaching of soluble fractions from the exocarp mesocarp complex. Under such conditions, significant amounts of native pectins, phenolic substances, simple sugars, nitrogenous compounds, and mineral constituents are irreversibly removed from the peel. This compositional depletion reflects the high permeability and solubility of cell wall and middle lamella components once the tissue architecture is weakened, and it undermines both the fermentative potential of the substrate and the valorization of its bioactive fraction [1]. Ambient temperature extraction with coarse fragments preserves the microstructure sufficiently to constrain the migration of mucilaginous polysaccharides, especially soluble pectins, from the mesocarp into the liquid phase. Lower solubilization kinetics maintain a relatively low viscosity medium, which facilitates filtration and decantation. In parallel, alcoholic fer-mentation converts diffusing monosaccharides into ethanol and CO_2, preventing oversaturation with dissolved solids. Ethanol generated in situ acts as a co solvent within the hydro ethanolic matrix, stabilizing thermolabile polyphenols while the exocarp mesocarp scaffold remains largely intact, un-derscoring the functional role of morphological preservation in process performance [3]. Within the peel, polyphenols occur both as soluble, medium to high polarity constituents and as insoluble, matrix bound fractions associated with cell wall polysaccharides. Soluble anthocyanins, flavonoids, hydroxycinnamic acids, punicalagins, ellagitannins, and related phenolics diffuse readily into aqueous or hydro ethanolic media during prolonged contact. In contrast, low polarity insoluble polyphenols remain tethered to structural polymers of the exocarp and mesocarp and are typically released only when thermal treatment or enzymatic hydrolysis disrupts these carbohydrate matrices. This differen-tial localization and binding reflects the heterogeneous microarchitecture of the peel and explains the strong dependence of extraction profiles on the degree of structural disruption imposed by processing [3,4]. Microstructural characteristics also influence microbiological stability. High endogenous organic acid content in the exocarp produces fermentation mixtures with pH values in the range 2.8–3.2, a domain that supports Saccharomyces cerevisiae while inhibiting many spoilage bacteria. Because the tissue is not fully disintegrated under cold extraction, acid rich domains within the peel continue to modulate the surrounding medium, contributing to a stable, low pH environment without the extensive release of structural polysaccharides that would otherwise increase viscosity and complicate handling [3].

2.2 Distribution of primary metabolites in different fruit tissues

Primary metabolites in pomegranate fruit exhibit distinct quantitative and qualitative distributions between the juice yielding tissues and the exocarp, and these patterns are central to peel valorization strategies. The peel, comprising mainly exocarp and associated mesocarp, has been characterized as comparatively rich in soluble carbohydrates, dietary fiber, mineral ash, and structurally bound polysaccharides, despite containing less crude protein than the seeds. Quantitative assessments report crude protein contents of 36 g/kg dry matter for peel versus 154 g/kg for seeds, yet the peel surpasses seeds in ash elements (54 g/kg vs. 24 g/kg) and soluble carbohydrates (695.9 g/kg vs. 135 g/kg dry matter), underscoring its role as a carbohydrate dense, mineral rich tissue within the fruit [5]. Detailed proximate analyses of dried peel and alcohol insoluble residues further refine this view of tissue specific metabolite distribution. Water content, protein, fat, neutral soluble fiber, and acid soluble fiber differ between these two preparations, with the alcohol insoluble residue enriched in structural carbohy-drates such as neutral and acid soluble fiber relative to whole dried peel. The pectin, hemicellulose, cellulose, and lignin fractions are also slightly higher in the alcohol insoluble residue, indicating that this fraction concentrates the cell wall bound carbohydrate matrix, whereas the original peel retains a higher proportion of soluble components. Essential amino acids including threonine, valine, isoleucine, leucine, phenylalanine, and lysine are present in both preparations, but methionine and tryptophan are deficient once the residue is reduced to fine powder. These data demonstrate that the peel tissue

not only accumulates structural polysaccharides and soluble sugars but also carries a non negligible amino acid pool, although its protein quality differs from that of seed tissue [6,7]. Beyond bulk nutrients, the exocarp constitutes the principal reservoir of phenolic metabolites and tannins within the fruit. Polyphenolic compounds are distributed among free (water soluble), acid hydrolyzable, and alkaline hydrolyzable fractions in the exocarp, with free phenols predominating. Quantitative work has estab-lished free phenols at 8.11 g, acid hydrolyzable at 1.56 g, and alkaline hydrolyzable at 4.05 g per 100 g air dried exocarp [8]. Subsequent fractionation using hydro ethanolic extraction and ultrasound assisted alkaline hydrolysis quantified free polyphenols, punicalagin anomers, and ellagic acid in the exocarp at 10159 ± 395 mg, 1197 ± 79 mg, and 515 ± 19 mg per 100 g dry exocarp, respectively, while bound phenols in the insoluble residue reached 4230 ± 190 mg per 100 g total dry weight [9]. These results confirm that the peel tissue concentrates both readily extractable and matrix bound phenolic pools, which differ in solubility and binding to cell wall polymers. The metabolite distribution within exocarp also determines the behavior of primary metabolites during fermentation assisted extraction.

In a rep-resentative experiment using 400 g of exocarp at a 1 : 1.5 hydromodule, the total phenolic content of 10.40 g in the substrate partitioned into 6.93 g in 700 mL wine extract and 3.46 g retained in the freshly pressed solid residue, corresponding to 66.63% and 33.37% of the initial mass, respectively. The liquid extract carried soluble dry substances of 10.70 ◦Brix, substantial monosaccharide and sucrose levels, and 14.00 mL/100 mL ethanol, whereas the solid residue contained concentrated dry matter, protein, and ash. This partitioning highlights the differential migration of soluble sugars and phenolics into the liquid phase, contrasted with the retention of structural carbohydrates and associated polyphenols in the peel matrix. Hydromodule manipulations further demonstrate how solvent volume modulates the distribution and metabolic utilization of primary metabolites originating from the exocarp. Increasing the peel to water ratio from 1 : 1 to 1 : 4 enhances yeast assimilation of proteins and carbohydrates, with maximum utilization at 1 : 4, while excessive dilution at 1 : 8 reduces nutrient density and slows Saccharomyces cerevisiae growth. Under the conditions of 18–22 ^{o} C, 0.13% yeast inoculum, and 18% exogenous sucrose, these patterns indicate that peel derived proteins, endogenous sugars, and externally added carbohydrate sources jointly govern the fermentative conversion into ethanol. The balanced hydromodule of 1 : 1.5–1.6 was selected to ensure complete submergence of coarse exocarp and to achieve ethanol levels comparable to dry wines, illustrating the interplay between tissue specific metabolite pools and process design [10].

3 Chemical Composition of Pomegranate Peel as a Functional Biomass

Phenolic constituents in pomegranate peel are organized into distinct classes that reflect their chemical structure, polarity, and binding state within the exocarp matrix. At the broadest level, polyphenols comprise tannins and non tannin phenolic acids and flavonoids, with tannins forming a functional subgroup characterized by high molecular weight and protein binding capacity. Within tannins, four principal groups are distinguished in plants: complex tannins, condensed tannins (proanthocyanidins), gallotannins, and ellagitannins, the latter two constituting the hydrolyzable tannin class. Pomegranate peel is dominated by ellagitannins, chiefly punicalagin α and β isomers, which account for 65.75–85% of total tannins and undergo hydrolysis to punicalin and ultimately ellagic acid [11, 12]. Additional ellagitan-nins reported in the exocarp include pedunculagin, granatin A, granatin B, corylagin, tellimagrandin, and gallagylhexoside, underscoring the structural diversity of the hydrolyzable tannin fraction [13]. These data formalize a ma-trix based classification into soluble free phenolics and insoluble, cell wall bound phenolics, each with characteristic quantitative profiles.

Within the free, medium to high polarity pool, the exo-carp contains flavonoids such as

anthocyanins, quercetin, and rutin in glycosidic forms, together with hydroxycinnamic acids including chlorogenic and p coumaric acids, and major ellagitannins such as punicalagins and ellagitannins broadly. Pomegranate peel also harbors phenolic acids encompassing gallic, ellagic, vanillic, caffeic, ferulic, cinnamic, chlorogenic, and p coumaric acids, as well as flavonoids like kaempferol, luteolin, rutin, quercetin, and hesperidin, and triterpenes such as oleanic and ursolic acids and phenylethyl alcohol derivatives exemplified by hydroxytyrosol. Chinese varieties exhibit av-erage gallic and ellagic acid contents of 0.57 mg/g and 1.34 mg/g, respectively, while other datasets report 123.79, 35.89, 20.56, and 4.48 mg/100 g for gallic, ellagic, caffeic, and p coumaric acids in peel material [14]. The exocarp further contains about 30% of the fruit total anthocyanins, with eight glycosidic derivatives identified in Tunisian cultivars, including delphinidin and cyanidin glycosides, reinforcing the role of the peel as a major chromophore reservoir [15-16]. In contrast, insoluble phenolic con-stituents exhibit low to negligible polarity and are tightly associated with cell wall polysaccharides, forming matrix bound fractions that are not readily extracted by simple aqueous or hydro ethano-lic infusion.

Research shows that these bound phenols become accessible predominantly under more aggressive conditions, such as alkaline hydrolysis or hydrothermal treatment, which disrupt the lig-nocellulosic and pectic frameworks of the peel. However, such treatments can simultaneously lead to irreversible loss of pectins, phenolic substances, natural sugars, and soluble nitrogenous and mineral fractions, which limits their suitability for food oriented valorization strategies focused on preserving the native phenolic profile. From an industrial perspective, commercial processes frequently target ellagitannins, particularly punicalagin and ellagic acid, as key bioactive markers in standardized peel extracts. Conventional schemes employ drying, grinding, heated aqueous extraction, and subse-quent adsorption chromatography on macroporous resins or XAD type sorbents, followed by ethanol elution, concentration, and drying to yield polyphenol rich powders. While effective for isolating high purity phenolic fractions, these multi stage, energy intensive operations suffer from fouling due to colloid release and excessive co extraction of sugars and biocolloids, reflecting their reliance on finely comminuted peel and thermal agitation, which intensify solubilization of both target and non target phenolic classes [4].

3.2 Variability in peel composition among cultivars and growing regions

Compositional attributes of pomegranate peel exhibit pronounced quantitative variability that can be linked to both genetic background and production context. Data on proximate composition show that dried peel and an alcohol insoluble residue derived from it differ in water, protein, fat, and fiber con-tents, indicating that even within a single raw material, fractionation procedures generate preparations with distinct nutritional profiles. The alcohol insoluble residue is enriched in protein and fat relative to whole dried peel and contains higher proportions of neutral soluble fiber and acid soluble fiber, as well as slightly elevated pectin, hemicellulose, cellulose, and lignin fractions. These observations demonstrate that cell wall associated carbohydrates and bound macromolecules are concentrated in structurally focused fractions, whereas the unfractionated peel retains a greater share of soluble com-ponents, including readily extractable sugars. At the level of essential amino acids, both preparations contain threonine, valine, isoleucine, leucine, phenylalanine, and lysine, but methionine and tryptophan become deficient once the residue is converted into fine powder, underlining the sensitivity of amino acid balance to processing history as much as to varietal factors. When considered as a functional biomass for feed or food applications, peel composition is compared with other agricultural residues such as alfalfa, apple pomace, citrus peel, corn silage, and tomato pomace. These comparisons indicate that pomegranate peel possesses a higher energy value than these reference materials, reflecting its elevated content of soluble carbohydrates and a favorable ratio of insoluble to soluble dietary fiber. Crude protein levels of 36 g/kg dry matter place peel below pomegranate seeds, which reach 154 g/kg, yet peel surpasses seeds in ash elements (54 g/kg vs. 24 g/kg) and soluble carbohydrates

(695.9 g/kg vs. 135 g/kg), highlighting a compositional profile skewed toward minerals and fermentable sugars [17].

Nutritionists evaluate the insoluble dietary fiber to soluble dietary fiber ratio as a key indicator of functionality, and peel exhibits IDF/SDF values of 1.6–1.7, which fall within the health beneficial window of 1–2.3. These metrics collectively characterize peel from the studied material as an energeti-cally dense, fiber rich, and carbohydrate dominated fraction that differs substantially from both seeds within the same fruit and from common horticultural by products. At the same time, high polyphenol levels reduce protein digestibility and limit direct use of raw peel in livestock diets, requiring polyphe-nol doses to be moderated when peel is incorporated into nutritionally balanced formulations such as fiber enriched bread for weight control. However, if the polyphenol dose is adjusted to levels acceptable for dietary supplements, they serve as necessary antioxidants for weight management. Clinical trials on bread, where 2.5%, 5%, and 7.5% of flour was replaced by pomegranate peel powder, showed that enrichment with fiber and antioxidant components can produce bread varieties suitable for weight loss [18].

Geographical and varietal diversity further modulates the concentration and profile of phenolic constituents in peel. These differences in absolute values and relative proportions of individual phe-nolic acids emphasize that cultivar origin and environmental conditions shape the phenolic spectrum found in exocarp tissue. Peel also contributes approximately 30% of total fruit anthocyanins, with eight glycosidic derivatives, including delphinidin and cyanidin based structures, identified in Tunisian varieties. Such findings demonstrate that pigmented phenolic pools in peel are not only abundant but also structurally diverse, and that specific anthocyanin glycosides can be associated with particular regional germplasm. In parallel, tannin composition varies measurably between cultivars; Spanish va-rieties show punicalagin concentrations ranging from 181 to 255 mg/g in the peel, while ellagitannins such as pedunculagin, granatin A and B, corylagin, tellimagrandin, and gallagylhexoside are reported across exocarp tissues more generally [19].

These data collectively underscore that peel from different growing regions and genetic backgrounds cannot be treated as compositional equivalents, especially when targeting specific phenolic markers for standardization in food, nutraceutical, or pharmaceutical applications.

4 Pomegranate Peel as an Agro Industrial by Product

4.1 Generation of peel waste along the fruit processing chain

Along industrial pomegranate processing chains, peel emerges as a dominant biomass stream whose generation is intrinsically linked to the technological choices adopted for juice and derivative produc-tion [20]. Global fruit output of Punica granatum exceeds 3 million tons, and the exocarp accounts for approximately 50–60% of the total fruit mass, so that roughly 1.62 million tons of peel are formed annually as bioactive by products rather than inert waste [21].

Despite this substantial resource base, many factories discard peel due to the logistical and economic burdens associated with drying, ex-traction, and downstream processing. Efficient dehydration plants and dedicated workshops for oil and polyphenol recovery require high capital investment, and the added value from selling seed oils or peel derived polyphenols to cosmetic and pharmaceutical sectors may not offset the cost of estab-lishing such non core operations within juice focused facilities.

4.2 Concepts of circular economy and co production in fruit processing

Valorization of pomegranate peel aligns closely with circular economy principles when biomass tradi-tionally treated as waste is reconceptualized as a reservoir of multiple high value products. Although this material is compositionally rich in polyphenols, tannins, sugars, proteins, fibers, and minerals, it is commonly dis-carded because conventional recovery schemes for seed oil and peel

polyphenols require costly drying plants and specialized extraction workshops that are difficult to justify within juice oriented facilities. Reframing peel as a bioactive by product rather than inert waste forms the conceptual basis for inte-grating it into closed loop processing chains that maximize resource utilization and minimize disposal burdens. A central element of this circular perspective is the transition from single product extraction to co production, in which the same fermentation assisted process yields discrete streams of phenolic concentrates, alcoholic beverages, and fiber rich solids [10]. The combined fractions lengthen the value chain, turning the old problem of recycling into nutritionally and pharmacologically significant ingredients that remain in the economic cycle rather than leaving it as waste.

5 CONCLUSIONS

Accordingly, these applications demonstrate how the combined fractions lengthen the value chain, turning the former disposal problem into nutritionally and pharmacologically significant ingredients that remain in the economic cycle rather than leaving it as waste.

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Implementation of a Business Data Analytics Model Using Power BI and DAX

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Abstract

In the modern business environment, organizations generate large volumes of data from operational processes, financial transactions, customer interactions, and sales activities. Transforming these data into meaningful information is essential for improving organizational performance, identifying business trends, and supporting evidence-based decision-making. Business intelligence technologies provide effective solutions for integrating, processing, analyzing, and visualizing business data. This study explores the implementation of a business data analytics model using Microsoft Power BI and Data Analysis Expressions (DAX), focusing on data modeling, analytical calculations, key performance indicators (KPIs), interactive visualization, and business decision support.

The primary objective of the study is to develop an integrated analytical approach that transforms raw business data into structured, measurable, and visually interpretable information. The proposed approach incorporates several stages, including data collection, data preparation, data transformation, data modeling, the definition of analytical measures, and the development of interactive dashboards. Power BI is used as the principal platform for integrating data from different sources, establishing relationships between datasets, and presenting analytical results through interactive reports. DAX is applied to define calculated measures, implement business rules, and evaluate performance indicators according to selected analytical criteria.

Particular attention is given to the role of data modeling in ensuring consistency, accuracy, and analytical flexibility. An appropriately structured data model enables relationships between business entities to be represented effectively and supports reliable calculations across different analytical dimensions. DAX measures facilitate the calculation of key business indicators, including sales revenue, total costs, profit, profit margin, and performance comparisons across periods, products, and customer segments. These indicators provide a quantitative basis for evaluating operational and financial performance.

The study also examines the contribution of interactive visualization to business analytics. Dashboards incorporating charts, tables, filters, and slicers allow users to explore data dynamically, identify significant patterns, compare performance indicators, and investigate deviations from

expected results. Integrating data modeling, DAX calculations, and interactive visualization creates a coherent analytical environment in which business information can be examined from multiple perspectives.

The proposed model demonstrates how Power BI and DAX can be combined to establish a practical framework for business data analytics. Its potential value lies in improving information accessibility, facilitating performance monitoring

Keywords: Business Data Analytics; Power BI; Data Analysis Expressions (DAX); Key Performance Indicators (KPIs); Interactive Visualization.

1. Introduction

In the modern business environment, data has become a strategic resource that influences organizational performance, competitiveness, and decision-making. Businesses generate increasing volumes of information through sales transactions, financial operations, customer interactions, supply chain activities, and digital services. However, the availability of large amounts of data does not automatically guarantee better decisions. Organizations must be able to integrate, process, analyze, and interpret this information to identify meaningful patterns, evaluate performance, and respond effectively to changing market conditions. Consequently, business data analytics has become an important component of modern management and business intelligence.

Traditional reporting methods often provide limited opportunities for analyzing complex datasets, identifying relationships between business indicators, and exploring performance across multiple dimensions. In this context, Microsoft Power BI offers an integrated environment for data preparation, modeling, analysis, and interactive visualization. It enables users to combine information from different sources, establish relationships between datasets, and present analytical findings through reports and dashboards. These capabilities can improve data accessibility and help managers monitor business performance more efficiently.

Data Analysis Expressions (DAX) plays a central role in developing analytical solutions within Power BI. DAX provides a formula language for creating calculated measures, evaluating business rules, and performing context-sensitive calculations. By using DAX, analysts can calculate key performance indicators (KPIs), including total revenue, costs, profit, profit margin, and sales growth. These indicators support the systematic evaluation of business performance and provide a quantitative foundation for managerial decisions.

Despite the availability of business intelligence technologies, the effective implementation of an analytical model requires appropriate data structures, reliable relationships between tables, correctly defined analytical measures, and meaningful visual representations. Poorly designed models or incorrectly formulated calculations may lead to misleading interpretations and ineffective decisions. Therefore, integrating data modeling, DAX-based calculations, and interactive visualization represents an important practical challenge in business analytics.

This study focuses on the implementation of a business data analytics model using Power BI and DAX. It examines how these technologies can be integrated to transform raw business data into structured analytical information, monitor key performance indicators, identify business trends, and support evidence-based decision-making. The research aims to demonstrate the practical value of an integrated business analytics model through its application to a representative business scenario.

2. Research Aim and Objectives

2.1. Research Aim

The primary aim of this study is to develop and implement a business data analytics model using Microsoft Power BI and Data Analysis Expressions (DAX) to improve business performance evaluation, facilitate data-driven decision-making, and strengthen organizational business intelligence capabilities. The research focuses on integrating data modeling, analytical calculations, key performance indicators (KPIs), and interactive visualization into a unified analytical framework that transforms raw business data into meaningful and actionable information.

The study seeks to demonstrate how Power BI can be used to integrate data from different sources, organize business information into a structured analytical model, and present results through interactive reports and dashboards. Particular attention is given to the application of DAX for defining analytical measures, calculating financial and operational indicators, comparing business performance across different periods and categories, and evaluating deviations from established targets.

Another important aim is to establish a practical connection between technical implementation and managerial requirements. Business managers require reliable information about revenue, costs, profitability, sales performance, and operational trends to identify opportunities, detect potential problems, and allocate resources effectively. An appropriately designed analytical model can facilitate access to these indicators and support their interpretation from different business perspectives.

The research also aims to examine the contribution of interactive dashboards to business analysis. Through filters, slicers, charts, tables, and comparative indicators, users can investigate datasets dynamically and identify patterns that may not be immediately apparent in conventional reports. The integration of these features provides a flexible environment for monitoring organizational performance and exploring relationships between business variables.

The practical component of the study involves implementing the proposed model in a representative business scenario, such as retail sales analytics. The model will incorporate structured datasets, relationships between business entities, DAX measures, and selected KPIs. Its analytical outputs will be examined to assess whether the implemented solution provides consistent, interpretable, and useful information for business performance evaluation.

Ultimately, the study aims to demonstrate the practical applicability of Power BI and DAX as complementary technologies for developing business analytics solutions. The expected contribution is a structured implementation approach that can be adapted to different organizational contexts and extended to support more advanced analytical requirements.

2.2. Research Objectives

To achieve the primary aim, the study establishes the following research objectives:

1. To examine the theoretical foundations of business data analytics and business intelligence. This includes identifying the role of data analysis in organizational performance evaluation, management reporting, and evidence-based decision-making.
2. To identify the analytical requirements of the selected business scenario. The study will determine which business indicators, data dimensions, and reporting functions are necessary to evaluate organizational performance effectively.
3. To design a structured business data model. This objective involves organizing relevant datasets, defining relationships between tables, and establishing a logical structure that supports consistent calculations and flexible analysis.
4. To prepare and integrate business data using Power BI. The study will address data import, transformation, cleaning, and preparation to improve data quality and ensure suitability for analytical processing.

5. To develop DAX formulas and analytical measures. These will include calculations for total sales revenue, costs, profit, profit margin, and comparisons across selected periods, products, or business segments.
6. To define and implement key performance indicators (KPIs). The selected indicators will support the evaluation of business performance against relevant targets and facilitate the identification of significant changes and deviations.
7. To design interactive reports and dashboards. The model will use appropriate visualizations, filters, and slicers to enable users to explore business data from different perspectives.
8. To evaluate the analytical outputs of the implemented model. The study will examine the consistency of calculations, clarity of visual representations, and usefulness of the resulting information for business analysis.
9. To assess the practical value and limitations of the proposed approach. The final objective is to identify how the integration of Power BI and DAX can support managerial decision-making and determine opportunities for further development of the analytical model.

3. Research Methodology

This study adopts an applied research approach to develop and evaluate a business data analytics model using Microsoft Power BI and Data Analysis Expressions (DAX). The methodological framework combines data preparation, data modeling, quantitative analysis, analytical measure development, and interactive visualization. The research is designed to demonstrate how business intelligence technologies can transform raw business data into structured information that supports performance monitoring and managerial decision-making.

The practical implementation is based on a representative business scenario, such as retail sales analytics. The dataset may include sales transactions, product information, customer records, dates, costs, and regional classifications. Where organizational data are unavailable, a clearly identified illustrative dataset can be used to demonstrate the model's functionality. The data sources and assumptions will be documented to ensure transparency and reproducibility.

The first methodological stage involves data collection, inspection, cleaning, and transformation using Power BI and Power Query. This stage includes identifying missing values, checking data types, removing duplicate records where appropriate, standardizing categorical values, and preparing datasets for analysis. These procedures aim to improve data consistency and reduce potential errors in subsequent calculations.

The second stage focuses on data modeling. Relevant tables are organized into a structured model, with relationships established between transaction data and descriptive dimensions such as products, customers, dates, and regions. A star-schema structure may be adopted to improve model clarity and facilitate analytical queries. The model is designed to support filtering, aggregation, and comparison across multiple business dimensions.

The third stage involves developing DAX measures for calculating key business indicators, including total sales, total costs, profit, profit margin, and period-based performance comparisons. These measures are incorporated into interactive Power BI reports and dashboards using charts, tables, slicers, and KPI cards.

Finally, the implemented model is evaluated using several criteria: calculation accuracy, consistency of results, data-model integrity, clarity of visualization, responsiveness to user selections, and relevance of the analytical outputs to business requirements. Where appropriate, DAX results are cross-checked against independent calculations using the underlying dataset. Comparative analysis is used to examine differences across products, regions, and time periods. The findings are interpreted in relation to the research objectives, while limitations associated with data availability, dataset representativeness, and model scope are acknowledged.

4. Business Analytics Model Implementation

4.1. Business Case Selection and Analytical Requirements

The practical implementation focuses on a retail business that aims to improve sales performance monitoring and support data-driven managerial decisions. Retail organizations generate substantial amounts of transactional data, including information about products, customers, sales dates, quantities, prices, costs, and geographical locations. Analyzing these data enables organizations to identify profitable product categories, evaluate regional performance, monitor sales trends, and assess progress toward business targets.

The proposed model is designed to answer several key business questions: What is the total sales revenue? Which products and regions generate the highest profit? How does sales performance change over time? Which categories demonstrate the strongest performance? To what extent does the business achieve its sales targets? These questions determine the data requirements, analytical measures, and visualizations incorporated into the model.

4.2. Dataset Structure and Data Preparation

The analytical solution uses a structured dataset consisting of sales transactions and related descriptive information. The principal tables include Sales, Products, Customers, Calendar, and Regions.

The Sales table contains transaction identifiers, product identifiers, customer identifiers, dates, quantities, unit prices, and unit costs. The Products table provides product names and categories, while Customers contains customer-related attributes. The Calendar table supports time-based analysis, and the Regions table enables geographical comparisons.

Data preparation is performed using Power Query in Power BI. The process includes checking data types, handling missing values, standardizing categorical information, identifying duplicate records, and calculating or validating transaction-level values. These procedures help establish a consistent dataset for analytical processing.

4.3. Data Modeling and Relationships

A star-schema approach is proposed to organize the analytical model. The Sales table functions as the central fact table, while Products, Customers, Calendar, and Regions act as dimension tables. Relationships are established through corresponding identifiers, allowing transaction data to be analyzed according to product category, customer segment, time period, and geographical region.

This structure separates transactional information from descriptive attributes and supports consistent filtering and aggregation. A clearly defined data model also simplifies DAX measure development and facilitates the extension of the analytical solution.

4.4. DAX Measures and KPI Development

Data Analysis Expressions (DAX) is used to define analytical measures that calculate key business performance indicators dynamically according to the filters, selections, and evaluation context applied in Power BI reports. These measures enable the systematic assessment of sales performance, cost efficiency, profitability, and sales volume.

The proposed business analytics model incorporates the following core DAX measures:

Total Sales Revenue. This measure calculates the total revenue generated from sales transactions and provides an overall view of sales performance.

```
Total Sales Revenue =
SUMX(
   Sales,
   Sales[Quantity] * Sales[UnitPrice]
)
```

Profit. This measure determines the financial result by calculating the difference between total sales revenue and total costs. It supports the evaluation of business profitability across products, customer segments, geographical regions, and reporting periods.

```
Profit =
[Total Sales Revenue]- [Total Cost]
```

Profit Margin. This measure expresses profit as a percentage of total sales revenue, enabling the assessment of profitability relative to revenue and facilitating comparisons across different business categories.

```
Profit Margin =
DIVIDE(
   [Profit],
   [Total Sales Revenue],
   0
)
```

Total Units Sold. This measure calculates the total quantity of products sold during a selected reporting period and supports the analysis of sales volume and product demand.

These measures form the analytical foundation of the proposed model and are used to develop key performance indicators (KPIs) for monitoring business outcomes. The principal KPIs include total sales revenue, total profit, profit margin, and total units sold. Where sales target data are available, an additional KPI can be implemented to measure actual sales performance against planned targets.

By integrating DAX measures with interactive Power BI visualizations, the model enables users to examine business performance from multiple perspectives and identify changes in revenue, profitability, and sales volume. This approach supports data-driven performance monitoring and provides managers with relevant information for operational planning and strategic decision-making.

```
Total Units Sold =
SUM(Sales[Quantity])
```

4.5. Interactive Dashboard Design

The dashboard is designed to present the most important business indicators in a clear and accessible format. KPI cards display total sales, total profit, profit margin, and units sold. Line charts illustrate sales trends over time, while bar charts compare product categories and regional performance. Tables provide detailed product-level results, and slicers enable users to filter the analysis by date, category, customer, or region.

The interactive design allows managers to investigate performance from multiple perspectives without creating separate reports for every analytical question. For example, selecting a particular region can update the displayed sales, profit, and product-category results.

4.6. Business Interpretation and Decision Support

The implemented model transforms transaction-level information into analytical indicators that support business performance evaluation. Managers can use the results to identify high-performing products, compare regional profitability, monitor changes in revenue, and investigate deviations from sales targets.

The practical value of the model depends on the accuracy of the underlying data, the validity of the DAX calculations, and the relevance of the selected KPIs. The proposed implementation provides a reusable analytical framework that can be adapted to different retail businesses and extended with additional indicators, forecasting techniques, or more advanced analytical capabilities.

A retail sales analytics model is an appropriate choice because it naturally incorporates DAX calculations, key performance indicators (KPIs), and interactive visualizations.

Data Model: Sales, Products, Customers, Calendar, and Regions tables.

1. DAX Measures: Total Sales, Total Cost, Profit, Profit Margin, and Year-over-Year Growth.
2. KPIs: Sales Target Achievement, Profit Margin, and Sales Growth
3. Visualization: Monthly sales trends, product category comparisons, regional performance, and interactive filters.
4. Business Decision-Making: Identifying which products and regions generate the highest profits, determining periods when sales decline, and identifying areas where corrective actions or improvements are needed.
5. Business Decision-Making: Identifying which products and regions generate the highest profits, determining periods when sales decline, and identifying areas where corrective actions or improvements are needed.

5. Results and Discussion

The implementation of the proposed business data analytics model in Microsoft Power BI demonstrates how data analysis expressions (DAX), key performance indicators (KPIs), and interactive visualizations can support the evaluation of business performance. The model is designed for retail sales analysis and integrates data from five related tables: Sales, Products, Customers, Calendar, and Regions. This structure enables the analysis of sales performance across different time periods, product categories, customer groups, and geographical areas.

The calculated measures include Total Sales, Total Cost, Profit, Profit Margin, and Year-over-Year Growth. These indicators provide a quantitative basis for evaluating revenue, profitability, and changes in business performance. Total Sales represents the overall value of completed sales, while Profit indicates the difference between sales revenue and associated costs. Profit Margin expresses profitability as a percentage of revenue. Year-over-Year Growth enables comparisons between corresponding periods and helps identify changes in sales performance.

The visualizations developed in Power BI present these indicators through KPI cards, time-series charts, category comparisons, and regional sales reports. Monthly sales charts can reveal seasonal fluctuations and periods of increased or decreased demand. Product category visualizations support the identification of high-performing and underperforming products, while regional comparisons help determine which geographical areas contribute most to overall sales. Interactive filters allow users to investigate these results by selecting specific periods, products, or regions.

From a business perspective, these analytical capabilities can improve the identification of sales trends, support resource allocation, and contribute to more informed management decisions. However, the reliability of the conclusions depends on data quality, the accuracy of the DAX calculations, and the completeness of the underlying dataset.

Overall, the proposed model demonstrates the practical value of combining data modeling, DAX calculations, KPIs, and interactive visualization in a unified business analytics environment. Actual business conclusions should be confirmed using the calculated results obtained from the implemented Power BI model.

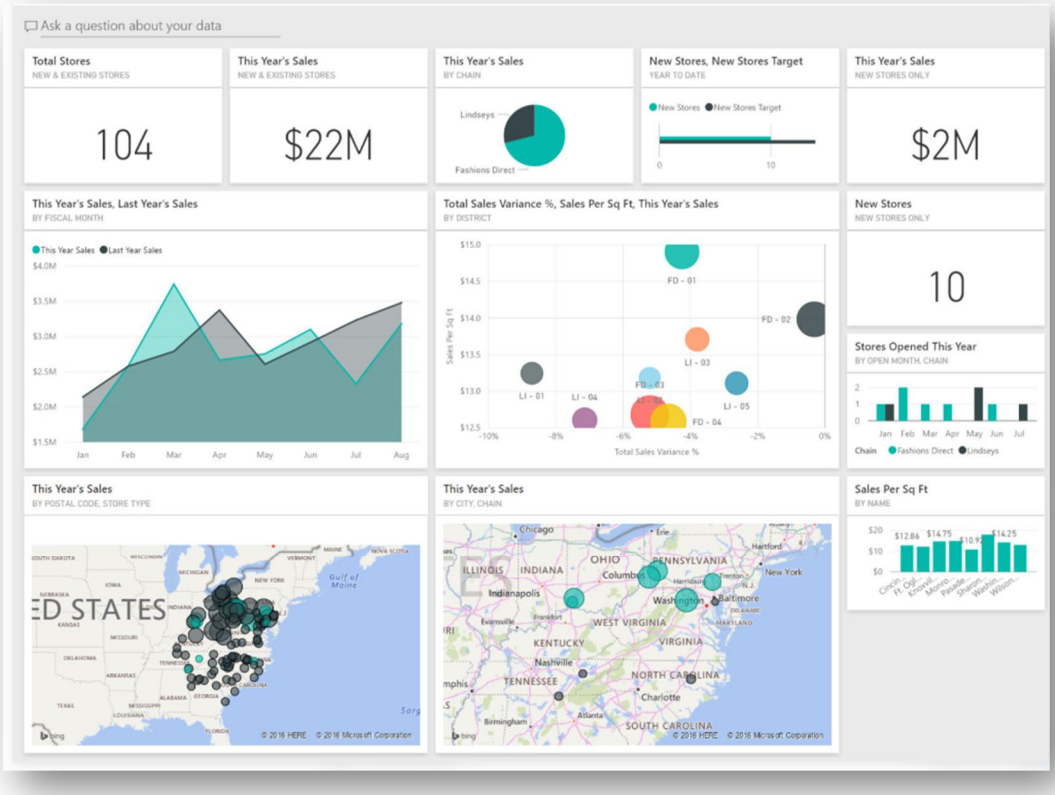


Figure 1. Power BI Business Analytics Dashboard

Description: The figure presents a business analytics dashboard developed in Microsoft Power BI. It provides a consolidated overview of key business performance indicators, including total sales, total profit, profit margin, sales growth, and sales trends.

Analysis: The dashboard enables decision-makers to monitor business performance through a unified interface. By presenting essential indicators and visualizations in a structured format, it facilitates the identification of trends, supports performance evaluation, and contributes to data-driven decision-making.

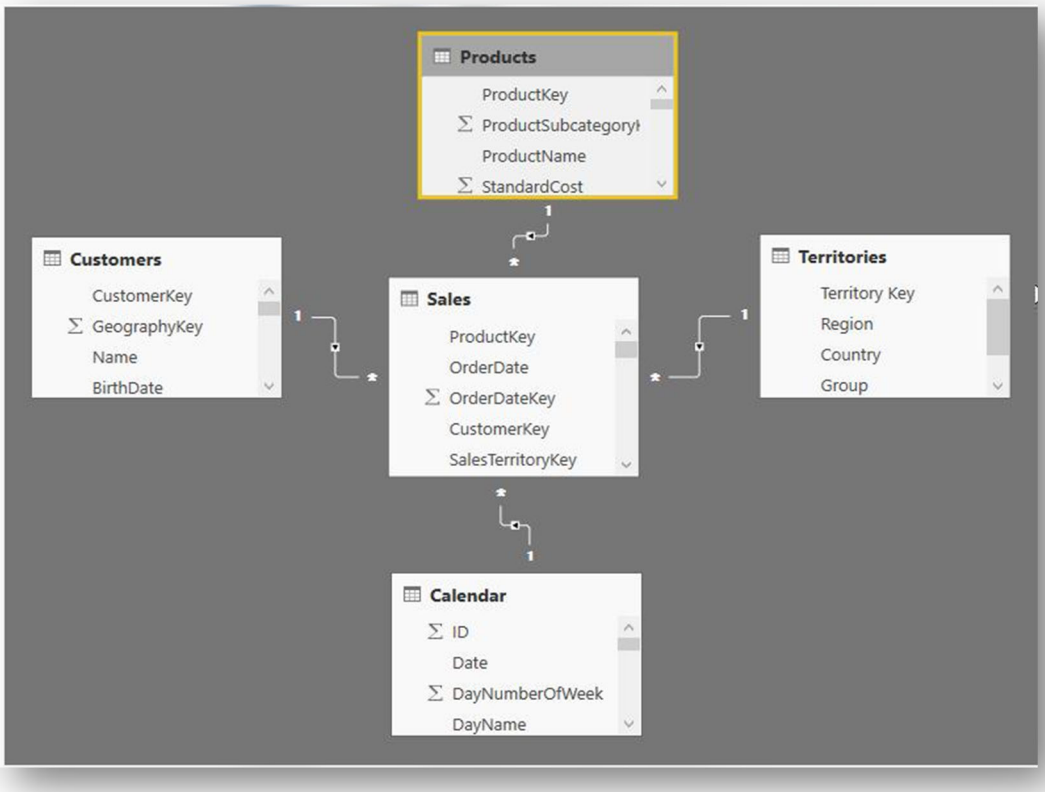


Figure 2. Data Model Structure

Description: The figure illustrates the structure of a business data model consisting of five tables: Sales, Products, Customers, Calendar, and Regions. Relationships between these tables enable integrated analysis of business transactions across different dimensions.

Analysis: A well-designed data model establishes consistency between datasets and supports accurate analytical calculations. Organizing business information into related tables improves flexibility, facilitates cross-dimensional analysis, and reduces unnecessary data duplication.

	A	B	C	D	E
1	Customer ID	Product Category	Quantity	Price per Unit	Total Amount
2	CUST002	Beauty	3	50	150
3	CUST002	Electronics	2	500	1000
4	CUST003	Clothing	1	30	30
5	CUST004	Beauty	1	500	500
6	CUST005	Beauty	2	50	100
7	CUST006	Beauty	1	30	30
8	CUST007	Clothing	2	25	50
9	CUST008	Electronics	4	25	100
10	CUST001	Electronics	2	300	600
11	CUST010	Clothing	4	50	200
12	CUST011	Clothing	2	50	100
13	CUST012	Beauty	3	25	75
14	CUST013	Electronics	3	500	1500
15	CUST014	Clothing	4	30	120
16	CUST005	Electronics	4	500	2000
17	CUST016	Clothing	3	500	1500
18	CUST017	Clothing	4	25	100
19	CUST018	Electronics	2	25	50
20	CUST001	Clothing	2	25	50
21	CUST020	Clothing	3	300	900

Figure 3. Sales Data Table

Description: The figure displays a sales dataset containing transaction dates, product identifiers, customer identifiers, quantities, unit prices, and total sales amounts.

Analysis: The Sales table serves as the central source of transactional information. Its structure provides the foundation for calculating revenue, sales volume, total costs, and other financial indicators required for business performance evaluation. The accuracy and completeness of these records directly influence the reliability of the analytical results.

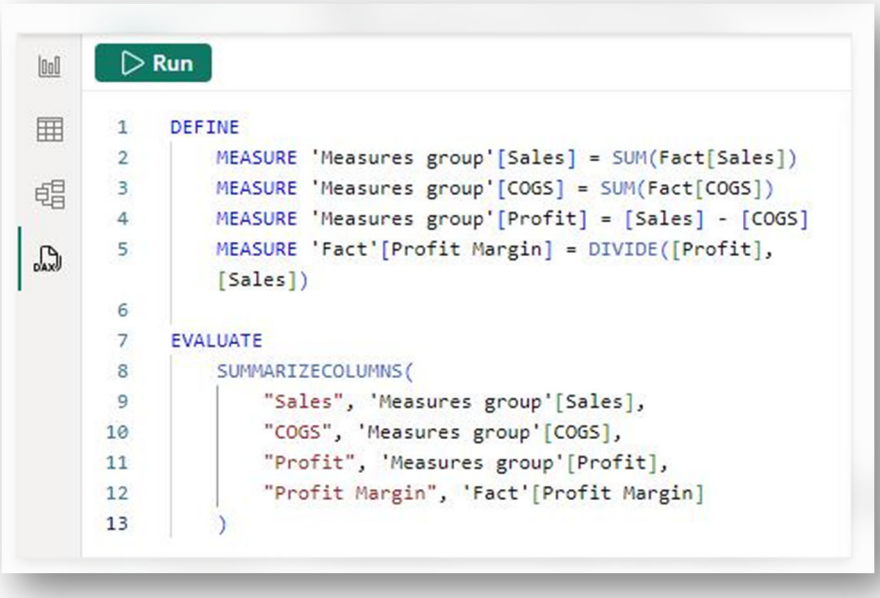


Figure 4. DAX Measures for Business Performance Evaluation

Description: The figure demonstrates the implementation of Data Analysis Expressions (DAX) measures in Power BI. The measures include Total Sales, Total Cost, Profit, and Profit Margin, which are used to evaluate the financial performance of the business.
Analysis: DAX enables the creation of reusable calculations that respond dynamically to report filters and changes in the analytical context. This functionality supports consistent financial analysis across products, regions, customers, and reporting periods, allowing users to investigate business performance from different perspectives.



Figure 5. Key Performance Indicators (KPIs)

Description: The figure presents key performance indicators, including Total Sales, Total Profit, Profit Margin, and Sales Growth. These indicators summarize the main dimensions of business performance in a concise visual format.
Analysis: KPIs transform detailed transactional data into measurable indicators that facilitate performance monitoring. Comparing actual results with predefined business targets can help managers assess progress, identify performance gaps, and determine areas requiring improvement. Their usefulness depends on the accuracy of the underlying data and the appropriate selection of performance targets.

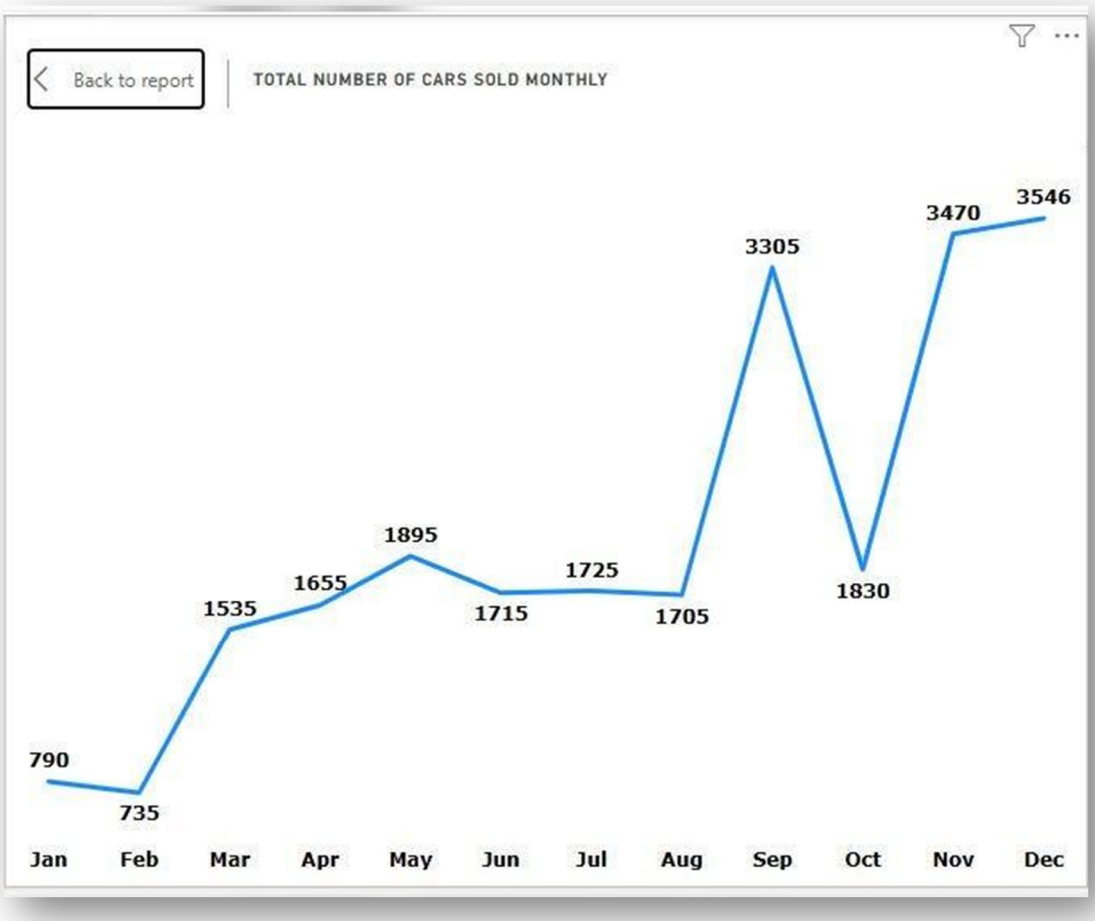


Figure 6. Monthly Sales Trend Analysis

Description: The figure illustrates monthly sales performance using a line chart. Sales values are arranged chronologically to demonstrate changes in revenue over the selected reporting period.

Analysis: Time-based visualization helps users examine fluctuations in sales and identify periods of growth or decline. When supported by sufficient historical data, these observations can contribute to demand forecasting, inventory planning, and resource allocation. Comparisons between different years can also help assess changes in business performance over time.

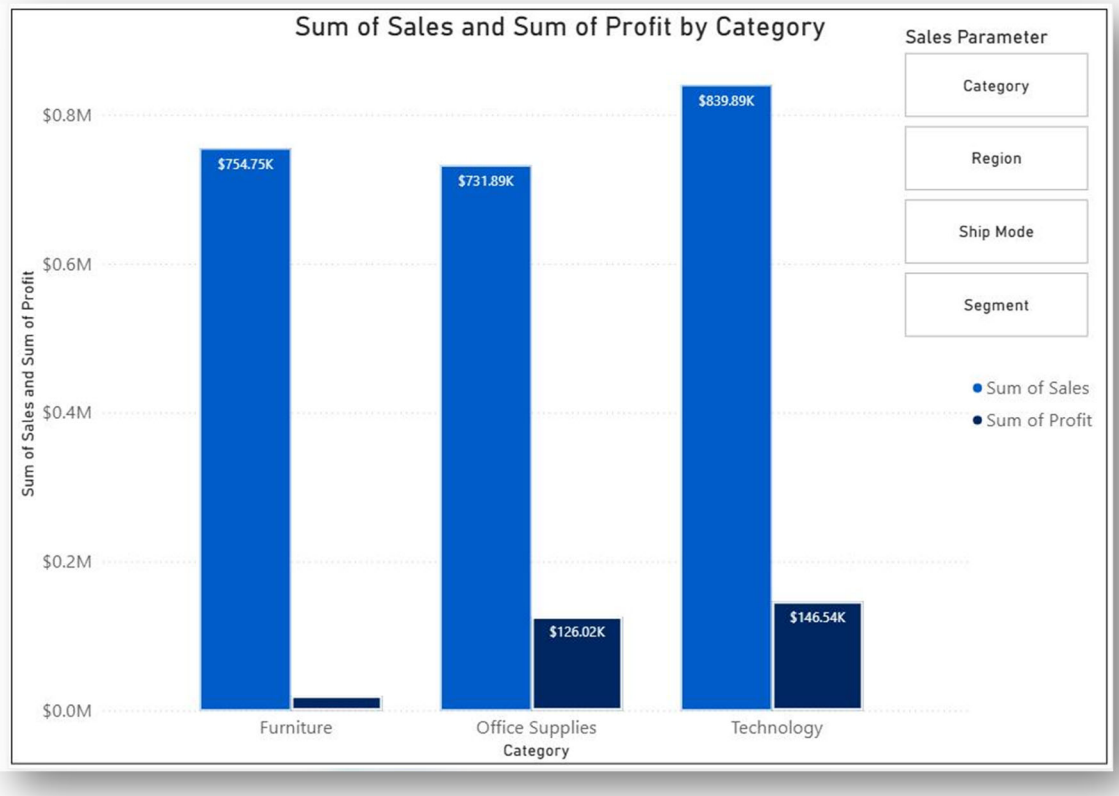


Figure 7. Product Category Performance

Description: The figure compares sales and profitability across different product categories using a comparative bar chart. This visualization allows users to examine the relative contribution of each category to overall business performance.

Analysis: Category-level analysis helps identify products or product groups that contribute significantly to revenue and profit. It can also reveal categories with comparatively lower performance, providing useful information for pricing decisions, marketing strategies, inventory management, and product portfolio optimization.

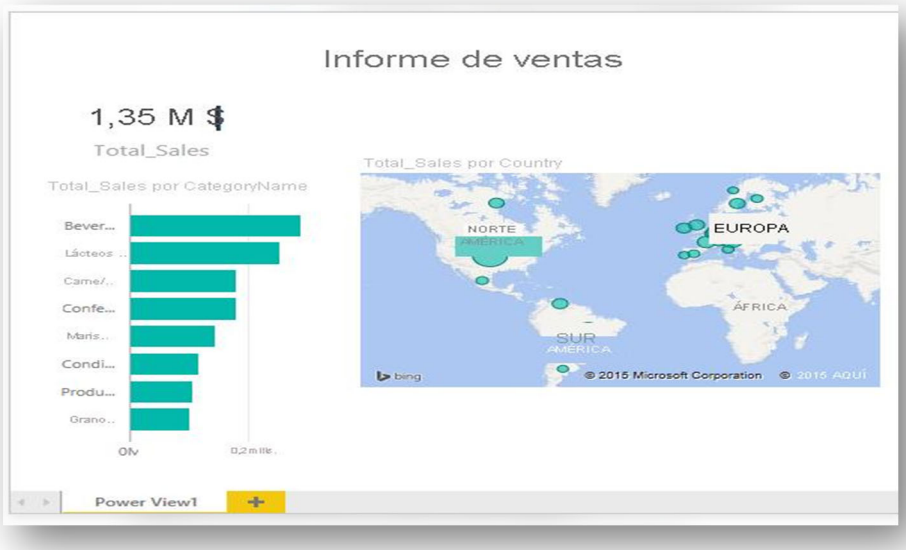


Figure 8. Regional Sales Analysis

Description: The figure presents sales performance across different geographical regions. Regional results are displayed through graphical indicators, enabling comparisons of sales contributions and overall performance among the selected areas.

Analysis: Regional analysis helps identify markets with relatively strong or weak sales performance. These insights can support regional planning, targeted marketing activities, and the allocation of business resources. However, meaningful comparisons should consider differences in market size, customer demand, and operating costs.



Figure 9. Interactive Filtering and Data Exploration

Description: The figure demonstrates interactive Power BI report elements, including slicers and filters for dates, product categories, regions, and customer segments. These controls allow users to adjust the displayed information according to specific analytical requirements.

Analysis: Interactive filtering enables users to examine selected subsets of business data without creating separate reports for each analytical scenario. By dynamically updating visualizations, filters improve analytical flexibility and help users investigate factors associated with changes in sales, profitability, and other performance indicators.

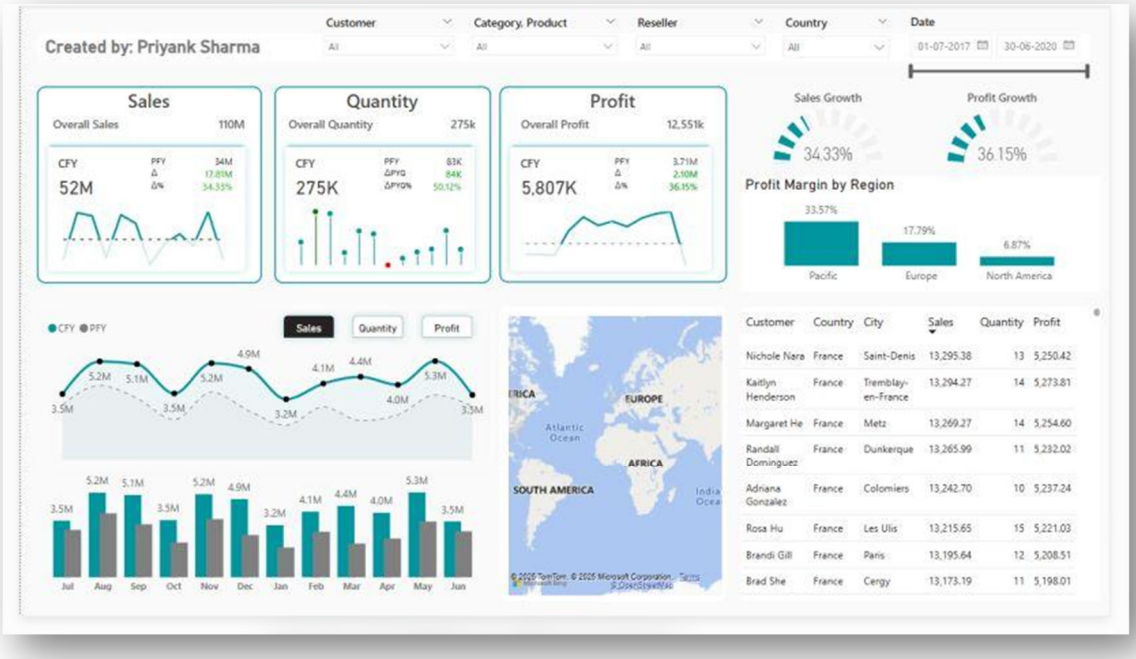


Figure 10. Integrated Business Decision-Support Dashboard

Description: The figure presents an integrated business analytics dashboard combining KPI cards, sales trend charts, product category comparisons, regional analysis, and interactive filtering capabilities within a single reporting environment.
Analysis: Integrating multiple analytical components provides a comprehensive view of business performance. By combining structured data modeling, DAX-based calculations, and interactive visualizations, the dashboard supports the identification of trends, the evaluation of performance indicators, and the comparison of results across business dimensions. Consequently, the proposed model provides a practical foundation for evidence-based managerial decision-making.

6. Conclusion

This study examined the implementation of a business data analytics model using Microsoft Power BI and Data Analysis Expressions (DAX). The main objective was to demonstrate how data modeling, financial calculations, key performance indicators (KPIs), and interactive visualizations can be integrated into a unified analytical environment to support evidence-based business decision-making.

The proposed model is based on retail sales analytics and incorporates five interconnected tables: Sales, Products, Customers, Calendar, and Regions. This structure provides a foundation for analyzing business performance across different products, customer groups, geographical regions, and time periods. The application of DAX measures, including Total Sales, Total Cost, Profit, Profit Margin, and Year-over-Year Growth, enables the calculation of essential business indicators and supports the evaluation of financial performance.

The integration of KPIs, interactive filters, and dynamic visualizations facilitates the monitoring of business objectives, comparison of results, and identification of sales trends and potential areas for improvement. By presenting complex business information in a clear and accessible format, the proposed model can help managers interpret data more effectively and make informed operational and strategic decisions. Its modular structure also allows adaptation to the analytical requirements of different organizations and business sectors.

However, the model has certain limitations. The reliability of analytical results depends on data quality, the accuracy of relationships between tables, the correctness of DAX formulas, and the availability of sufficient historical data. Furthermore, the model's practical effectiveness should be evaluated using real organizational data before implementation in a business environment.

Future research could extend the model by incorporating predictive analytics, machine learning algorithms, automated data integration, and real-time reporting. These developments could improve forecasting capabilities and provide deeper insights into business performance.

In conclusion, the integration of Power BI, DAX, KPIs, and interactive visualization offers a flexible and practical approach to business data analytics, transforming structured data into meaningful insights and supporting informed managerial decision-making.

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Biological Sciences

Quantum-Engineered Biocompatible Hydrogels: A Convergent Framework for Synthetic Cartilage Replacement and Multiscale Tissue Regeneration

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Abstract
Articular cartilage remains one of the most unforgiving targets in regenerative medicine: it is avascular, aneural, essentially alymphatic, sparsely populated by a single terminally differentiated cell type, and burdened by an extracellular matrix whose tensile, compressive, and tribological demands exceed those of nearly every other soft tissue in the human body. Existing clinical strategies — microfracture, autologous chondrocyte implantation, matrix-associated autologous chondrocyte implantation, and osteochondral autograft transfer — relieve symptoms but rarely restore durable hyaline-like tissue. Hydrogels have emerged as the most plausible synthetic analogue of the cartilage matrix because their hydrated, porous, and highly tunable architecture approximates the physicochemical environment in which chondrocytes reside. Yet conventional hydrogels are mechanically fragile, biochemically inert, and functionally blind: they cannot sense the forces they transmit, report on their own degradation, or respond to the biological state of the cells they host. This review argues that a class of materials here termed quantum-engineered biocompatible hydrogels — polymer networks in which quantum dots, carbon dots, nanodiamonds with nitrogen-vacancy centres, quantum-confined piezoelectric nanocrystals, and other quantum-scale functional building blocks are integrated as structural, sensory, and

stimulatory elements — offers a coherent route beyond these limitations. We synthesise the biological design requirements of articular cartilage, the chemistry and topology of tough and self-healing hydrogel networks, the emerging evidence on carbon and semiconductor quantum dots in cartilage scaffolds, the use of nitrogen-vacancy magnetometry and quantum-enhanced tension microscopy to quantify cellular forces at the nanoscale, and the exploitation of piezoelectricity as a self-powered electrical stimulus for chondrogenesis. We then examine fabrication through three- and four-dimensional bioprinting, mechanical benchmarking against native tissue, biofunctionalisation with growth factors and gene vectors, biocompatibility and immunocompatibility constraints, preclinical evidence in small and large animal models, and the regulatory pathway for combination products in which a nanoscale therapeutic and a device are inseparable. We conclude with a critical appraisal of unresolved problems, including the long-term fate of heavy-metal-containing quantum dots, the difficulty of validating quantum sensing in opaque and scattering tissue, the absence of standardised fatigue protocols for hydrogel cartilage, and the conceptual gap between quantum effects at the single-emitter level and macroscopic tissue function. The central claim is that quantum engineering should be understood not as decoration of an existing scaffold, but as a design grammar for creating implants that measure, adapt, and defend themselves.

1. Introduction

1.1 The Clinical Burden of Cartilage Loss

Focal chondral and osteochondral defects are among the most common orthopaedic pathologies and among the least satisfactorily treated. Because articular cartilage lacks vascular supply and contains no resident progenitor population capable of robust repair, lesions that penetrate the tidemark provoke a repair response that is quantitatively and qualitatively inadequate: the resulting fibrocartilaginous tissue is rich in type I collagen, poor in aggrecan, mechanically inferior, and prone to progressive degeneration. The downstream consequence is early-onset post-traumatic osteoarthritis, a condition that imposes a substantial and growing burden on health systems worldwide and that disproportionately affects young, physically active individuals whose productive years coincide with the period of maximal disability. The clinical imperative, therefore, is not merely to fill a defect but to restore a matrix whose composition, zonal organisation, and mechanical behaviour approximate those of the native tissue over decades of cyclic loading.

The engineering problem is unusually severe because cartilage is a living composite that owes its function to a hierarchical architecture spanning at least five orders of magnitude, from the nanoscale organisation of collagen fibrils and proteoglycan aggregates to the millimetre-scale zonal stratification of the tissue. Any synthetic replacement must therefore satisfy simultaneous constraints that are often mutually antagonistic: high water content with high compressive stiffness; low friction with high wear resistance; permeability to nutrients with retention of large macromolecules; and sufficient initial rigidity to bear load with sufficient remodelling capacity to be replaced by living tissue [Liu et al., 2017].

1.2 Why Conventional Hydrogel Scaffolds Fall Short

Hydrogels — three-dimensional polymer networks swollen with water — are the closest synthetic approximation of the cartilage matrix [Zhao et al., 2020]. Their high water content, tunable mesh size, and chemical versatility permit cell encapsulation, nutrient diffusion, and the presentation of biochemical cues. Natural hydrogels derived from gelatin, hyaluronic acid, chondroitin sulfate, alginate, chitosan, and fibrin reproduce aspects of the cartilage extracellular environment with high fidelity [Levett et al., 2014; Tan et al., 2009]. Synthetic hydrogels such as poly(ethylene glycol) diacrylate, polyacrylamide, and poly(vinyl alcohol) offer superior control over crosslink density, degradation kinetics, and mechanical properties [Olov et al., 2022].

Nevertheless, four limitations recur with striking regularity in the literature. First, mechanical inadequacy: single-network hydrogels typically exhibit compressive moduli and fracture energies far below those of native cartilage, and they fatigue rapidly under the cyclic loads characteristic of joint function [Sabzi et al., 2017; Deng et al., 2018]. Second, biological inertness: most synthetic networks provide no intrinsic chondroinductive or anti-inflammatory signal and depend entirely on exogenous growth factors whose delivery is difficult to control [Madry et al., 2014; Ao et al., 2025]. Third, functional blindness: a hydrogel implant cannot report on the local mechanical environment, the rate of its own degradation, or the phenotype of the cells within it; assessment depends on destructive endpoint analysis or on expensive imaging that is poorly resolved in vivo [Shou et al., 2023]. Fourth, static behaviour: conventional implants are designed for a single target state and cannot adapt to the changing mechanical and biochemical demands of a healing joint [Wang et al., 2022]. These four deficiencies define the design space that quantum-scale engineering is uniquely positioned to address.

1.3 The Quantum-Scale Proposition

The term quantum-engineered biocompatible hydrogel is used in this review to describe a hydrated polymer network in which nanoscale objects whose behaviour is governed by quantum confinement, spin, or tunnelling are integrated as functional elements rather than as passive fillers. Four families of such elements are considered.

The first comprises semiconductor quantum dots and their carbon-based analogues, whose size-dependent photoluminescence arises from quantum confinement of charge carriers. Embedded in a hydrogel, they confer a combination of long-term fluorescence tracking, reactive oxygen species scavenging, and — in the case of carbon dots — intrinsic antioxidant and pro-chondrogenic activity [Ghanbari et al., 2021; Farshidfar et al., 2023].

The second comprises nanodiamonds containing nitrogen-vacancy centres, whose optically addressable electron spin permits nanoscale magnetometry, thermometry, and relaxometry within living systems. These defects allow the mechanical and thermal state of a hydrogel–cell interface to be read out at length scales of tens of nanometres, converting an otherwise dumb material into a quantified sensing platform [Xu et al., 2024; Kołodziej et al., 2024; Mzyk et al., 2026].

The third comprises quantum-confined piezoelectric and ferroelectric nanocrystals, including barium titanate, zinc oxide, and poly-L-lactic acid crystallites, which transduce physiological loading into local electrical potentials and thereby deliver a self-powered biophysical stimulus to chondrocytes and stem cells [Kapat et al., 2020; Liu et al., 2022; Yao et al., 2025].

The fourth, currently the most speculative, comprises deliberately engineered electronic and photonic coupling between these elements — quantum dot networks that support exciton transport, spin-defect arrays that report on the collective mechanical state of the matrix, and piezo-quantum composites in which deformation modulates both charge separation and optical emission. It is at this fourth level that the concept becomes genuinely architectural rather than additive, and it is also where the scientific uncertainty is greatest.

1.4 Scope, Aims, and Structure of This Review

This review has four aims. The first is to establish the biological and mechanical specification that any synthetic cartilage must meet, because quantum functionality is meaningful only within a quantitative design envelope. The second is to evaluate critically the evidence that quantum-scale building blocks improve hydrogel performance in cartilage and related musculoskeletal applications, distinguishing demonstrated effects from plausible extrapolation. The third is to synthesise the fabrication, characterisation, and regulatory landscape for these materials. The fourth is to identify the conceptual and technical bottlenecks that currently separate laboratory demonstrations from clinical translation, and to propose an experimental agenda for the coming decade.

The review is organised as follows. Section 2 establishes the biological and biomechanical foundations of articular cartilage and derives design requirements. Section 3 surveys hydrogel chemistries and topologies as synthetic cartilage matrices. Section 4 defines quantum-scale engineering as a design framework and distinguishes it from conventional nanocomposite reinforcement. Sections 5 through 7 examine, in turn, quantum dots and carbon dots, nanodiamond spin-defect sensing, and piezoelectric quantum-confined stimulation. Section 8 addresses fabrication and additive manufacturing, including four-dimensional printing. Section 9 treats mechanical benchmarking, constitutive description, and fatigue. Section 10 covers biofunctionalisation, growth factor delivery, and immunomodulation. Section 11 addresses biocompatibility, degradation, and the toxicological constraints specific to quantum materials. Section 12 reviews preclinical evidence. Section 13 examines translation and regulation. Section 14 identifies open problems and future directions, and Section 15 concludes.

2. Biological and Biomechanical Foundations of Articular Cartilage

2.1 Zonal Architecture and the Extracellular Matrix

Articular cartilage is a stratified tissue approximately two to four millimetres thick in the human knee, composed of four zones whose collagen orientation, proteoglycan content, water fraction, and cellular morphology differ systematically with depth. The superficial tangential zone contains densely packed collagen fibrils aligned parallel to the articular surface, a high water content, and flattened chondrocytes; it resists shear and distributes contact stresses. The middle or transitional zone contains randomly oriented collagen and spherical chondrocytes. The deep zone contains radially oriented collagen columns and the largest chondrocytes, and it bears the highest compressive load. The calcified zone anchors the tissue to subchondral bone through the tidemark. This graded architecture is not incidental: it is the mechanism by which a tissue with a compressive modulus on the order of a megapascal and an equilibrium water content of roughly seventy to eighty per cent withstands contact stresses that can exceed several megapascals during activity, while maintaining friction coefficients as low as one thousandth under boundary lubrication.

The extracellular matrix comprises approximately twenty per cent of the wet weight and consists principally of type II collagen, aggrecan, and smaller proteoglycans, glycoproteins, and minor collagens. Aggrecan forms large aggregates with hyaluronic acid through link protein, generating a fixed negative charge density that draws water osmotically into the tissue and produces a Donnan swelling pressure. The equilibrium between swelling pressure and the tensile restraint of the collagen network determines the tissue's compressive stiffness — a mechanism that must be reproduced, at least phenomenologically, by any hydrogel intended as a substitute [Zhu et al., 2018]. Recent strategies explicitly incorporate cartilage matrix constituents, including hyaluronic acid and chondroitin sulfate, into photocurable gelatin networks to reconstitute this charge–restraint balance [Levett et al., 2014; Li et al., 2021] (Fig. 1).

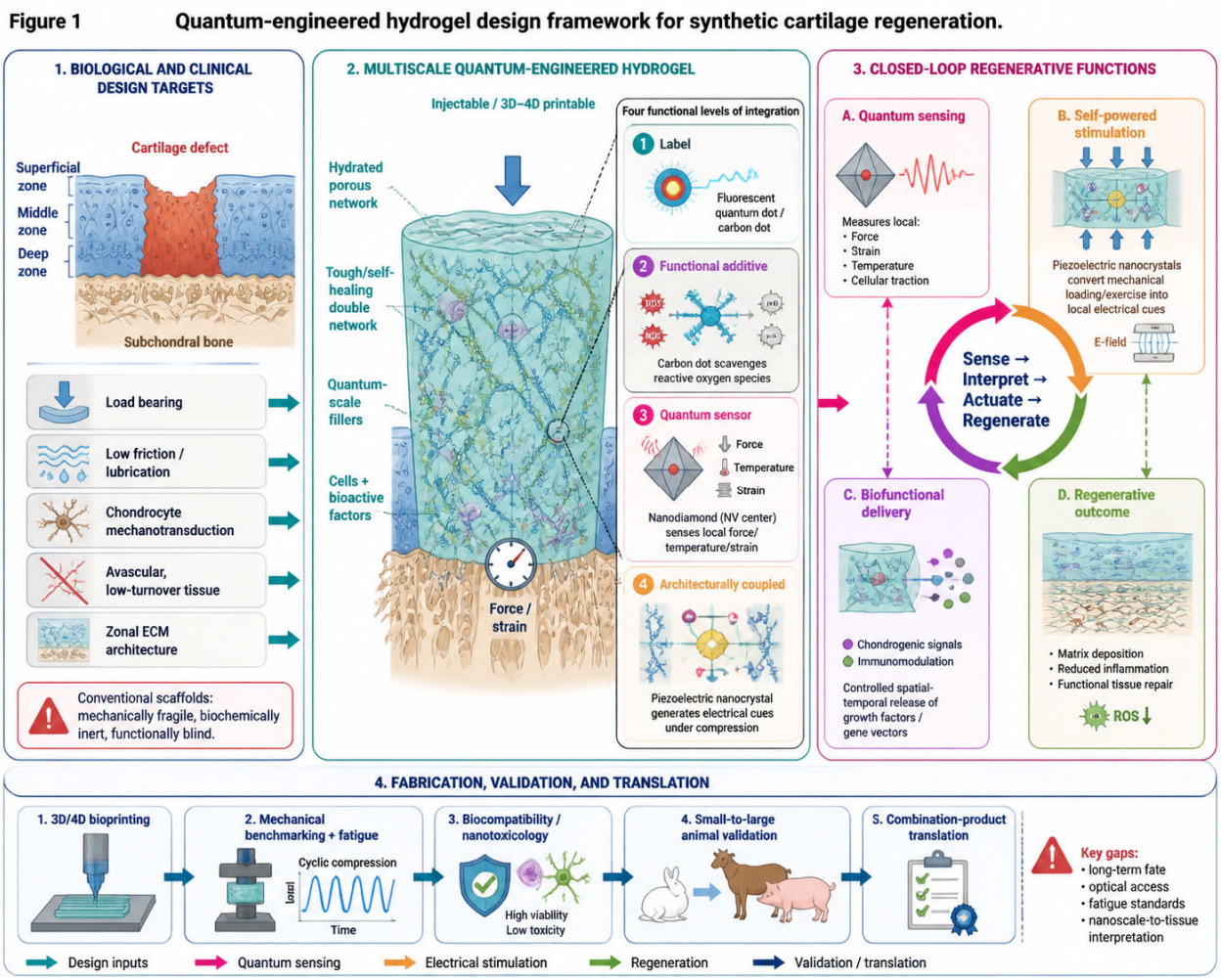


Figure 1. Quantum-engineered hydrogel design framework for synthetic cartilage regeneration. The proposed framework links the biological and biomechanical requirements of articular cartilage with a multifunctional hydrogel platform. The design begins with the principal demands of cartilage repair, including load bearing, low-friction lubrication, chondrocyte mechanotransduction, zonal extracellular-matrix organization, and compatibility with the avascular, low-turnover joint environment. These requirements guide the construction of a hydrated, porous, tough, and self-healing polymer network that can be delivered by injection or fabricated using three-dimensional or four-dimensional bioprinting. Quantum-scale components are integrated at four functional levels: fluorescent labeling, functional additives such as reactive-oxygen-species-scavenging carbon dots, quantum sensing using nitrogen-vacancy nanodiamonds, and architecturally coupled piezoelectric or ferroelectric nanocrystals. Together, these elements are proposed to provide local information about force, strain, temperature, and cellular traction; convert mechanical loading into self-powered electrical stimulation; regulate the delivery of chondrogenic and immunomodulatory signals; and support matrix deposition and functional tissue repair. The lower pathway emphasizes the validation and translational requirements for the platform, including additive manufacturing, mechanical and fatigue testing, biocompatibility and nanotoxicology assessment, animal studies, and combination-product regulation. The closed-loop arrows represent the proposed convergence of sensing, interpretation, actuation, and regeneration rather than a capability that has already been fully demonstrated in a single implant.

2.2 Chondrocyte Phenotype and Mechanotransduction

The articular chondrocyte is a highly specialised, low-turnover cell that occupies lacunae within the matrix and maintains the tissue through a slow balance of synthesis and catabolism. Because it is embedded in a charged, hydrated, and mechanically active matrix, the chondrocyte is

continuously exposed to osmotic, hydrostatic, and shear stimuli. Its primary cilium, integrins, mechanosensitive ion channels, and the actin–nuclear axis jointly transduce these inputs into transcriptional responses that determine matrix turnover. Perturbation of this mechanotransduction axis is implicated in both degeneration and failed repair.

The sensitivity of the chondrocyte to substrate mechanics has been documented repeatedly. In one influential study, chondrocyte mechanoresponses were shown to depend jointly on substrate stiffness and the presence of soluble factors, implying that biochemical and mechanical cues are integrated rather than independent [Chen et al., 2014]. Human chondrocytes encapsulated in agarose hydrogels of differing stiffness exhibit metabolite and biosynthetic responses to compression that scale with the surrounding matrix modulus [McCutchen et al., 2017]. Earlier work established that cell adhesion of chondrocytes to modified alginate surfaces is itself modulated by substrate mechanics, linking integrin engagement to matrix rigidity [Genes et al., 2004]. More recent analysis has extended this picture to viscoelasticity, showing that the time-dependent mechanical behaviour of a hydrogel, and not merely its equilibrium modulus, tunes chondrocyte phenotype [Lan et al., 2024]. Dynamic stimulation regimes, in which the mechanical properties of extracellular-matrix-mimicking hydrogels are varied in time, have been proposed as a means of programmed cell reprogramming and therapy [Shou et al., 2023].

For the designer of a synthetic cartilage, these findings carry a direct implication: the mechanical specification is not a single number but a trajectory. The implant must present an appropriate initial modulus for load bearing, a viscoelastic relaxation spectrum compatible with physiological loading rates, and a temporally evolving stiffness that guides encapsulated or recruited cells toward a stable chondrogenic phenotype rather than toward fibrous or osteogenic differentiation.

2.3 Tribology and Load-Bearing Behaviour

Cartilage tribology is dominated by interstitial fluid pressurisation and by the boundary lubrication provided by surface-active macromolecules, including lubricin and hyaluronic acid. Under physiological loading, the interstitial fluid carries the majority of the applied load during the early loading phase, so that the solid matrix experiences far less stress than the nominal contact pressure suggests. This mechanism requires a compliant, permeable matrix with a high water content and an appropriate hydraulic permeability — properties that hydrogels possess in principle [Zhao et al., 2020]. It also requires that the matrix resist the progressive loss of fluid under sustained load, which places a premium on the equilibrium modulus and on resistance to fatigue crack growth rather than on initial stiffness alone.

Synthetic approaches to cartilage tribology have therefore converged on two strategies: the incorporation of charged polysaccharides that reconstitute the Donnan swelling pressure and the boundary lubricating layer [Levett et al., 2014; Li et al., 2021], and the architectural reinforcement of the polymer network to resist crack propagation under cyclic load [Sabzi et al., 2017; Deng et al., 2018]. Neither strategy, however, provides the implant with any capacity to report on wear, friction, or incipient failure. This is a gap in which quantum sensing is directly relevant.

2.4 Design Requirements Derived from Biology

Synthesising the preceding sections, a satisfactory synthetic cartilage should satisfy the following requirements. Biologically, it must be cytocompatible and non-immunogenic, support chondrocyte or mesenchymal stem cell viability and chondrogenic differentiation, resist fibrous encapsulation, and degrade into non-toxic products at a rate matched to matrix deposition [Antich et al., 2021; Huang et al., 2022]. Biochemically, it must present or release chondroinductive signals in a spatially and temporally controlled manner [Madry et al., 2014; Ao et al., 2025]. Mechanically, it must achieve a compressive modulus in the range of native cartilage, sustain cyclic loading without fatigue failure, and provide a relaxation spectrum compatible with physiological rates. Architecturally, it must be stratified or gradient in composition to approximate zonal organisation, or at least permit zonal organisation to develop [Zhu et al., 2018]. Surgically, it must be implantable

by minimally invasive means where possible, which favours injectable and in situ gelling systems [Chen et al., 2016; Liu et al., 2017]. Finally, and this is the requirement that motivates the present review, it should be observable: the implant should provide quantitative information about its own state so that the surgeon and the materials scientist can distinguish a successful remodelling trajectory from a silent failure (Fig. 2).

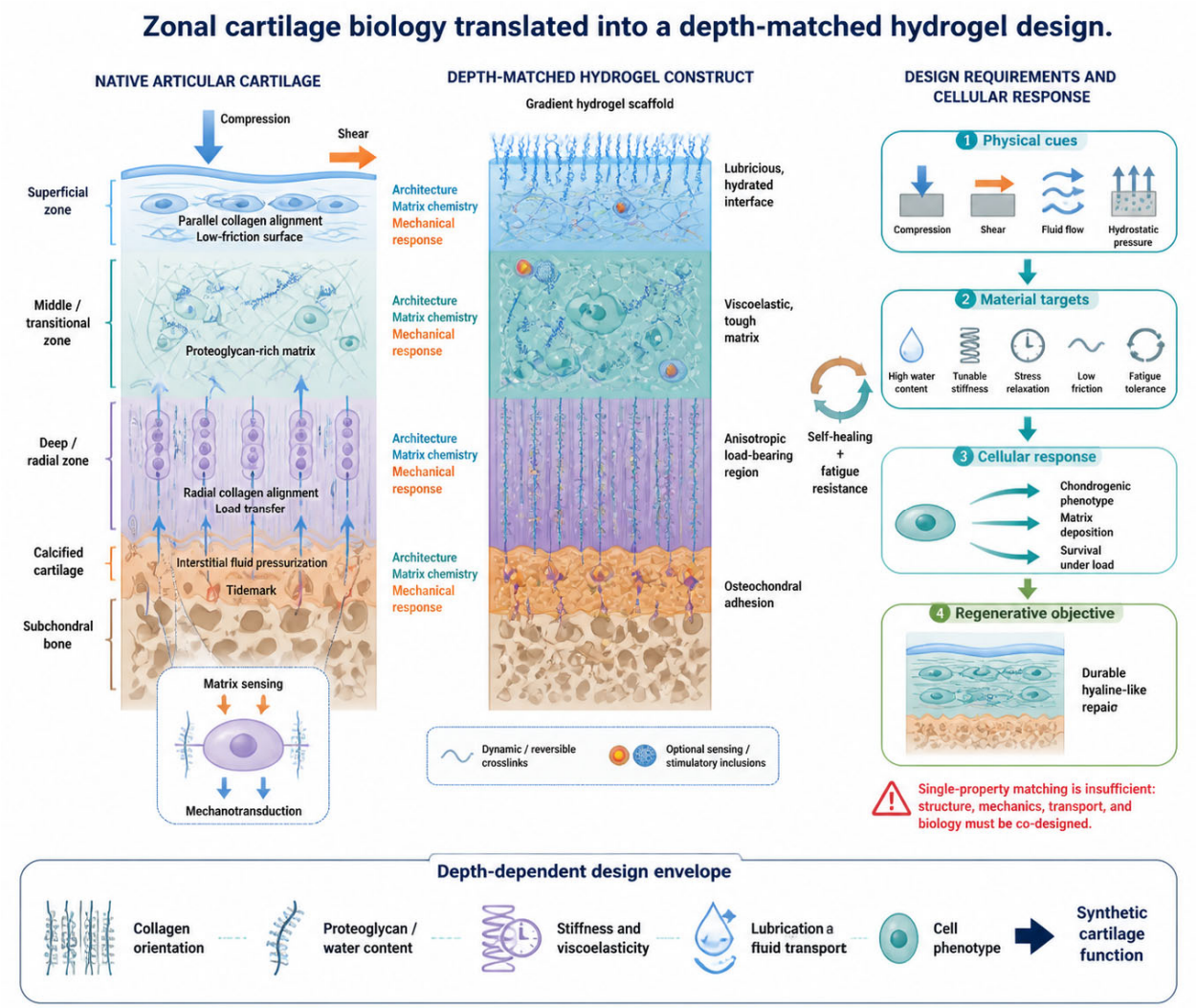


Figure 2. Zonal cartilage biology translated into a depth-matched hydrogel design. Native articular cartilage is a stratified, anisotropic tissue in which cell morphology, extracellular-matrix composition, collagen orientation, water content, and mechanical function vary with depth. The superficial zone provides a lubricated, low-friction interface and contains flattened chondrocytes with predominantly surface-parallel collagen fibrils. The middle zone contains rounded chondrocytes within a proteoglycan-rich matrix, whereas the deep zone contains columnar chondrocytes and radially oriented fibrils that transfer load toward the calcified cartilage and subchondral bone. Interstitial fluid pressurisation, compression, shear, and hydrostatic pressure jointly regulate cartilage mechanics and chondrocyte mechanotransduction.
The corresponding engineered construct is represented as a gradient hydrogel with a lubricious hydrated surface, a tough and viscoelastic middle network, an anisotropic load-bearing deep region, and an adhesive interface with the osteochondral unit. This depth-matched architecture is designed to reproduce coupled gradients in lubrication, water transport, stiffness, stress relaxation, fatigue resistance, and cell–matrix signalling rather than matching a single bulk modulus. Optional quantum-scale inclusions provide additional opportunities for local sensing and mechanical stimulation. The resulting design chain links biological cues to material targets, cellular responses, and the regenerative objective of durable hyaline-like tissue repair. The figure

emphasizes that cartilage replacement requires coordinated control of structure, mechanics, transport, and biology.

3. Hydrogels as Synthetic Cartilage Matrices

3.1 Natural Polymer Networks

Natural hydrogels dominate cartilage tissue engineering because their chemical motifs intersect with those of the native matrix. Gelatin, derived by hydrolysis of collagen, presents arginine–glycine–aspartate sequences that support integrin-mediated adhesion and contains matrix metalloproteinase cleavage sites that permit cell-mediated remodelling. Its methacryloyl derivative, gelatin methacryloyl, is photo-crosslinkable, cytocompatible at appropriate concentrations, and printable, and it has become the most widely used bioink for cartilage bioprinting [Ghosh et al., 2023; Chen et al., 2023]. Hyaluronic acid, a non-sulfated glycosaminoglycan that binds the CD44 receptor and contributes directly to the osmotic swelling of cartilage, is readily functionalised and has been used extensively as an injectable carrier for chondrogenic growth factors and stem cells [Bian et al., 2011; Tan et al., 2009]. Chondroitin sulfate, the sulfated glycosaminoglycan that carries much of the fixed charge of the native matrix, has been incorporated into gelatin and pullulan networks to increase glycosaminoglycan content and chondrogenic gene expression [Levett et al., 2014; Chen et al., 2016; Li et al., 2021]. Alginate, chitosan, and fibrin provide complementary properties, including rapid ionic gelation, antibacterial activity, and intrinsic bioactivity [Olov et al., 2022; Liu et al., 2017].

The shortcomings of natural hydrogels are equally well documented. Gelatin-based networks dissolve or degrade rapidly and their mechanically weak character limits load bearing; hyaluronic acid gels require chemical modification to be stabilised; alginate is bioinert in the absence of adhesive ligands. These limitations have driven the development of composite and hybrid systems, in which natural and synthetic components are combined, and of the reinforced architectures discussed in Section 9.

3.2 Synthetic and Semi-Synthetic Networks

Synthetic networks permit precise control over crosslink density, mesh size, degradation kinetics, and mechanical response. Poly(ethylene glycol) derivatives are the archetype: they resist protein adsorption, can be end-functionalised with peptides, and can be crosslinked photochemically or enzymatically. Polyacrylamide, poly(vinyl alcohol), and poly(2-hydroxyethyl methacrylate) have been used as model cartilage materials and as synthetic cartilage replacements in early clinical experiments. Semi-synthetic systems, in which a synthetic backbone is decorated with biological motifs, combine the reproducibility of the former with the bioactivity of the latter [Olov et al., 2022].

The advantage of synthetic chemistry is also the key to the incorporation of quantum-scale elements, because the same functional group strategies that attach peptides and growth factors to a network can be used to attach quantum dots, nanodiamonds, and piezoelectric nanoparticles with controlled valency and spatial distribution. This point deserves emphasis: the machinery of modern polymer chemistry already provides the conjugation tools required for quantum engineering, and the barrier to adoption is therefore not synthetic access but functional justification and regulatory acceptance.

3.3 Interpenetrating and Double-Network Hydrogels

The toughness problem — the difficulty of combining high stiffness with high fracture energy — has been addressed through network topology. Interpenetrating polymer networks consist of two independently crosslinked networks that are not covalently bonded to one another; double-network hydrogels combine a brittle, sacrificial first network with a stretchable, energy-dissipating second network. In physically cross-linked double-network systems, the sacrificial network fractures locally and dissipates energy, while the second network maintains macroscopic integrity.

A bioinspired fully physically cross-linked double-network hydrogel was shown to recover a substantial fraction of its original mechanical performance after damage, demonstrating that self-healing and toughness can coexist [Sabzi et al., 2017]. Dual physically cross-linked κ-carrageenan-based double-network hydrogels exhibit superior self-healing performance and have been proposed specifically for biomedical application, exploiting the reversible formation of double helices in the second network [Deng et al., 2018].

Self-healing is particularly attractive for cartilage. A hydrogel that can re-form bonds after local damage recovers a property that native cartilage possesses only vestigially, and that conventional implants lack entirely. In combination with quantum-scale sensing, self-healing networks raise an intriguing possibility: a material that senses its own damage through a change in its optical or magnetic signature and repairs it autonomously through dynamic bond reformation. The realisation of such a closed sensing–actuation loop remains a research frontier.

3.4 Nanocomposite Hydrogels

Nanocomposite hydrogels incorporate inorganic or carbon-based nanoparticles within the polymer network, either as passive reinforcement or as functional elements. Reviews of nanoparticle-containing hydrogels for cartilage repair catalogue a wide range of fillers, including nanocellulose, graphene oxide, layered silicates, hydroxyapatite, and metallic oxides, and report improvements in compressive modulus, stiffness, and glycosaminoglycan deposition relative to the corresponding neat gels [Ao et al., 2022; Zhao et al., 2020]. Bacterial nanocellulose reinforcement of gelatin methacryloyl hydrogels, for example, increased both the biomechanical properties and the glycosaminoglycan content of three-dimensionally bioprinted cartilage constructs [Zeng et al., 2022]. Carbon nanomaterial-based hydrogels, including those containing graphene derivatives and carbon dots, have been reviewed as scaffolds for tissue engineering more broadly [Stocco et al., 2023].

Nanocomposite hydrogels also feature prominently in the emerging treatment of degenerative joint disease, where the nanoparticle component is exploited not only for mechanical reinforcement but for anti-inflammatory and imaging functions [Chen et al., 2024]. This convergence of mechanical, biological, and informational function within a single filler is precisely the logic of quantum engineering, and it is why the distinction between a nanocomposite and a quantum-engineered hydrogel depends on the mechanism of action rather than on the particle size alone.

4. Quantum-Scale Engineering: A Design Framework

4.1 Definition and Boundary Conditions

Not every nanoscale filler is quantum-engineered. A particle is quantum-engineered, in the sense used here, when its function derives from phenomena that cannot be described classically: quantum confinement of charge carriers, spin-dependent optical transitions, tunnelling, or the coupling of mechanical deformation to quantum-mechanical order parameters. This distinction is operational rather than semantic, because it determines what measurements are meaningful. A graphene oxide sheet strengthens a hydrogel by load transfer and by physical crosslinking; its mechanism is continuum mechanical. A nitrogen-vacancy centre in a nanodiamond, by contrast, reports a local magnetic field through the shift of an optically detected magnetic resonance, and its sensitivity depends on spin coherence times, microwave driving, and photon collection efficiency — quantities that have no classical analogue.

Three boundary conditions follow. First, quantum functionality must survive the hydrogel environment: a defect centre that is quenched by radicals generated during photo-crosslinking, or a quantum dot whose emission is screened by a dense polymer mesh, delivers no benefit. Second, quantum functionality must be compatible with biological timescales and temperatures: phenomena requiring cryogenic conditions or ultrahigh vacuum are excluded. Third, the functional

element must not compromise the host's biocompatibility, and this is the constraint that most severely restricts the semiconductor quantum dot family.

4.2 Four Functional Levels of Integration

It is useful to distinguish four levels at which quantum-scale elements can be integrated into a cartilage hydrogel.

At level one, quantum elements serve as labels. Fluorescent quantum dots or carbon dots are dispersed in the network to allow the implant to be tracked optically, to visualise its degradation, and to localise encapsulated cells during in vitro studies [Farshidfar et al., 2023; Boakye-Yiadom et al., 2019]. This is the most mature and least demanding application, and it already provides substantial value in preclinical work, where the distinction between a retained implant and a degraded one is often ambiguous.

At level two, quantum elements serve as functional additives. Carbon dots scavenge reactive oxygen species and thereby attenuate the oxidative stress that accompanies joint inflammation; piezoelectric nanocrystals generate charge under load and thereby provide electrical stimulation; nanodiamonds improve mechanical properties while also acting as drug carriers [Ghanbari et al., 2021; Kapat et al., 2020].

At level three, quantum elements serve as sensors. Nitrogen-vacancy magnetometry measures the forces transmitted across a cell–matrix interface; nanoscale thermometry measures local heating during loading or photothermal therapy; relaxometry reports on the nanoscale viscosity of the pericellular environment [Xu et al., 2024; Kołodziej et al., 2024].

At level four, quantum elements are architecturally coupled. Arrays of emitters communicate through energy transfer; deformation modulates both the electrical and the optical response of a composite; the hydrogel becomes a distributed transducer whose collective output reports on macroscopic mechanical state. Level four is largely aspirational, and this review treats it as a research programme rather than a demonstrated capability.

4.3 Why Quantum-Scale Phenomena Are Relevant to Cartilage

The relevance of quantum-scale engineering to cartilage is not incidental. Three arguments support it.

The first is dimensional. The critical processes in cartilage mechanobiology occur at length scales of tens of nanometres: integrin clustering, focal adhesion maturation, primary cilium deflection, and nuclear pore transport. Classical sensors based on fluorescence resonance energy transfer or traction force microscopy resolve forces either at molecular scale with poor multiplexing or at micrometre scale with limited sensitivity. Quantum sensing occupies the intermediate regime with unmatched sensitivity, and it is therefore the natural instrument for the mechanobiology of a synthetic matrix [Xu et al., 2024].

The second argument is energetic. Electrical and electrochemical cues modulate chondrocyte and osteochondral behaviour, and piezoelectric materials provide those cues without external power, converting physiological loading directly into charge. A review of piezoelectric smart biomaterials documented the breadth of materials available for bone and cartilage applications [Jacob et al., 2018], and the field has since produced demonstrations in vivo, including exercise-induced piezoelectric stimulation for cartilage regeneration in rabbits using a poly-L-lactic acid nanofibre scaffold that acted as a self-powered electrical stimulator [Liu et al., 2022].

The third argument is informational. A cartilage implant that senses its own state generates longitudinal data, and longitudinal data are what the field most conspicuously lacks. Nearly all mechanistic claims in cartilage tissue engineering rest on endpoint histology, which cannot distinguish a construct that remodelled gradually and well from one that degraded abruptly and late. Quantum sensing offers a route to non-destructive, quantitative, and spatially resolved monitoring [Mzyk et al., 2026].

4.4 Distinguishing Genuine Quantum Advantage from Rhetorical Quantum

The rapid growth of "quantum" branding in biomedical materials science warrants a cautionary note. Four tests are proposed here. First, mechanistic necessity: would a classical object of the same size and surface chemistry produce the same effect? If so, the phenomenon is nanoscale, not quantum. Second, measurability: is the claimed quantum property actually measured, with reported coherence times, quantum yields, or magnetometric sensitivities? Third, persistence: is the property verified after incorporation into the hydrogel and after implantation, rather than only in colloidal suspension? Fourth, benefit: does the quantum property translate into a quantifiable improvement in a functionally relevant outcome, such as glycosaminoglycan content, compressive modulus after fatigue, or defect filling in vivo? Where a study satisfies only the first two, its contribution should be described as promising rather than established. Throughout the remainder of this review, evidence is assessed against these tests.

5. Quantum Dots and Carbon Dots in Cartilage Engineering

5.1 Semiconductor Quantum Dots: Composition, Surface Chemistry, and Aqueous Compatibility

Semiconductor quantum dots are colloidal nanocrystals, typically two to ten nanometres in diameter, in which the spatial confinement of electron–hole pairs produces a size-dependent band gap and therefore a tunable emission wavelength. Canonical systems include cadmium selenide, cadmium telluride, indium phosphide, copper indium sulfide, and lead halide perovskites. Their optical advantages are substantial: high extinction coefficients across a broad excitation band, narrow and symmetric emission peaks, exceptional photostability relative to organic fluorophores, and accessible surface chemistry for bioconjugation. These properties underpinned the emergence of quantum dot theranostics, in which a single nanocrystal provides simultaneous imaging contrast and therapeutic function [Ho & Leong, 2010]. The near-infrared-emitting copper indium sulfide–zinc sulfide system exemplifies the ambition, combining fluorescence and photoacoustic contrast with photothermal therapeutic capacity in an all-in-one platform [Lv et al., 2016].

The translation of these advantages into a hydrogel for cartilage regeneration encounters three obstacles. The first is aqueous and biological compatibility: as-synthesised nanocrystals are stabilised by hydrophobic ligands and must be transferred to water through ligand exchange or amphiphilic polymer encapsulation, a step that can reduce quantum yield and introduce labile surface chemistry. The second is photochemical interference: the ultraviolet or blue light used to photo-crosslink many hydrogel precursors can excite the nanocrystals, generating reactive oxygen species that damage encapsulated cells and degrade the polymer network. The third is toxicity, discussed in Section 5.5. These obstacles do not exclude semiconductor quantum dots from cartilage engineering, but they shift the burden of proof: a cadmium-based emitter must justify itself against a carbon-based alternative that is cheaper, more biocompatible, and bright enough for most purposes.

5.2 Carbon Dots and the Ascendancy of Metal-Free Emitters

Carbon dots — quasi-spherical carbonaceous nanoparticles below ten nanometres with graphitic or amorphous cores and abundant surface functional groups — have displaced semiconductor quantum dots in most tissue engineering contexts. They combine bright, excitation-dependent photoluminescence with low cytotoxicity, excellent water dispersibility, and facile doping. Nitrogen doping, in particular, introduces additional emissive surface states and enhances quantum yield, while also conferring antioxidant activity that is directly relevant to inflammatory joint pathology.

The evidence for carbon dots in musculoskeletal regeneration has accumulated rapidly. Thermosensitive alginate–gelatin scaffolds incorporating nitrogen-doped carbon dots were developed as injectable hydrogels for cartilage tissue engineering, and the formulation containing the highest-performing carbon dot loading was selected on the basis of combined rheological,

mechanical, and biological criteria [Ghanbari et al., 2021]. A broader review of carbon dots across tissue engineering and regenerative medicine documented applications spanning bone, cartilage, neural, and wound-healing contexts, and specifically identified thermosensitive alginate–gelatin–nitrogen-doped carbon dot scaffolds as an injectable route to cartilage regeneration [Farshidfar et al., 2023]. Carbon nanomaterial-based hydrogels have been reviewed comprehensively as scaffolds, with the authors noting that carbon dots offer photostability and multicolour fluorescence comparable to semiconductor quantum dots while avoiding heavy-metal toxicity, and highlighting their use in nanocomposites for articular cartilage regeneration [Stocco et al., 2023]. The trajectory is clear: the metal-free emitter has become the default fluorescent and antioxidant nanofiller for cartilage hydrogels.

5.3 Reactive Oxygen Species Scavenging and Anti-Inflammatory Function

The mechanistic value of carbon dots in cartilage extends well beyond imaging. Oxidative stress is a central mediator of chondrocyte senescence, matrix metalloproteinase activation, and the catabolic cascade that follows joint injury. A nanofiller that catalytically consumes superoxide, hydrogen peroxide, and hydroxyl radicals therefore acts as a therapeutic component rather than an inert additive. Nitrogen-doped and heteroatom-doped carbon dots possess enzyme-mimicking activities, including superoxide dismutase- and peroxidase-like behaviour, and thereby attenuate the oxidative burden within the construct and in the surrounding synovial environment.

This function is particularly valuable because it couples to mechanics. Reactive oxygen species degrade the polymer network and accelerate the loss of stiffness; an antioxidant filler therefore extends the functional lifetime of the implant while simultaneously protecting the encapsulated cell population, and the effect is self-reinforcing. Nanocomposite hydrogels for degenerative joint disease have been reviewed with explicit attention to this dual role, in which the nanoparticle component moderates inflammation while contributing to the mechanical performance of the network [Chen et al., 2024]. In the design language proposed in Section 4, this constitutes level-two quantum engineering: the quantum-confined electronic structure of the dot is what enables the catalytic redox chemistry, and the benefit is functional rather than merely decorative.

5.4 Imaging, Tracking, and Theranostic Monitoring

Level-one quantum engineering — fluorescent labelling — remains the most immediately useful function in a pre-clinical setting, because it addresses an experimental bottleneck. Cartilage tissue engineering studies typically assess outcome by endpoint histology, which cannot report on the fate of an implant between implantation and sacrifice. Carbon dots and quantum dots dispersed within a hydrogel permit non-destructive optical monitoring of construct position, volumetric change, and degradation, and because the emitters are distributed throughout the network rather than attached to a single component, their release profile doubles as a proxy for network disassembly. Live tracking of this kind has been demonstrated in the broader nanomedicine literature for carbon dots [Boakye-Yiadom et al., 2019] and for quantum dot theranostics [Ho & Leong, 2010], and the green-chemistry shift toward biowaste-derived carbon dots has addressed the toxicity critique that previously limited the semiconductor family [Bhattacharya & Das, 2025].

Two methodological cautions apply. First, fluorescence intensity is not a linear measure of material quantity: quenching, scattering, and pH-dependent emission all modulate the signal, and quantitative degradation kinetics should be established by complementary methods such as mass loss or gel permeation chromatography. Second, the excitation light itself may perturb the system through photothermal heating or radical generation, and control experiments must demonstrate that the observation does not alter the observed.

5.5 Toxicity, Retention, and the Heavy-Metal Question

The toxicity of cadmium- and lead-containing quantum dots is the single largest obstacle to their clinical use in a load-bearing implant. Cadmium selenide nanocrystals can release cadmium ions under oxidative or acidic conditions, and cadmium is a classified carcinogen with nephrotoxic and

osteotoxic effects. Although encapsulation within a zinc sulfide shell and a polymer coating substantially reduces leaching, an implant intended to reside in a joint for years cannot rely on barrier integrity indefinitely. The problem is compounded in cartilage specifically, because the tissue's low turnover and poor lymphatic drainage prolong residence time and reduce clearance.

Three mitigation strategies are available. The first is compositional substitution: indium phosphide, copper indium sulfide, silicon, and carbon-based emitters avoid regulated heavy metals entirely, and the safety-oriented literature now explicitly frames the move toward carbon dots as a response to the toxicity of conventional metal quantum dots [Alavi et al., 2022; Bhattacharya & Das, 2025]. The second is covalent tethering: anchoring the nanocrystal to the polymer backbone by a stable bond converts a diffusible nanoparticle into an immobilised component that cannot migrate to the liver or kidney unless the network itself degrades. The third is degradation-programmed release with renal-clearable size, in which the particle is designed to disassemble into sub-six-nanometre fragments after a defined residence time. Each strategy carries a cost: substitution may reduce brightness, tethering may reduce mobility and quenching behaviour, and programmed degradation requires exquisite kinetic control. The rational choice for a cartilage implant is compositional substitution combined with covalent tethering, reserving semiconductor emitters for in vitro mechanistic studies where their superior optical properties are decisive and the exposure window is short.

6. Nanodiamond Spin Defects as Quantum Sensors in Living Matrices

6.1 The Nitrogen-Vacancy Centre as a Nanoscale Transducer

A nitrogen-vacancy centre is a point defect in diamond in which a substitutional nitrogen atom is adjacent to a vacant lattice site. In its negatively charged state the centre possesses an electron spin whose ground-state sublevels can be manipulated by microwaves and read out optically through spin-dependent fluorescence. Because the spin is shielded within a rigid, chemically inert lattice, coherence is preserved for microseconds to milliseconds even at room temperature and within living cells. This combination — optical initialisation and readout, microwave control, long coherence, and biocompatibility — makes the nitrogen-vacancy centre the most versatile quantum sensor available for biological measurement.

The quantities it can transduce are precisely those that matter for a cartilage implant. Magnetic field sensing, through the Zeeman shift of the spin sublevels, reports on the magnetic environment. Relaxometry, through the dependence of coherence time on the fluctuating magnetic noise produced by nearby spins, reports on nanoscale viscosity and on the dynamics of macromolecules in the immediate vicinity of the sensor. Thermometry, through the temperature dependence of the zero-field splitting, reports on local heating with millikelvin sensitivity. Strain and stress couple to the defect through the crystal field, enabling mechanical readout. Each of these modalities has been demonstrated in cellular contexts.

6.2 Quantum-Enhanced Force Microscopy at the Cell–Matrix Interface

The most directly relevant application for tissue engineering is the measurement of cellular traction forces. Conventional traction force microscopy infers forces from the displacement of fiducial markers within a deformable substrate, and its resolution is limited by marker density and by the optical diffraction limit. A quantum-enhanced approach replaces or augments the fiducial markers with nanodiamond sensors and reads the force through the magnetic or strain response of the defect. Quantum-enhanced diamond molecular tension microscopy was developed precisely for this purpose: the authors integrated a nitrogen-vacancy-based sensing substrate with tension-sensing molecular probes to quantify integrin-mediated cellular forces, achieving sensitivity that classical approaches cannot match [Xu et al., 2024].

A complementary capability has been demonstrated through torsional analysis. Nanodiamond-enabled torsion microscopy was used to uncover multidimensional cell–matrix mechanical interactions in live macrophages, extending the accessible degrees of freedom from simple in-

plane traction to the rotational and out-of-plane components that dominate in a three-dimensional matrix [Hou et al., 2026]. Because chondrocytes reside in a three-dimensional charged matrix and experience shear and hydrostatic rather than predominantly planar loading, this extension is not a marginal refinement but a necessary capability.

6.3 Thermometry, Relaxometry, and Metabolic Readout

Beyond force, quantum sensing provides a window on cellular metabolism and on the local physicochemical state of the matrix. A diamond-embedded substrate was used for multimodal analysis of traction forces and temperature dynamics in living cells, demonstrating simultaneous mechanical and thermal readout [Kołodziej et al., 2024]; an accompanying methodological study examined the same combination and its implications for tracking force and heat together [Mrózek et al., 2024]. Because chondrocyte matrix synthesis is strongly temperature-sensitive and because inflammatory joints exhibit regional hyperthermia, local thermometry is a clinically meaningful observable rather than a technical curiosity.

Relaxometry-based approaches have been applied to intracellular behaviour in a fibrosis model. Nanodiamond quantum sensing revealed changes in endo-lysosomal activity of stimulated cardiac fibroblasts, with approximately five hundred nitrogen-vacancy centres incorporated per particle and with measurements resolved in space and time within organelles of living cells; the authors framed the work as opening new avenues for studying the mechanobiology of fibrotic remodelling [Mzyk et al., 2026]. The relevance to cartilage is direct: chondrocyte dedifferentiation in monolayer culture and fibrous degeneration in vivo are processes of phenotypic drift in which lysosomal and cytoskeletal remodelling are central, and both are invisible to conventional endpoint assays.

6.4 Embedding Quantum Sensors Within a Cartilage Hydrogel

Integrating nitrogen-vacancy sensing into a load-bearing hydrogel raises design problems that have only begun to be addressed. The first is optical. A hydrogel several millimetres thick scatters light strongly, and the fluorescence collection efficiency required for magnetometry degrades with depth. Practical solutions include confining the sensors to an optically accessible surface layer, using nanodiamonds with high nitrogen-vacancy yield to maximise photons per particle, and adopting fibre-coupled or widefield geometries that tolerate scattering.

The second problem is mechanical coupling. A sensor embedded in a compliant network measures the local strain field, not the macroscopic stress; converting one to the other requires a constitutive model and knowledge of the particle–matrix interfacial mechanics. If the particle debonds from the network, the measurement becomes meaningless without any obvious signature of failure. Covalent tethering, together with particles whose elastic modulus is matched as closely as possible to the surrounding matrix, mitigates but does not eliminate this issue.

The third problem is biological obscuration. Cells internalise nanoparticles, and an internalised sensor measures the intracellular environment rather than the matrix. Controlled surface chemistry — for instance, zwitterionic or poly(ethylene glycol) coatings that resist protein adsorption and phagocytosis — is required if extracellular placement is the objective.

6.5 The Interpretive Gap Between Spin Physics and Tissue Function

The deepest limitation of quantum sensing in this context is conceptual rather than technical. A nitrogen-vacancy centre reports a magnetic field or a temperature averaged over its nanoscale sensing volume, with a sensitivity quantified by a coherence time and a photon collection rate. Tissue function is expressed in terms of macroscopic quantities: aggregate modulus, glycosaminoglycan content, hydraulic permeability, equilibrium friction coefficient. Bridging these descriptions requires a multiscale model that propagates nanoscale observations to macroscopic constitutive behaviour and, crucially, that specifies the averaging and coarse-graining procedures involved. No such model currently exists for a quantum-sensing hydrogel, and its absence means

that quantum measurements presently serve as mechanobiological insight rather than as engineering specification.

There is a second, subtler gap. The phenomena that make nitrogen-vacancy sensing possible — spin coherence, optical pumping, microwave manipulation — have no bearing on the biology they measure. The quantum character of the sensor does not make the sensed biology quantum. This distinction should be stated plainly, because the alternative framing invites the expectation that quantum sensing reveals quantum biology in cartilage, for which there is at present no compelling evidence. The value of quantum sensing in this field is instrumental and epistemological: it yields measurements that were previously unobtainable, and it thereby tests models that were previously untestable.

7. Piezoelectric and Quantum-Confined Electrical Stimulation

7.1 Endogenous Electrical Cues in Musculoskeletal Tissues

Bone and cartilage are electrically active tissues. Deformation of bone generates streaming potentials through the flow of interstitial fluid past charged matrix constituents, and the piezoelectric character of collagen produces direct charge separation under strain. Chondrocytes likewise reside in a fixed-charge environment in which mechanical loading redistributes ions and generates measurable potentials across the tissue. These endogenous signals are not epiphenomena; they participate in the regulation of matrix synthesis, and their disruption accompanies degeneration. The therapeutic proposition is therefore to supply the missing cue by restoring the electro-mechanical coupling of the tissue.

Reviews of piezoelectric smart biomaterials for bone and cartilage tissue engineering have catalogued the candidate materials and the mechanisms by which electrical stimulation influences cell behaviour, and have noted early demonstrations of accelerated bone regeneration exploiting the piezoelectric properties of implanted materials [Jacob et al., 2018]. The field has since expanded to a systematic treatment of electrically active materials for stimulation and regeneration across tissues, including cartilage, muscle, skin, and cardiac tissue, documenting that chondrogenic and osteogenic cells respond to both endogenous and exogenous electrical fields [Park et al., 2025]. A comprehensive review of advances in electrical materials for bone and cartilage regeneration identified the endogenous electric field as critical for bone regeneration and analysed how piezoelectric characteristics can be harnessed to deliver stimulation without external power [Yao et al., 2025].

7.2 Quantum-Confined Piezoelectric Nanocrystals

The piezoelectric response of a nanoscale crystal is not simply a scaled-down version of the bulk effect. As particle dimensions approach the exciton Bohr radius, quantum confinement alters the electronic structure, and surface and depolarisation effects modify the effective piezoelectric coefficients, in some cases substantially enhancing the electromechanical response at small size. Ferroelectric nanocrystals such as barium titanate exhibit spontaneous polarisation whose magnitude depends on particle size and on the balance between depolarisation energy and surface charge screening. Zinc oxide nanorods, poly-L-lactic acid crystallites, and two-dimensional transition-metal dichalcogenides provide alternative platforms with differing biocompatibility, degradation, and processing profiles.

Reviews of piezoelectric nano-biomaterials for biomedicine and tissue regeneration have described this design space in detail, including the embedding of piezoelectric nanostructures within bone- and cartilage-mimetic matrices and the mechanisms by which nanoscale confinement and surface chemistry determine the delivered charge [Kapat et al., 2020]. The engineering task is to select a composition whose piezoelectric output under physiologically realistic strain amplitudes is sufficient to influence cells without exceeding the electroporation threshold, and whose degradation products are tolerable over the implant lifetime.

7.3 Self-Powered Stimulation In Vivo

The decisive demonstration for cartilage came from an in vivo study in rabbits in which exercise-induced piezoelectric stimulation produced cartilage and subchondral bone regeneration. The authors fabricated a piezoelectric poly-L-lactic acid nanofibre scaffold that served as a self-powered electrical stimulator, generating charge from the animals' own locomotion and thereby coupling rehabilitation to regeneration without an implanted power source or an external field generator [Liu et al., 2022]. The result is significant for three reasons. First, it establishes that the magnitude of charge generated by normal joint loading is biologically sufficient. Second, it removes the practical obstacles of wires, batteries, and external coils that have limited electrically stimulated tissue engineering. Third, it converts the mechanical environment from a design constraint into a therapeutic input, which is precisely the logic that a quantum-engineered hydrogel extends by coupling piezoelectric generation to optical or magnetic readout.

7.4 Coupling Electrical Stimulation to Quantum Sensing and Optical Output

A convergence that has not yet been demonstrated, but that is technically coherent, would combine piezoelectric generation with quantum-scale readout in a single construct. Deformation generates charge; charge modulates the occupation of emissive states in embedded quantum dots or carbon dots; the modulation is detected optically. The construct then reports on its own loading history and on cumulative mechanical demand, a capability with obvious value for both preclinical mechanistic studies and, eventually, for postoperative monitoring. Related logic is already present in the literature on multifunctional nanocomposite fillers that combine mechanical reinforcement with imaging contrast [Chen et al., 2024; Lv et al., 2016], and the materials chemistry required for a piezo-emitter composite is unremarkable — the open problems are quantitative rather than conceptual, namely whether the modulation depth is detectable against a bright background and whether it survives the ionic and protein-rich environment of a joint (Fig. 3).

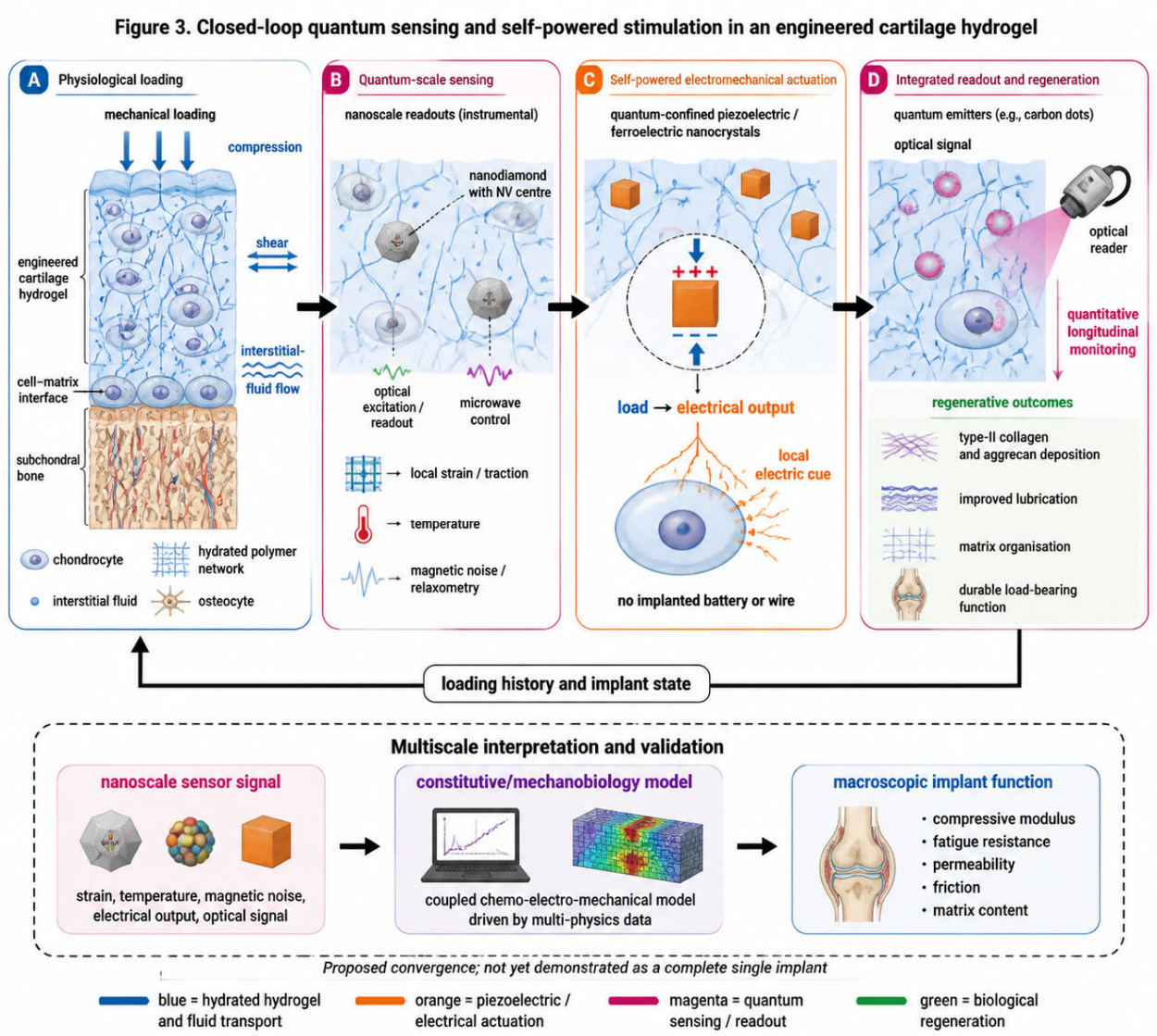


Figure 3. Closed-loop quantum sensing and self-powered stimulation in an engineered cartilage hydrogel. The schematic illustrates how physiological compression, shear, and interstitial-fluid flow deform a hydrated hydrogel network designed for cartilage regeneration. Mechanical loading is detected locally by nitrogen-vacancy nanodiamond sensors, which provide nanoscale information about strain, cellular traction, temperature, magnetic noise, and matrix dynamics. At the same time, embedded quantum-confined piezoelectric or ferroelectric nanocrystals convert deformation into electrical signals, providing self-powered stimulation to nearby chondrocytes without implanted batteries, wires, or external power sources. Carbon dots or other quantum-scale emitters provide optical labeling and readout, enabling longitudinal monitoring of implant loading history, degradation, and biological response. These sensing and actuation functions are connected to regenerative outcomes, including chondrocyte activity, type-II collagen and aggrecan deposition, improved lubrication, matrix organisation, and restoration of load-bearing function. The lower section emphasizes the necessary multiscale interpretation: nanoscale sensor signals must be translated through constitutive and mechanobiological models into macroscopic endpoints such as compressive modulus, fatigue resistance, permeability, friction, and matrix content. The integrated closed-loop architecture is proposed rather than demonstrated as a complete single implant.

8. Fabrication and Additive Manufacturing

8.1 Bioink Design for Quantum-Loaded Hydrogels

Three-dimensional bioprinting requires a formulation that is simultaneously printable, cytocompatible, and capable of retaining its printed geometry. Gelatin methacryloyl is the most widely adopted bioink for cartilage because it satisfies these requirements over a useful window of concentration and degree of substitution, and reviews of its synthesis, properties, and applications document the relationship between methacryloyl substitution, polymer concentration, and crosslink density that determines both printability and final mechanics [Ghosh et al., 2023]. Progress in three-dimensional printing of gelatin methacrylate-based biomaterials for articular cartilage repair has been reviewed specifically, cataloguing the formulations used and the outcomes obtained [Chen et al., 2023]. Low-temperature printing strategies have been used to overcome the narrow concentration window of gelatin methacrylamide and thereby print cartilage engineered tissue at reduced polymer content [Luo et al., 2020], and composite systems have been developed to improve the mechanical and biological performance of the printed construct, including an arch-like bioprinted structure based on gelatin methacryloyl and silk fibroin–gelatin bioinks [Chakraborty et al., 2023]. Reinforcement with bacterial nanocellulose has been shown to enhance both the biomechanical properties and the glycosaminoglycan content of three-dimensionally bioprinted cartilage [Zeng et al., 2022]. Broader reviews of bioprinted gelatin methacrylate-based hydrogels for tissue repair place these advances in context [Rajabi et al., 2021].

Introducing quantum-scale fillers into such a bioink changes its rheology. Nanoparticles increase viscosity and shear-thinning behaviour at low shear rates, which can improve shape fidelity but also raise the extrusion pressure and therefore the shear stress experienced by encapsulated cells. Optical fillers absorb and scatter the light used for crosslinking, reducing cure depth and creating a gradient of crosslink density through the printed structure. Both effects are tractable — through dilution, through the use of longer-wavelength photoinitiators, and through sequential rather than bulk crosslinking — but they must be characterised per formulation rather than assumed to be negligible.

8.2 Four-Dimensional Printing and Programmed Morphogenesis

Four-dimensional printing adds a time dimension by exploiting stimuli-responsive materials whose geometry or properties evolve after fabrication. Reviews of four-dimensional printing strategies for next-generation tissue regeneration and medical devices have identified the dependence of the strategy on the stimuli-responsive character of the printed filament, and have noted that thermoresponsive hydrogels and liquid crystalline polymers have been the most widely applied platforms [Wang et al., 2022]. A review of stimuli-responsive materials in four-dimensional bioprinting has analysed the problem of achieving dual responsiveness, in which the construct responds to two independent cues, and discussed the application of such systems in tissue engineering [Bhandari et al., 2026]. The fabrication of smart materials for regenerative medicine, including shape-memory polymers and programmable hydrogels, has been surveyed with attention to the printing modalities required [Alanazi et al., 2025], and the specific case of alginate hydrogels has been reviewed in detail, with the authors emphasising that the stimuli-responsive nature of the material enables constructs to mimic the structural adaptation of natural tissue [Liu & Ding, 2025].

Cartilage is an unusually favourable target for four-dimensional approaches because the tissue itself is a shape-memory system: it deforms under load and recovers, and its zonal architecture arises from mechanically driven developmental processes. A printed construct that swells anisotropically, folds, or densifies on implantation could approximate the curvature of a femoral condyle or create the gradient of proteoglycan content that defines the transition from superficial to deep zone [Zhu et al., 2018]. Quantum-scale fillers can serve as the responsive elements in such

constructs: photothermal nanoparticles convert light into local heating that drives a thermoresponsive transition; piezoelectric particles generate charge that modulates electrostatic swelling; magnetic nanoparticles under an alternating field produce both heating and mechanical actuation. Each provides a stimulus channel orthogonal to the others, which is the practical prerequisite for multi-responsive behaviour.

8.3 Hybrid Manufacturing and Hierarchical Assembly

The zonal complexity of native cartilage cannot be reproduced by a single printing pass with a single material. Hybrid strategies therefore combine multiple nozzles, interleaved casting and printing, electrospinning of oriented fibre layers, and post-printing directional freezing or diffusion gradients. Electrospun poly-L-lactic acid layers provide both the orientational anisotropy and the piezoelectric function discussed in Section 7.3 [Liu et al., 2022], while casting steps fill the interstices with cell-laden hydrogel. The integration of printed scaffolds with cell therapies and controlled drug delivery has been reviewed as a convergent strategy for in vivo regeneration of cartilage, bone, and osteochondral tissue, with the authors emphasising the need for evaluation criteria that anticipate clinical rather than purely laboratory requirements [Abbadessa et al., 2024].

9. Mechanical Benchmarking, Constitutive Description, and Fatigue

9.1 Target Properties and the Benchmarking Problem

Benchmarking a synthetic cartilage against native tissue is deceptively difficult because the reported properties of native cartilage vary enormously with species, joint, anatomical site, age, and measurement protocol. Compressive aggregate moduli spanning two orders of magnitude appear in the literature, and tensile, shear, and frictional properties vary similarly. A defensible benchmarking framework must therefore specify the reference tissue, the test configuration, the strain rate, and the preconditioning regime. Without such specification, comparisons between reported hydrogel properties and "native cartilage" are frequently meaningless.

Two practical benchmarks recur in the literature. The first is compressive modulus, with values in the range of a few tenths of a megapascal to a few megapascals commonly cited as relevant for cartilage regeneration; nanocomposite scaffolds have been reported in a compression modulus range of roughly 0.2 to 0.45 megapascals, explicitly matched to the requirements of cartilage regeneration [Zhao et al., 2020]. The second is glycosaminoglycan content, which serves as a biochemical proxy for matrix quality and is measured per unit dry weight. Reviews of nanoparticle-containing hydrogels for cartilage tissue engineering report improvements on both axes relative to unfilled gels [Ao et al., 2022], and specific composites have demonstrated concurrent gains in biomechanical property and glycosaminoglycan content [Zeng et al., 2022].

9.2 Native Tissue Mechanics as a Design Envelope

The native tissue provides not a single target but an envelope. Articular cartilage exhibits a compressive modulus that varies by zone, a tensile modulus that is highly anisotropic and depth-dependent, a permeability that decreases with compressive strain, and a friction coefficient that depends on loading history and on the availability of boundary lubricants. The tissue is also viscoelastic over many decades of time and poroelastic over the timescale of fluid redistribution. Hydrogels reproduce some of these behaviours naturally — poroelasticity in particular — and can be tuned to approximate others, but no single homogeneous hydrogel will match the full envelope. This is the strongest argument for graded and architecturally organised constructs rather than uniform gels, and it is a requirement independent of any quantum functionality.

9.3 Constitutive Modelling of Quantum-Loaded Networks

Describing the mechanical behaviour of a hydrogel containing rigid nanoscale inclusions requires a constitutive framework that accounts for the filler–matrix interaction. Standard approaches include mixing rules, micromechanical homogenisation, and network models in which the fillers act as additional crosslinks or as energy-dissipating inclusions. For the tough, self-healing doubly

cross-linked networks described in Section 3.3, the constitutive description must additionally capture bond reformation kinetics and the recovery of stiffness following damage [Sabzi et al., 2017; Deng et al., 2018].

Quantum-loaded networks present a specific modelling problem: the filler's contribution may be mechanical, as in conventional reinforcement, but it may also be electromechanical if the filler is piezoelectric. In that case the constitutive law becomes coupled, and the local electric field generated by deformation influences the swelling state of the network, which in turn modifies the stress. Fully coupled poroelastic–piezoelectric–electrochemical models of this kind are rare in the cartilage literature, and their absence is a genuine barrier to rational design, because without a coupled model the respective contributions of mechanical reinforcement and electrical stimulation cannot be separated experimentally.

9.4 Fatigue, Wear, and Long-Term Reliability

The most conspicuous gap in the literature on hydrogel cartilage is fatigue. Joint loading is cyclic, and the relevant number of cycles over a decade of use is on the order of millions. Relatively few studies report fatigue crack growth, and those that do rarely adopt standardised protocols comparable to those used for engineering elastomers. The consequence is that reported static moduli and fracture energies convey little about durability, and materials that appear excellent in single-load to failure tests may fail within thousands of cycles.

Three recommendations follow. First, fatigue testing should be reported as a matter of course, with specified load amplitude, frequency, hydration condition, and temperature, and with crack propagation tracked where fracture mechanics are relevant. Second, self-healing efficiency should be reported as a function of recovery time and of the number of damage–recovery cycles, since individual-cycle self-healing does not imply indefinite recyclability [Sabzi et al., 2017; Deng et al., 2018]. Third — and here quantum engineering makes a distinctive contribution — the sensing capability of the material should be used to monitor fatigue. A construct containing nitrogen-vacancy sensors or emissive dots can, in principle, report incipient damage through changes in local strain, matrix viscosity, or fluorophore mobility before macroscopic failure occurs. Demonstrating that such a signature antecedes mechanical failure would be a genuinely novel result and would justify the additional complexity of quantum-loaded design.

10. Biofunctionalisation, Growth Factor Delivery, and Immunomodulation

10.1 Chondroinductive Signals and Their Delivery Problem

The chondrogenic programme in mesenchymal stem cells and in expanded chondrocytes depends on a defined set of soluble signals, of which the transforming growth factor beta superfamily, bone morphogenetic proteins, fibroblast growth factors, and insulin-like growth factor 1 are the most extensively studied. Transforming growth factor beta 3 is the canonical chondrogenic stimulus in vitro, and its delivery within a scaffold has been shown to promote cartilage formation in vivo; alginate microspheres releasing the factor within hyaluronic acid hydrogels enhanced mesenchymal stem cell chondrogenesis both in vitro and after implantation [Bian et al., 2011]. Scaffolds engineered specifically to release transforming growth factor beta have been reviewed as a distinct design class, with attention to the dose, duration, and spatial presentation required for stable chondrogenesis [Madry et al., 2014]. Injectable biodegradable hydrogel composites have been used to co-deliver marrow-derived mesenchymal stem cells and growth factors in a rabbit model, establishing the feasibility of combining cellular and molecular therapy within a single injectable carrier [Park et al., 2007]. Gene delivery provides an alternative to protein administration, allowing sustained local expression; co-delivery of the genes encoding transforming growth factor beta 3 and bone morphogenetic protein 2 within a mesenchymal stem cell-laden alginate hydrogel directed differentiation toward either chondrogenic or endochondral pathways depending on the construct design [Gonzalez-Fernandez et al., 2016]. Covalent conjugation of the growth factor to the scaffold, rather than simple entrapment, has been shown

to drive chondrogenic differentiation of synovium-derived stem cells in chitosan–collagen hydrogels, an approach that addresses the rapid diffusion and short half-life that limit bolus delivery [Kim et al., 2015]. Delivery strategies for growth factors in cartilage tissue engineering have been reviewed comprehensively, including the use of stimuli-responsive carriers loaded with fibroblast growth factor [Ao et al., 2025]. Nanoparticle-mediated release of transforming growth factor beta 3 from microribbon-based hydrogels has been shown to accelerate stem cell-based cartilage formation in vivo, demonstrating that the particulate carrier itself can serve as the delivery controller [Barati et al., 2020].

The delivery problem is fundamentally spatial and temporal. Cartilage is avascular, so a factor released into the joint is cleared by synovial fluid turnover rather than delivered efficiently to the deep zone. The appropriate dose varies with differentiation stage: early chondrogenesis requires high transforming growth factor beta signalling, whereas prolonged exposure promotes hypertrophy and calcification, an outcome that is actively undesirable in an articular cartilage implant. A functional implant must therefore release its payload in a programmed sequence rather than a monotonic decay, and this requirement is precisely where quantum-scale carriers become attractive, because their release kinetics can be triggered by externally addressable stimuli such as light, magnetic field, or local heating.

10.2 Externally Triggered and On-Demand Release

Photothermal and magnetothermal nanoparticles convert absorbed radiation or alternating magnetic field energy into local heat, and that heat can be used to trigger the collapse or permeabilisation of a thermoresponsive polymer shell. The thermosensitive alginate–gelatin–carbon dot scaffolds developed for cartilage tissue engineering exploit precisely this principle of temperature-responsive behaviour, although in that work the thermoresponsiveness governs gelation rather than drug release [Ghanbari et al., 2021]. The near-infrared-emitting copper indium sulfide–zinc sulfide system illustrates the multifunctionality achievable in a single particle, since it combines fluorescence imaging, photoacoustic contrast, and photothermal therapeutic action [Lv et al., 2016]. In a cartilage context, the analogous design would use a near-infrared-absorbing quantum-scale particle both to image the implant and to trigger growth factor release on demand, allowing the clinician to control the chondrogenic stimulus from outside the body.

10.3 Immunomodulation and the Inflammatory Joint

The joint environment in which a cartilage implant is placed is rarely quiescent. Trauma, surgery, and the underlying degenerative process all generate inflammatory mediators, and the resulting macrophage phenotype strongly influences the outcome of any implanted material. An immunomodulatory implant must therefore do more than avoid provoking inflammation; it must actively favour a repair-associated macrophage phenotype. Reviews of nanocomposite hydrogels for degenerative joint disease have highlighted the anti-inflammatory capacity of nanoparticle fillers as a principal advantage, alongside their mechanical and imaging contributions [Chen et al., 2024]. Carbon dots contribute through their reactive oxygen species scavenging activity, and preparations derived from biological waste streams have been developed specifically to reduce the toxicity associated with conventional metal-containing emitters while retaining antioxidant and imaging function [Bhattacharya & Das, 2025].

Immunomodulation also modulates mechanotransduction indirectly. Inflammatory cytokines alter chondrocyte cytoskeletal organisation and matrix synthesis, so a material that suppresses inflammation changes the mechanical signalling environment without any change in its own stiffness. This coupling is one reason that the design of a cartilage implant cannot treat its mechanical, biological, and immunological functions as separable, and it is a strong argument for multifunctional fillers rather than single-purpose reinforcements.

11. Biocompatibility, Degradation, and Nanotoxicology

11.1 Cytocompatibility of Quantum-Scale Fillers

The cytocompatibility of carbon dots is well established at concentrations relevant to hydrogel loading, and the move toward biowaste-derived precursors has been motivated explicitly by the goal of eliminating the toxic metal content characteristic of semiconductor quantum dots [Bhattacharya & Das, 2025]. Reviews of carbon dot applications in bioimaging and theranostics document their use as drug carriers and imaging agents with favourable biological profiles [Boakye-Yiadom et al., 2019], and reviews of carbon dots within tissue engineering and regenerative medicine report their application across bone, cartilage, neural, and wound-healing contexts [Farshidfar et al., 2023]. Safety-oriented assessments of quantum dots have concluded that newer compositions can serve as theranostic agents provided that surface chemistry and dose are controlled, while cautioning that the safety profile is composition-specific rather than class-specific [Alavi et al., 2022].

Nanodiamonds occupy a favourable position because diamond is chemically inert, and the nitrogen-vacancy sensing work discussed in Section 6 was conducted in living cells and organelles without reported cytotoxicity at the concentrations used [Mzyk et al., 2026; Xu et al., 2024]. Piezoelectric nanocrystals are more variable: barium titanate and zinc oxide can leach metal ions under physiological conditions, and the degradation products of lead-containing piezoelectrics are unacceptable. Poly-L-lactic acid, by contrast, hydrolyses into lactic acid, a metabolite, and is already established in resorbable orthopaedic devices [Liu et al., 2022].

11.2 Degradation Kinetics and the Fate of the Inorganic Phase

A hydrogel implant must degrade at a rate matched to the deposition of new matrix. If it degrades too quickly, mechanical support is lost before the neo-tissue can bear load; if too slowly, it shields the regenerating tissue from mechanical stimulus and may provoke a chronic foreign-body response. Natural polymer networks degrade through enzymatic and hydrolytic pathways with rates that can be tuned through crosslink density and through the inclusion of matrix metalloproteinase-cleavable sequences.

The degradation of the inorganic phase is a distinct and less tractable problem. A covalently tethered nanoparticle cannot be cleared independently of the network, so its residence time equals the implant's residence time; if the network is designed to persist for years, so does the particle. Conversely, if the particle is released, it must be small enough for renal clearance or degradable into excretable fragments. The literature on injectable hydrogels for cartilage and bone emphasises the necessity of a degradation profile compatible with tissue ingrowth [Liu et al., 2017; Olov et al., 2022], but the specific question of the long-term fate of a tethered quantum-scale filler has not been systematically studied for cartilage, and this is a genuine gap rather than a neglected detail.

11.3 The Special Constraints of Cartilage

Cartilage presents three constraints that make nanotoxicology assessment more demanding than in well-vascularised tissue. First, avascularity: a particle released into the matrix has no direct route to the systemic circulation and may remain locally for years, concentrating any effect within the tissue. Second, low turnover: chondrocytes divide rarely and the matrix is long-lived, so cumulative exposure to a slowly releasing particle is prolonged. Third, lymphatic drainage is limited and indirect through the synovium, which delays clearance of any material that reaches the joint space. These considerations argue for a conservative approach in which the quantum-scale filler is either intrinsically benign, such as carbon or diamond, or covalently immobilised, and in which the cumulative dose delivered to the joint is explicitly budgeted rather than inferred from in vitro cytotoxicity thresholds.

11.4 Immunological Response to Nanoscale Fillers

Beyond cytotoxicity, a nanoscale filler may elicit an immunological response through complement activation, opsonisation, or inflammasome engagement, and the response depends sensitively on surface charge, protein corona composition, and shape. Particles that aggregate within the hydrogel create micron-scale clusters with different biological recognition than the dispersed primary particles, and dispersion state must therefore be reported as a formulation variable rather than assumed. The immunomodulatory framing of nanocomposite hydrogels for degenerative joint disease acknowledges this explicitly, treating the host response as a design target rather than a failure mode [Chen et al., 2024].

12. Preclinical Evidence and Animal Models

12.1 In Vitro Evidence

The in vitro case for quantum-loaded cartilage hydrogels rests on three converging bodies of evidence. First, carbon dot-containing injectable scaffolds support chondrocyte viability, promote chondrogenic gene expression, and improve mechanical properties relative to the corresponding unfilled gels; the alginate–gelatin–nitrogen-doped carbon dot system was optimised on precisely these combined criteria [Ghanbari et al., 2021]. Second, piezoelectric scaffolds deliver electrical cues that enhance chondrogenic differentiation, and the review literature documents the breadth of cell types and stimulation parameters explored [Kapat et al., 2020; Jacob et al., 2018; Park et al., 2025]. Third, quantum sensing has been applied successfully to living cells, establishing that nitrogen-vacancy sensors function within the ionic, protein-rich, and mechanically active environment of a cell culture [Xu et al., 2024; Kołodziej et al., 2024; Mzyk et al., 2026].

Two caveats apply. Most in vitro studies of quantum-loaded hydrogels report short-term outcomes over days to a few weeks, whereas chondrogenesis requires months; and nearly all use static rather than dynamically loaded culture, which omits the mechanical environment that defines the application.

12.2 Small Animal Models

The rabbit is the workhorse of cartilage repair research because it offers a knee joint large enough for reproducible critical-size defects and a healing response that differs enough from the human one to be informative but not pathological. The decisive in vivo demonstration for piezoelectric stimulation was performed in rabbits, where an exercise-induced piezoelectric poly-L-lactic acid nanofibre scaffold produced both cartilage regeneration and subchondral bone regeneration, with the animal's own locomotion supplying the stimulus [Liu et al., 2022]. Injectable hydrogel composites carrying mesenchymal stem cells and growth factors have similarly been evaluated in rabbit models, establishing both feasibility and the practical challenges of cell retention after injection [Park et al., 2007]. Regeneration of both cartilage and subchondral bone in a single procedure is the specific challenge addressed in the wider osteochondral literature, and the reviews of that field document the difficulty of achieving stable integration at the calcified interface [Barui et al., 2023; Santos-Beato et al., 2022].

12.3 Large Animal Models and the Translation Gap

The distance between a rabbit study and a human trial is substantial. Large animal models, principally the sheep, goat, pig, and horse, provide joint scale, load magnitude, cartilage thickness, and healing biology closer to the human case. Reviews of the translational pathway for three-dimensionally bioprinted cartilage identify the choice of model as a determinant of predictive value, and note that many materials that perform acceptably in small animals fail in large animals or in humans, chiefly because the mechanical demand and the immune environment differ [Murphy et al., 2020; Datta et al., 2017]. Osteochondral regenerative engineering has been reviewed with explicit attention to the gap between laboratory success and clinical adoption, including the need for evaluation domains that anticipate regulatory requirements [Barui et al., 2023].

12.4 Outcome Measures and the Case for Longitudinal Monitoring

The outcome measures used in preclinical cartilage studies are predominantly histological, relying on scoring systems applied at a single terminal time point. Such measures cannot distinguish a construct that gradually remodelled into hyaline cartilage from one that rapidly degraded and was replaced by fibrocartilage, because both endpoints may look similar at the moment of assessment. Quantitative biochemical measures such as glycosaminoglycan content and collagen typing improve the picture but remain destructive or terminal. This methodological limitation is the strongest practical argument for quantum-enabled longitudinal monitoring, because a sensor-laden implant can be interrogated repeatedly in the living animal, converting a sequence of terminal snapshots into a continuous trajectory. Demonstrating that an optically or magnetically readable signature correlates with histological outcome would legitimise the additional complexity of quantum-loaded design on evidential rather than aesthetic grounds.

12.5 Composite Scaffolds and the Zonal Question

The literature on hybrid and composite scaffolds based on extracellular matrix components documents repeated attempts to reproduce the zonal organisation of native cartilage, and the recurring finding is that homogeneous constructs yield homogeneous, mechanically inferior tissue [Setayeshmehr et al., 2019]. Gradient hydrogels engineered as three-dimensional cell niches have been shown to support zonal organisation at tissue scale [Zhu et al., 2018]. A quantum-engineered construct can contribute to this problem in a distinctive way: because the filler can be distributed non-uniformly, its concentration gradient can encode a mechanical and functional gradient, and because the filler reports on its local state, the evolution of the gradient can be tracked. Whether such a construct outperforms a simpler gradient gel has not been tested.

13. Translation, Manufacture, and Regulation

13.1 The Combination-Product Problem

A quantum-engineered hydrogel cartilage implant is a combination product. The device component is the load-bearing hydrogel matrix; the biological or pharmaceutical component is the growth factor, gene vector, or living cell; and the nanoscale quantum element may be classified as a device constituent, a nanomaterial requiring separate toxicological assessment, or, if it exerts its primary action by chemical or metabolic means, a drug. Because the intended primary mode of action determines the regulatory pathway, and because the primary mode of action of a filled hydrogel is mechanical, the device pathway is the more probable route in most jurisdictions, but the nanomaterial component triggers additional requirements for characterisation, stability, and leaching.

Reviews of the translational pathway for additive manufacturing in medicine identify the challenges that confront such products: the absence of standardised characterisation methods for printed constructs, the difficulty of demonstrating batch-to-batch equivalence for a process whose output depends on many coupled parameters, and the need for quality systems adapted to personalised manufacture [Murphy et al., 2020]. The regulatory considerations specific to three-dimensionally bioprinted orthopaedic grafts for bone, cartilage, and osteochondral repair have been synthesised in a narrative review that sets out design specifications, evaluation domains, and the regulatory framework applicable to each [Chen et al., 2026]. Practical accounts of the osteochondral pipeline emphasise that patient-specific geometry, which is the principal selling point of additive manufacture, is also a principal regulatory complication, because it complicates the definition of a batch [Barui et al., 2023; Santos-Beato et al., 2022].

13.2 Characterisation and Quality Control of Quantum Components

Regulatory acceptance of a nanomaterial requires a characterisation package that has no precedent in conventional biomaterials: particle size distribution by multiple orthogonal methods, shape and agglomeration state, surface chemistry and ligand density, purity with respect to residual synthesis reagents, and stability of all of these properties through the manufacturing

process and during storage. For quantum dots and carbon dots, additional properties must be specified and controlled: emission wavelength and quantum yield, photostability under the illumination conditions of intended use, and — for semiconductor systems — leachate analysis for regulated heavy metals. For nitrogen-vacancy nanodiamonds, the relevant parameters include nitrogen-vacancy concentration per particle, charge state stability, and the coherence properties that determine sensing performance, none of which are currently part of any biomaterials standard.

The identity and function of the nanoscale component must also be demonstrated to be stable over the implant's shelf life. A hydrogel that has been sterilised by gamma irradiation or electron beam may experience radical-mediated damage to both the polymer network and the nanoparticle surface, and the effect on quantum yield or on spin coherence must be measured rather than assumed. This is a concrete, near-term experimental requirement that follows directly from the design framework proposed in this review.

13.3 Sterilisation, Shelf Life, and Distribution

Terminal sterilisation is a persistent obstacle for hydrogel devices. Autoclaving degrades most biopolymer networks; gamma irradiation generates radicals that can quench fluorophores and alter crosslink density; ethylene oxide leaves residues that are unacceptable in a cell-laden product; aseptic processing is compatible with cells but imposes stringent manufacturing controls. For quantum-loaded hydrogels the constraint is sharper than usual, because the functional element may be more sensitive to radiation than the matrix. A carbon dot whose emission is required for tracking cannot be allowed to lose half its quantum yield during sterilisation, and a nitrogen-vacancy centre whose charge state is converted by radiation to the neutral form loses its sensing function entirely. Sterilisation compatibility must therefore be treated as a materials design variable, with the same status as mechanical performance.

13.4 Cost, Scale, and Health Economics

The economic case for a tissue-engineered cartilage implant is not straightforward. Established procedures such as microfracture are inexpensive and moderately effective in the short term; the value proposition of a synthetic cartilage must therefore rest on durability and on the avoidance of revision surgery and early arthroplasty. Quantum engineering adds cost at three points: the synthesis and purification of the nanoscale filler, the additional characterisation and quality control, and the loss of manufacturing flexibility that accompanies any regulated nanomaterial. For carbon dots and nanodiamonds these costs are modest at laboratory scale and need not be prohibitive at production scale, since both are derived from inexpensive precursors and are manufactured by scalable routes. For semiconductor quantum dots the economics are less favourable and the regulatory burden greater, reinforcing the earlier conclusion that the metal-free emitter is the rational engineering choice.

13.5 An Evidence Hierarchy for Quantum-Engineered Cartilage Implants

Translating a claim about a quantum-engineered hydrogel into a clinical proposition requires an explicit evidence hierarchy. At the first level, the quantum function must be demonstrated in the hydrated, ionic, protein-containing environment of the hydrogel, with quantitative performance metrics. At the second level, the function must survive the fabrication process, including printing, crosslinking, and sterilisation. At the third level, the function must correlate with a biologically or mechanically meaningful outcome, such as glycosaminoglycan content, compressive modulus after fatigue, or defect filling in vivo. At the fourth level, the additional function must produce a measurable improvement over a control implant without that function, in an adequately powered animal study. At the fifth level, the improvement must persist in a large animal model at human-relevant scale and loading. No quantum-engineered cartilage hydrogel has been reported at the fifth level, and relatively few have been reported at the fourth. Stating this plainly is not a criticism of the field but a specification of the work that remains.

14. Open Problems, Controversies, and Future Directions

14.1 Nine Unresolved Problems

The following problems are, in the assessment of this review, the principal obstacles to the development of genuinely quantum-engineered cartilage.

The first is the interpretative gap between nanoscale measurement and macroscopic function, discussed in Section 6.5. Quantum sensors report local quantities; clinical and regulatory decisions depend on macroscopic ones. A multiscale constitutive framework that propagates nanoscale observations to tissue-scale properties is required, and its construction is a modelling problem that has not been attempted for this material class.

The second is optical access in scattering tissue. Neither fluorescence nor optically detected magnetic resonance penetrates more than a few millimetres of hydrated biological tissue. Solutions may come from fibre-based delivery, from the use of near-infrared emitters whose absorption and scattering in tissue are lower, or from entirely non-optical readout modalities such as magnetic particle imaging, but each entails trade-offs that have not been evaluated in a cartilage context.

The third is the disentanglement of mechanisms. A piezoelectric nanoparticle in a hydrogel contributes mechanical reinforcement, electrical stimulation, and possibly altered swelling behaviour. Without coupled constitutive models and without carefully designed controls, published improvements cannot be attributed to a specific mechanism. This is the most immediate and most tractable of the problems, because it requires experimental discipline rather than new physics.

The fourth is long-term biological fate. The literature documents short-term biocompatibility but not multi-year residence, degradation, or chronic immune response for tethered nanoscale fillers in an avascular tissue [Liu et al., 2017; Olov et al., 2022].

The fifth is fatigue. As argued in Section 9.4, the field lacks standardised cyclic loading protocols, and static properties dominate the reported literature on tough hydrogels [Sabzi et al., 2017; Deng et al., 2018].

The sixth is the stability of quantum function within the implant. Quenching by radicals generated during polymerisation, charge-state conversion of defect centres by sterilisation, and screening by a dense polymer mesh all degrade function, and none is routinely reported.

The seventh is the absence of immunological realism. Most in vitro work uses cell culture in the absence of the inflammatory milieu characteristic of an injured joint, and the advantage of antioxidant fillers may be substantially larger — or substantially smaller — in vivo than in vitro.

The eighth is the tension between injectability and architectural control. Injectable systems are surgically attractive but offer limited control over final geometry and zonal organisation, whereas printed systems offer architectural control but require open implantation and a longer manufacturing cycle [Chen et al., 2016; Liu et al., 2017; Chakraborty et al., 2023].

The ninth is conceptual: the possibility that the quantum functionality, however elegant, does not improve the clinical outcome enough to justify its cost, complexity, and regulatory burden. The counter-argument is the one developed throughout this review — that the informational capability of a quantum-loaded implant addresses the field's most acute methodological deficiency, namely the inability to observe remodelling non-destructively.

14.2 Emerging Opportunities

Several directions appear especially promising.

Sensing–actuation closed loops. A construct that measures its local strain state and responds by altering its own mechanical or biochemical behaviour would be a genuine advance. Self-healing networks already provide the actuation half through dynamic bond reformation [Sabzi et al., 2017; Deng et al., 2018], and quantum sensors provide the measurement half [Xu et al., 2024]. What is missing is the coupling: a feedback element that converts a sensor output into an actuation input.

Mechanobiology-informed design of zonal constructs. Because chondrocyte phenotype is sensitive to matrix viscoelasticity as well as to stiffness [Lan et al., 2024; Shou et al., 2023], and because the native tissue is zoned, constructs in which the filler concentration encodes a mechanical gradient that evolves as the filler degrades are a natural extension of existing gradient hydrogel work [Zhu et al., 2018].

Multi-material four-dimensional printing. The stimuli-responsive printing literature is rapidly expanding, with alginate systems reviewed specifically for tissue regeneration and dual-responsive hydrogels identified as a frontier [Liu & Ding, 2025; Bhandari et al., 2026; Alanazi et al., 2025; Wang et al., 2022]. Quantum-scale fillers offer orthogonal, externally addressable stimulus channels — photothermal, magnetothermal, piezoelectric — that are well matched to this requirement.

Self-powered stimulation coupled to rehabilitation. The exercise-induced piezoelectric result establishes that patient activity can serve as the therapeutic input [Liu et al., 2022]. A quantum-enhanced version would additionally record the loading history, providing an objective measure of rehabilitation compliance and a mechanistic link between activity and outcome.

Standardisation of characterisation. The field would benefit substantially from consensus protocols for reporting quantum-loaded biomaterials: specified measurement conditions, mandatory reporting of filler dispersion state and stability, and inclusion of a filler-free control. The evidence hierarchy proposed in Section 13.5 could serve as the basis for such a standard.

14.3 A Twenty-Four-Month Experimental Agenda

Three concrete experiments would materially advance the field, ordered by feasibility.

The first is a rigorous mechanistic decomposition of a piezoelectric cartilage hydrogel. Construct a series of four materials — unfilled hydrogel, hydrogel with piezoelectric nanoparticles short-circuited by an external conductor, hydrogel with non-piezoelectric nanoparticles of matched size and modulus, and hydrogel with active piezoelectric nanoparticles — and characterise them mechanically, electrically, and biologically under the same conditions. Any difference between the third and fourth materials is attributable to the electrical mechanism; any difference between the first and third is attributable to mechanical reinforcement. This experiment requires no new instrumentation and would resolve the most widely cited ambiguity in the field.

The second is a demonstration of fatigue-aware sensing. Load a nanodiamond-containing hydrogel cyclically and record the optical and magnetic signatures alongside mechanical stiffness until failure. If a signature change reliably precedes mechanical failure, the result establishes the value proposition of quantum sensing in load-bearing implants on functional grounds.

The third is a large animal study with longitudinal readout. Implant a gradient construct containing a covalently tethered near-infrared emitter in a sheep or goat osteochondral defect, and follow the optical signal non-destructively over twelve months alongside mechanical and histological endpoints. The correlation between the non-destructive signal and the terminal outcome would, if demonstrated, validate the entire monitoring rationale, and would do so with a filler that is biologically conservative.

15. Conclusions

Articular cartilage remains a demanding target for regenerative engineering because its function arises from a hierarchical composite architecture that must be reproduced simultaneously in its mechanical, biochemical, and zonal dimensions. Hydrogels are the natural starting point, and the past two decades have produced tough, self-healing, printable, and injectable networks that approximate the tissue with increasing fidelity.

This review has argued that the next increment in capability will come not from further incremental refinement of the polymer network alone, but from the deliberate incorporation of quantum-scale functional elements that give the material the capacity to sense, to stimulate, and to report. Carbon and semiconductor quantum dots provide imaging contrast, antioxidant activity, and theranostic multifunctionality, with the metal-free carbon family now clearly favoured on

biocompatibility grounds. Nitrogen-vacancy centres in nanodiamond provide the only available means of measuring mechanical and thermal quantities at the nanoscale within living systems, and their application to cellular force microscopy is already established. Piezoelectric and quantum-confined nanocrystals convert physiological loading into an electrical stimulus, a capability now demonstrated to promote cartilage and subchondral bone regeneration in vivo using no external power source.

The synthesis of these capabilities into a single implant remains unrealised. Six requirements must be met for it to become credible: quantum function must be demonstrated within the hydrated implant and after sterilisation; mechanisms must be disentangled experimentally rather than inferred; durability must be assessed through standardised fatigue testing rather than through static properties alone; the long-term fate of the inorganic phase must be established; a multiscale framework must connect nanoscale measurement to macroscopic function; and the resulting capability must improve a biologically meaningful outcome in a large animal model. None of these requirements is beyond current technique, and several are within reach of a well-designed two-year study.

The broader claim of this review is conceptual. Quantum engineering in cartilage regeneration should not be understood as the decoration of an existing scaffold with exotic nanoparticles, nor as an appeal to quantum biology. Its value is instrumental and architectural: it converts a passive implant into an instrumented one, and it thereby supplies the very thing the field most lacks, which is the ability to observe a healing tissue as it heals rather than only after it has finished. If a synthetic cartilage could be made to know and report its own state, the design of cartilage implants would cease to be a problem of static imitation and become a problem of controlled biological adaptation — which is, in the end, what the native tissue already solves.

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Philosophical Sciences

THE PATH TO HAPPINESS IN AL-FARABI AND AL-GHAZALI THROUGH VIRTUE AND SPIRITUAL PERFECTION: A COMPARATIVE ANALYSIS

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Abstract. This article compares Abu Nasr al-Farabi's and Abu Hamid al-Ghazali's accounts of the path toward human happiness. It uses "path" as an interpretive category for examining processes of human perfection, without treating al-Farabi's philosophical account as identical to the Sufi tariqa. Al-Farabi's Attainment of Happiness and his account of the virtuous city are examined in relation to intellectual and practical virtue, education, and social life. Al-Ghazali's Persian Kimiya-yi saʿadat is considered through its themes of self-knowledge, knowledge of God, moral discipline, and the afterlife. The study applies hermeneutic, comparative-historical, and conceptual analysis. It argues that both thinkers understand happiness as a telos requiring knowledge and cultivated action, while assigning different weight to civic-political formation and inward spiritual discipline. The comparison offers a historically cautious framework for relating the dissertation's study of "the path" in Arabic-Muslim philosophy and Sufism to al-Farabi's thought.
Keywords: al-Farabi, al-Ghazali, happiness, saʿada, virtue, spiritual perfection, tariqa, knowledge, virtuous city.

INTRODUCTION

The human pursuit of happiness in Arab-Islamic philosophy extends beyond mere subjective states of well-being. It encompasses foundational questions regarding human nature, cognitive capabilities, moral character, social order, and the ultimate purpose of existence. Abu Nasr al-Farabi places the concept of happiness (saʿada) at the center of his ethical and political philosophy, conceptualizing it as the supreme good of human life. Conversely, Abu Hamid al-Ghazali explicates happiness through self-knowledge, the cognition of God, the cultivation of the heart and moral character, and an orientation toward the afterlife. Analyzing these two thinkers side by side allows for a comprehensive comparative examination of the intellectual, ethical, social, and spiritual dimensions of human perfection.

This comparative inquiry is equally significant for a dissertation examining the phenomenon of "the path." However, the term "path" is not employed here as an identical historical term shared by both thinkers, nor as an equivalent to the Sufi tariqa in al-Farabi's philosophy. Rather, it functions as an analytical category describing the oriented movement of a human being toward a supreme end through knowledge, education, and practice. While tariqa represents an established spiritual-practical concept in Islamic Mysticism, directly labeling al-Farabi's framework of attaining happiness as a tariqa would obscure historical and conceptual distinctions. Therefore, this study maintains the distinct conceptual vocabulary of each doctrine while analyzing their common thematic structure.

The objective of this study is to compare al-Farabi's and al-Ghazali's perspectives on the conditions for achieving happiness, clarifying the roles of knowledge, virtue, practical discipline, and the social environment in this process. The primary source material comprises al-Farabi's treatises The Attainment of Happiness (Tahsīl al-saʿāda) and Principles of the Views of the Citizens of the Virtuous City, alongside al-Ghazali's Kimiya-yi saʿadat (The Alchemy of Happiness). The interpretation of al-Farabi's heritage incorporates current encyclopedic and contemporary studies, while the textual structure and historical context of al-Ghazali's work draw upon established scholarly literature (Butterworth, 2019; Khismatulin, 2022).

RESEARCH METHODS

This study employs hermeneutic analysis to interpret primary concepts within their original historical and textual contexts. The comparative-historical method allows for an examination of shared themes without detaching either thinker from their specific intellectual tasks. Conceptual analysis systematizes the relationships between the categories of "happiness," "virtue," "knowledge," "discipline," and "path." The comparison is structured across five analytical dimensions: ultimate end, instruments of perfection, relationship between knowledge and action, role of the social environment, and the nature of practical discipline. These dimensions serve to clarify structural convergences and conceptual divergences rather than forcibly equating the two philosophical systems.

THE ATTAINMENT OF HAPPINESS IN AL-FARABI'S PHILOSOPHY

For al-Farabi, happiness (saʿada) is not equivalent to fleeting emotional satisfaction or temporary success; it is the ultimate good that is sought for its own sake and never as a means to another end. In The Attainment of Happiness, human actions oriented toward happiness are not restricted to theoretical cognition alone: the pursuit of perfection requires the development of cognitive faculties alongside choice, deliberate will, and virtuous actions (al-Farabi, 2001, pp. 13–50). From this perspective, attaining happiness is not a static condition, but a dynamic process of shaping human capacities toward a specific telos.

Intellect occupies a central role in this transformative journey. Through intellect, human beings comprehend the causes and order of reality, advancing toward true knowledge. However, theoretical knowledge does not exist in isolation from practice: practical reasoning, volition, and moral character must translate knowledge into harmonious action. Scholars of al-Farabi's philosophy emphasize his integration of education and moral discipline as a unified process of intellectual and ethical maturation (Imanbayeva et al., 2023, pp. 13–23; Yedilbaeva & Amirkulova, 2019, pp. 44–54).

Al-Farabi conceptualizes the attainment of virtue across two complementary levels: first, the acquisition of theoretical truths and the refinement of intellect; second, the cultivation of virtuous deeds and moral habits. Consequently, human happiness depends not merely on possessing knowledge, but on converting that knowledge into a coherent way of life. The analytical category of "the path" captures this systematic transition from cognition to action, and from repeated action to stable moral character.

The social dimension of happiness is fully articulated in al-Farabi's doctrine of the Virtuous City (al-Madina al-Fadila). An individual cannot achieve full perfection or satisfy all human needs in isolation; it is only within a cooperative society structured around mutual assistance and division of labor that human beings collectively strive toward the supreme good. The role of the virtuous city is to guide, educate, and habituate citizens to virtuous conduct. Thus, governance and civic education are not merely external conditions, but essential social frameworks that enable the realization of human potential (al-Farabi, 1985/1998; Butterworth, 2019; Suleymenov & Kassymbayev, 2020, pp. 20–26).

SPIRITUAL PERFECTION IN AL-GHAZALI'S KIMIYA-YI SAʿADAT

Al-Ghazali's Kimiya-yi saʿadat (The Alchemy of Happiness) is a comprehensive Persian work detailing the systematic path to happiness and religious-ethical life. As noted in scholarly evaluations, the text was composed around 1102–1106 during al-Ghazali's Khurasan period and is structured around four foundational pillars: self-knowledge, knowledge of God, knowledge of the world, and knowledge of the afterlife (Khismatulin, 2022). This structural arrangement reflects a spiritual-cognitive trajectory leading the seeker from external observation to internal self-awareness, and ultimately to the comprehension of Divine reality.

The section on self-knowledge demonstrates that a human being cannot be defined solely by corporeal attributes. Understanding the inner self requires recognizing the appetitive and irascible powers of the soul and subjecting them to moral discipline. Self-knowledge serves as the indispensable gateway to the knowledge of God, highlighting al-Ghazali's conviction that true knowledge must actively transform human character and spiritual state (al-Ghazali, 2008).

Spiritual discipline in Kimiya-yi saʿadat does not advocate total ascetic rejection of the physical world. While al-Ghazali warns against the dangers of worldly distractions that obscure the afterlife, he highlights the necessary role of knowledge and righteous action. Worldly engagements acquire value when subordinated to the ultimate spiritual goal. Thus, spiritual perfection is framed not as flight from daily existence, but as the reorientation of intentions and actions (al-Ghazali, 2008; Zahari, 2026, pp. 79–102).

Al-Ghazali's framework links knowledge, action, character, and the internal state of the heart into an interdependent whole. Knowledge without corresponding action remains incomplete, just as external ritual devoid of inner intention fails to yield spiritual fruit. While al-Ghazali's methodology aligns closely with the Sufi path (tariqa) through its emphasis on purifying the ego (tazkiyat al-nafs) and intimate cognition of God, Kimiya-yi saʿadat serves as a broader ethical-spiritual manual rather than a restrictive manual for a specific Sufi order.

CONVERGENCES AND DIVERGENCES BETWEEN THE TWO DOCTRINES

A comparative analysis of both thinkers reveals primary convergences in their understanding of the ultimate end and the integration of knowledge with virtue. For al-Farabi, happiness combines intellectual and moral perfection with virtuous civic life. For al-Ghazali, ultimate happiness is anchored in the cognition of God and salvation in the afterlife. In both doctrines, happiness is not mere subjective pleasure, but a normative standard evaluating human existence. However, while al-Farabi prioritizes political-philosophical order and intellectual cultivation, al-Ghazali places primary emphasis on the inward state of the heart, intention, and mystical experience.

Both thinkers maintain that knowledge and virtue are inseparable. Al-Farabi treats theoretical knowledge and practical virtue as mutually reinforcing, while al-Ghazali asserts that genuine knowledge inherently impels the individual toward righteous action and spiritual purity. The analytical schema of "the path" highlights this common developmental logic: definition of the goal → acquisition of knowledge → habituation to virtuous action → perfection of the human person. In al-Farabi, this trajectory extends outward into civic education and political organization; in al-Ghazali, it converges inward through self-knowledge and spiritual purification toward eternal beatitude.

RELEVANCE TO CONTEMPORARY HUMANITARIAN DISCOURSE

Examining al-Farabi and al-Ghazali offers valuable insights for contemporary ethical and civic discourse. Al-Farabi's vision of the virtuous city emphasizes the alignment of individual well-being with the common good, underscoring the role of civic education in cultivating responsible citizenship. Al-Ghazali enriches this perspective by highlighting the indispensable role of internal moral discipline and self-examination. Together, their insights provide a holistic framework that grounds civic responsibility not merely in external legal enforcement, but in deep moral and spiritual integrity.

CONCLUSION

Al-Farabi and al-Ghazali conceptualize happiness as a teleological process of human perfection requiring knowledge, virtue, and deliberate practice. Al-Farabi establishes this process on the development of intellect, practical virtue, education, and the structure of the virtuous city. Al-Ghazali articulates spiritual perfection through self-knowledge, divine cognition, moral discipline, and an afterlife orientation. Within academic inquiry, the category of "the path" serves as an effective interpretive bridge for comparing their frameworks, preserving historical nuances while highlighting the multifaceted ontological, epistemological, ethical, and social dimensions of human perfection in Arab-Islamic thought.

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Sociological Sciences

ОРГАНИЗАЦИОННАТА КУЛТУРА В ОБРАЗОВАТЕЛНИТЕ ИНСТИТУЦИИ: НРАВСТВЕНИ НОРМИ И ПРОФЕСИОНАЛНИ ВЗАИМОДЕЙСТВИЯ

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Резюме: Докладът разглежда организационната култура в образователните институции като система от споделени ценности, нравствени норми и модели на професионално взаимодействие. Анализира се значението на справедливостта, почтеността, взаимното уважение и отговорността за отношенията между ръководството, педагогическите специалисти, обучаемите и техните семейства. Акцент се поставя върху съответствието между формално утвърдените етични принципи и ежедневните институционални практики. Обсъжда се ролята на лидерския пример, диалога и прозрачността при вземането на решения за изграждането на доверие и разрешаването на конфликти. Организационната култура се представя като съществен фактор за професионалното сътрудничество, чувството за принадлежност и създаването на подкрепяща образователна среда. Очертават се възможности за нейното развитие чрез осмисляне на общите ценностни ориентири и насърчаване на отговорното участие в институционалния живот.

Ключови думи: организационна култура, образователни институции, нравствени норми, професионална етика, професионални взаимодействия.

ORGANISATIONAL CULTURE IN EDUCATIONAL INSTITUTIONS: MORAL NORMS AND PROFESSIONAL INTERACTIONS

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Abstract: The paper examines organisational culture in educational institutions as a system of shared values, moral norms, and patterns of professional interaction. It analyses the importance of fairness, integrity, mutual respect, and responsibility in relationships among institutional leaders, educators, learners, and their families. Particular emphasis is placed on the alignment between formally established ethical principles and everyday institutional practices. The role of leading by example, dialogue, and transparency in decision-making is discussed in relation to building trust and resolving conflicts. Organisational culture is presented as a significant factor in professional collaboration, a sense of belonging, and the creation of a supportive educational environment. Opportunities for its development are outlined through reflection on shared values and the encouragement of responsible participation in institutional life.

Keywords: organisational culture, educational institutions, moral norms, professional ethics, professional interactions.

Етиката като философско осмисляне на морала предоставя основа за анализ на принципите и нормите, които направляват човешкото поведение и отношенията в обществото. В контекста на образователните институции тя позволява да се изследват нравствените основания на професионалната дейност, критериите за справедливо взаимодействие и отговорността към развитието на обучаемите. Моралните ценности служат като ориентири за оценяване на собствените действия и поведението на другите и участват във формирането на общи представи за допустимо, желателно и отговорно поведение.

Споделените ценности имат съществено значение за организационната култура, тъй като придават смисъл на общите цели и очертават приемливите средства за тяхното постигане. В образователната институция те намират израз в отношенията между ръководството, педагогическите специалисти, обучаемите и семействата, както и в установените практики за вземане на решения, оценяване и разрешаване на конфликти. Организационната култура се изгражда чрез взаимодействието между формално утвърдените принципи и ежедневното поведение, посредством което тези принципи се потвърждават, преосмислят или обезсилват.

Съществен етичен проблем възниква при разминаване между заявените нравствени ценности и практиките, които получават признание като успешни. Когато постигането на резултати се оценява без внимание към използваните средства и последствията за участниците, могат да бъдат легитимирани действия, противоречащи на справедливостта, почтеността и взаимното уважение. В образователната среда подобно несъответствие може да се прояви чрез непрозрачни решения, неравнопоставено отношение или формално прилагане на правила. Това отслабва доверието и поставя под съмнение убедителността на институционалните послания. От тази перспектива понятията „полезно“ и „успешно“ следва да бъдат разграничавани от нравствените категории „добро“ и „справедливо“. Постигането на конкретна цел само по себе си не е достатъчно основание за положителна етична оценка. Необходимо е да бъдат разгледани мотивите, средствата и отражението на действията върху човешкото достойнство и отношенията в общността. За образователните институции това означава ефективността да се осмисля във връзка с качеството на педагогическото взаимодействие, равнопоставеността и отговорността към обучаемите.

Нравствените ценности и нормите на поведение се включват и в съдържанието на професионалния дълг. Принадлежността към педагогическата общност предполага ангажимент към компетентното изпълнение на професионалните задачи, справедливото оценяване, уважението към личността и защитата на доверието в образователния процес. Този ангажимент се осъществява както в непосредствената работа с обучаемите, така и в отношенията с колегите и ръководството. Колегиалността, взаимната подкрепа и готовността за аргументирано обсъждане на различията са важни проявления на професионалната етика.

Следователно нравствените норми и професионалните взаимодействия представляват взаимосвързани измерения на организационната култура в образователните институции. Тяхното съгласуване изисква ясни етични ориентири, последователен лидерски пример и възможности за обсъждане на възникващи нравствени противоречия. По този начин етиката придобива практическо значение като основа за решенията и отношенията, чрез които институцията изпълнява своята образователна и обществена мисия.

Изборът на учителската професия може да бъде обусловен от разнообразни личностни, познавателни и социални мотиви. Сред тях се открояват интересът към знанието и неговото споделяне, стремежът към общественополезна дейност и осъзнаването на

отговорността за развитието на бъдещите поколения. Значимо влияние може да оказва и личният пример на преподаватели, чиито професионални качества и нравствено поведение са оставили траен отпечатък върху образователния опит на младия човек.

Независимо от конкретните мотиви, ориентацията към учителската професия има съществено нравствено измерение. Нейното упражняване предполага спазване на етични принципи и активно участие в утвърждаването и предаването на ценности и модели на поведение. Чрез отношението си към обучаемите, начина на оценяване и взаимодействието с колегите учителят допринася за формирането на представи за справедливост, уважение и отговорност. В този смисъл професионалният избор е свързан с поемането на ангажимент към нравственото развитие на личността и към възпроизвеждането на моралните основания на обществения живот (Стоилова, 2012). Развитието на цифровите технологии разширява пространствата за учене отвъд границите на училището. Достъпът до научна информация, културно наследство, дигитализирани текстове, образователни платформи и инструменти, основани на изкуствен интелект, създава разнообразни възможности за самостоятелно придобиване на знания. Ученето все по-често се осъществява чрез съчетаване на институционални, неформални и самостоятелни практики, които позволяват гъвкавост по отношение на времето, мястото и индивидуалния темп. Тези възможности поставят пред образователните институции задачата да преосмислят своите подходи към организацията на обучението, педагогическата подкрепа и оценяването на резултатите.

В подобни условия значението на училището се свързва със способността му да подпомага осмислянето на информацията, критичната преценка и отговорното използване на знанията. Разширеният достъп до съдържание изисква критерии за неговата достоверност, значимост и етична употреба. Организационната култура на образователната институция придобива особена роля, тъй като определя доколко новите възможности се включват в среда на сътрудничество, взаимно уважение и споделена отговорност.

Съвременните форми на индивидуализирано и диалогично учене позволяват да бъдат преосмислени и образователни практики, предхождащи масовото училище. Сред тях се открояват непосредственото общуване между наставник и обучаем, обсъждането в малки групи и следването на индивидуални познавателни интереси. Тази перспектива насочва към съчетаване на исторически утвърдени педагогически принципи с възможностите на съвременната технологична среда. В този контекст систематизираните от Ян Амос Коменски идеи за организация на обучението могат да бъдат разглеждани като важна основа на училищния модел, чиито принципи подлежат на осмисляне спрямо променящите се образователни потребности (Коменски, 2018).

Историко-културна перспектива към преосмислянето на образователните практики предоставя ренесансовата рецепция на античното наследство. Обръщането към класическите образци може да бъде разглеждано като творческо усвояване на идеи, чрез които се обновяват представите за човека, познанието и обществените отношения. В тази перспектива историческото наследство придобива значение като ресурс за критична оценка на съвременните педагогически подходи и за осмисляне на връзката между индивидуалното развитие и участието в общността.

Фреската „Атинската школа“ на Рафаело предлага възможност за интерпретация на интелектуалната общност като пространство на диалог между различни философски позиции. Композицията представя разнообразни форми на познавателна дейност — размишление, обсъждане, аргументация и обмен на идеи, обединени от стремежа към знание. Централното разположение на Платон и Аристотел може да бъде осмислено като художествен акцент върху взаимодействието между различни подходи към познанието.

От педагогическа гледна точка творбата позволява да се изведе връзката между самостоятелното интелектуално търсене и съвместното изграждане на разбиране.

Различието на позициите се вписва в общо пространство за общуване, в което индивидуалният принос придобива значение чрез отношенията с другите. Приложена към образователните институции, тази интерпретация насочва към организационна култура, основана на аргументиран диалог, уважение към многообразието на идеи и споделена отговорност за познавателния процес.

В контекста на организационната култура на образователните институции „Атинската школа“ може да бъде интерпретирана като метафора на общност, обединена от споделени познавателни стремежи и уважение към различните позиции. Подобен прочит насочва към разбирането, че институционалната съгласуваност се изгражда чрез общи ценности, аргументиран диалог и признаване на индивидуалния принос. Историко-културният образ позволява съвременната образователна институция да бъде осмислена като пространство за професионално сътрудничество, нравствена отговорност и съвместно създаване на знание.

От тази перспектива възниква въпросът доколко понятието „корпоративна култура“ е приложимо към училището. Неговото използване изисква разграничаване между правния статут на институцията и аналитичните понятия, чрез които се изследват нейните вътрешни отношения. Наличието на споделени ценности, устойчиви норми и общи цели позволява училището да бъде разглеждано като организирана общност, без това да предполага отъждествяването му с корпорация в юридически или стопански смисъл. Поради това понятието „организационна култура“ предоставя по-подходяща основа за анализ на неговата образователна и обществена специфика. Училищната общност надхвърля състава на персонала, определен чрез длъжностите и трудовите отношения. Нейното функциониране се осъществява чрез взаимодействието между ръководството, учителите, административните и помощните служители, учениците и родителите. Тези участници имат различни роли, права и отговорности, но са свързани чрез общия ангажимент към образованието и развитието на обучаемите. Следователно училищният персонал и училищната общност следва да бъдат разграничавани, като се отчита приносът на всяка група към институционалния живот.

Ограничаването на представата за училището до административно организиран колектив от служители затруднява разбирането на сложните отношения, чрез които се осъществява образователната дейност. Учениците и родителите участват във формирането на очакванията, комуникационните практики и моделите на сътрудничество. Техният опит и обратна връзка имат значение за развитието на институционалната среда. Разпознаването на този принос предполага създаване на възможности за участие, съобразени с компетентностите и отговорностите на отделните участници.

В този аналитичен контекст училището може да бъде разглеждано като социален организъм, чиито отделни звена функционират във взаимна зависимост. Организационното му единство се поддържа чрез координация на дейностите, споделени образователни цели и нравствени принципи, които придават смисъл на съвместната работа. Това единство включва и способността различията и противоречията да бъдат обсъждани и разрешавани чрез справедливи процедури и професионален диалог.

Организационната култура обединява тези отношения в устойчива система от значения, очаквания и практики. Нейното качество се проявява в съответствието между институционалната мисия, заявените етични принципи и ежедневното поведение. Така целостта на училището може да бъде осмислена като организационно, педагогическо, нравствено и културно единство, което съхранява различните роли и създава условия за сътрудничество, доверие и споделена отговорност.

Организационната култура представлява съществено измерение на функционирането на образователните институции, чрез което споделените ценности и

нравствените норми придобиват израз в ежедневните отношения и практики. Нейното изследване предполага анализ на институционалните послания, комуникационните подходи и устойчивите модели на поведение. Особено значение има съпоставянето между официално заявените принципи и начина, по който те се осъществяват в професионалното взаимодействие. Анализът на тези източници изисква съобразяване с тяхната специфика и ограничения. Официалните комуникационни канали представят предимно институционалната гледна точка, докато публичните отзиви отразяват индивидуални оценки и конкретни преживявания. Поради това те следва да бъдат разглеждани в съпоставка с наблюдения и мнения на различни участници в образователния процес. Така се създава възможност да бъдат разграничени устойчивите характеристики на организационната култура от отделни ситуации или субективни впечатления.

Непосредствените взаимодействия също предоставят важна информация за ценностните основания на училищния живот. Посрещането на посетители, отношението на служителите, общуването между учители и ученици и начинът на реагиране при конфликт разкриват практическото съдържание на уважението, отговорността и професионалната етика. В тези ситуации се проявяват и неформалните правила, които определят чии позиции се изслушват, как се упражнява авторитет и доколко участниците могат свободно да споделят затруднения.

Материалната и символичната среда допълва разбирането за организационната култура. Подредбата и достъпността на пространствата, оформлението на класните стаи и коридорите, институционалните символи и училищните празници могат да изразяват приоритети, традиции и представи за принадлежност. Тяхното значение се установява чрез начина, по който се използват и възприемат от общността. Например възможностите за представяне на ученически постижения или за съвместна дейност могат да показват как институцията признава индивидуалния принос и насърчава сътрудничеството. Поведението на учениците и участието на родителите предоставят допълнителна перспектива към качеството на отношенията. Готовността за задаване на въпроси, изразяване на мнение и включване в общи инициативи може да насочва към наличието на доверие и чувство за принадлежност. Тези прояви следва да се оценяват с внимание към конкретните обстоятелства, тъй като ограниченото участие може да бъде обусловено и от социални, времеви или комуникационни затруднения. Комплексният анализ позволява организационната култура да бъде осмислена чрез реалните условия за справедливо отношение, професионално сътрудничество и отговорно участие в училищната общност.

Отделните наблюдения върху училищния живот придобиват аналитична значимост, когато се разглеждат в конкретния институционален контекст и се съпоставят с данни от различни източници. Единични прояви, като поведението на служител, шумът през междучасието или определено пространствено решение, могат да насочат към въпроси за изследване, но не предоставят достатъчна основа за обобщена оценка на организационната култура. Тяхната интерпретация изисква внимание към обстоятелствата, честотата и устойчивостта на наблюдаваното поведение, както и към значението, което участниците му придават.

Нравственото измерение на организационната култура се разкрива чрез начина, по който тези управленски и комуникационни механизми се осъществяват. Централизирането на определени решения може да бъде обосновано от характера на отговорностите, но изисква ясни основания, последователност и отчетност. Също така широкото участие придобива реална стойност, когато позициите се разглеждат равнопоставено и отговорностите са конкретно определени. Следователно качеството на училищната култура се оценява чрез съответствието между организационните практики и принципите на справедливост, уважение, почтеност и професионална отговорност. Понятията

„корпоративна култура“ и „организационна култура“ се използват с близко съдържание, но тяхната приложимост следва да бъде уточнявана съобразно характера на изследваната институция. В настоящия анализ понятието „организационна култура“ обозначава системата от споделени ценности, убеждения, норми, символи и практики, чрез които образователната общност осмисля и организира съвместната си дейност. То позволява да бъдат обхванати както формално установените правила, така и неявните очаквания, които влияят върху професионалното поведение и ежедневните отношения.

Организационната култура следва да бъде разграничавана от организационната структура, която определя длъжностите, правомощията, отговорностите и процедурите за координация. Двете измерения са взаимосвързани: структурата установява рамката на институционалната дейност, а културата влияе върху начина, по който тази рамка се прилага и възприема. Поради това сходни управленски структури могат да бъдат съпроводени от различни модели на общуване, сътрудничество и упражняване на авторитет.

В образователните институции организационната култура има значение за осмислянето на мисията и за практическото утвърждаване на етичните принципи. Формулираните цели придобиват реално съдържание чрез решенията, разпределянето на отговорности и отношението към участниците в образователния процес. Аналогично, нравствените норми се утвърждават чрез последователното им прилагане в ситуации, които изискват преценка, избор и поемане на отговорност. Така ежедневните практики показват кои ценности действително направляват институционалния живот.

Особено важен аспект на тази култура е отношението към различието и професионалното несъгласие. Неявните очаквания могат да насърчават аргументираното изразяване на позиции или да ограничават диалога чрез страх от неодобрение и неблагоприятни последствия. Когато различните гледни точки се обсъждат с уважение и според ясни критерии, те предоставят възможност за откриване на затруднения, преразглеждане на решения и подобряване на практиките. Подобен диалог изисква готовност за изслушване и отговорност за начина, по който критиката се формулира и използва.

Зрелостта на организационната култура се проявява в способността на образователната институция да съчетава споделени нравствени ориентири с откритост към критична оценка. Общите принципи осигуряват устойчивост на отношенията, а професионалната рефлексия позволява тяхното прилагане да бъде осмисляно спрямо конкретните обстоятелства. В този процес лидерството има задачата да създава условия за справедливо участие, прозрачност и конструктивно обсъждане на противоречията. Така организационната култура се развива като основа за доверие, професионално сътрудничество и осъзната отговорност към образователната мисия.

В образователните институции екипната комуникация представлява сложен процес на взаимодействие, чрез който се съгласуват цели, разпределят се отговорности и се изграждат професионални отношения. Нейното съдържание се формира както от изрично предаваната информация, така и от индивидуалните нагласи, очаквания, емоционални реакции и отношенията между участниците. Разбирането на тези измерения изисква от ръководителя активно слушане, чувствителност към контекста и готовност да изяснява основанията на различните позиции. Подобен подход подпомага своевременното разпознаване на напрежението и конструктивното разрешаване на конфликти.

Сътрудничеството в името на общата образователна мисия предполага споделено разбиране за целите, взаимна отговорност и готовност за професионална подкрепа. То се развива чрез ясна координация, справедливо разпределение на задачите и признаване на индивидуалния принос. Различията в интересите и професионалните позиции могат да бъдат съгласувани чрез диалог и прозрачни правила. Съществено условие е участниците да

възприемат общите резултати като свързани с качеството на съвместната работа. Когато индивидуалните стремежи към признание и влияние се откъснат от институционалните цели, взаимодействието може да придобие характер на съперничество. То може да се прояви чрез ограничаване на обмена на информация, недостатъчна координация или обезценяване на постиженията на колегите. В подобна среда успехът на отделния специалист се възприема като заплаха за професионалния статус на останалите, което затруднява взаимопомощта и отслабва доверието. Конкуренцията може да има конструктивна роля, когато стимулира усъвършенстването и се осъществява при ясни, справедливи и общоприети критерии. Нейният положителен потенциал зависи от добросъвестността на участниците, равнопоставения достъп до възможности и съхраняването на колегиалното уважение. Тя придобива разрушителен характер, когато се използват средства, противоречащи на професионалната етика, или когато личното утвърждаване се постига за сметка на другите и на общата мисия.

Отговорността на ръководството е да създава организационни условия, при които индивидуалните постижения подкрепят колективното развитие. Това предполага прозрачност при оценяването, насърчаване на обмена на опит и признаване както на личния принос, така и на резултатите от съвместната дейност. По този начин комуникацията и етичните норми се превръщат във взаимосвързани основания на организационна култура, която подкрепя професионалното сътрудничество и качеството на образователния процес.

Образователните политики, проекти и програми са насочени към подготовката на младите хора за пълноценно личностно развитие и отговорно участие в обществения живот. Тяхното разработване предполага взаимодействие между специалисти от различни области, обединени от стремежа към подобряване на индивидуалното и общественото благополучие. Постигането на тези цели поставя въпроса доколко нравствените основания на поведението са системно включени в образователното съдържание и практически осъществени в институционалните отношения.

В тази перспектива съществено значение има мястото на етиката в общообразователната и професионалната подготовка. Усвояването на знания и практически умения следва да бъде съпроводено с развитие на способности за нравствена преценка, аргументиране на решения и осъзнаване на последствията от тях за другите. Когато тези измерения остават фрагментарно представени или недостатъчно свързани с реални ситуации, възниква риск етичната подготовка да бъде възприемана като периферен компонент на образованието.

Особено важен е този въпрос при подготовката за професии, свързани с обучение, грижа, подкрепа и обществено въздействие. Педагогическата дейност, психологията, социалната работа, публичната администрация и комуникационните професии изискват решения, които засягат човешкото достойнство, правата, доверието и възможностите за развитие. Поради това професионалната компетентност в тези области предполага и способност за разпознаване на етични проблеми, оценяване на противоречиви интереси и поемане на отговорност за избраното действие

Оценката на етичната подготовка изисква внимание както към наличието на специализирани дисциплини, така и към тяхното съдържание, статут, преподавателска обезпеченост и връзка с професионалната практика. Включването на етични теми в други учебни дисциплини може да има принос, когато е концептуално обосновано и осигурява последователно развитие на нравствената преценка. Същевременно формалното присъствие на такива теми не е достатъчно, ако липсват ясни образователни цели, подходящи методи и критерии за оценяване. Категоричните изводи за ограничаване или отсъствие на етиката следва да се основават на сравнителен анализ на конкретни учебни планове и програми.

В контекста на организационната култура етичното образование придобива значение и чрез средата, в която се осъществява. Обсъжданите нравствени принципи трябва да намират убедително проявление в оценяването, общуването, управленските решения и отношенията между участниците. Несъответствието между преподаваните ценности и институционалните практики може да отслаби възпитателното въздействие на обучението. Затова развитието на етична компетентност предполага съчетаване на системна теоретична подготовка, анализ на професионални казуси и участие в отношения, основани на справедливост и взаимно уважение.

Необходимостта от укрепване на етичното образование следва да бъде разглеждана като част от цялостната отговорност на образователните институции. Тя включва осмисляне на ценностните основания на учебното съдържание, подкрепа за професионалната квалификация и създаване на условия за обсъждане на нравствени дилеми. По този начин етиката може да се утвърди като съществен компонент на професионалната подготовка и като практическа основа на организационна култура, ориентирана към човешкото достойнство и общото благо.

Чрез метафората за капитана и екипажа Липман (Липман, 2003)поставя въпроса за отношенията между експертното знание, доверието и способността за преценка в условия на криза. Компетентността на ръководителя не гарантира сама по себе си, че основанията на неговите решения ще бъдат разбрани и приети. Същевременно ограниченото време за действие затруднява както обсъждането на алтернативите, така и изграждането на необходимото общо разбиране. Така се откроява значението на предварителната подготовка, която създава условия за информирано участие и координирани действия при непредвидени обстоятелства.

Тази интерпретация насочва към образованието като дългосрочна предпоставка за индивидуална и обществена устойчивост. Развитието на знания, критично мислене и нравствена преценка подпомага разпознаването на рискове, оценяването на аргументи и разграничаването между обоснован авторитет и привидна компетентност. Образователните дефицити могат да задълбочават кризисните процеси, като ограничават възможностите за разбиране на ситуацията и за отговорен избор. Това обаче не означава, че всички кризи произтичат единствено от образованието: тяхното възникване и развитие могат да бъдат обусловени и от икономически, политически, институционални и други фактори.

В контекста на образователните институции метафората разкрива необходимостта професионалната компетентност да се съчетава с комуникативна яснота и нравствена отговорност. Ръководителят следва да създава условия основанията на решенията да бъдат разбираеми, а членовете на общността да развиват способност за аргументирана оценка и сътрудничество. Доверието се укрепва чрез последователност, прозрачност и уважение към различните позиции. Подобна организационна култура позволява при възникване на затруднения участниците да се опират на предварително изградени отношения и споделени правила за действие.

Следователно инвестирането в образование, наука и нравствено развитие има значение както за предотвратяването на определени рискове, така и за ограничаването на последствията от кризите. Образователната мисия включва подготовка за преценка в ситуации на несигурност, когато информацията е непълна, интересите са противоречиви, а решенията засягат други хора. От тази перспектива нравствените норми и професионалните взаимодействия са съществени основания на институционална култура, която подкрепя компетентното ръководство, отговорното участие и съвместното справяне с предизвикателствата.

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ТРАНСФОРМАЦИЯ НА ЛИДЕРСТВОТО В ОБРАЗОВАНИЕТО: ОТ ЙЕРАРХИЧНО УПРАВЛЕНИЕ КЪМ СПОДЕЛЕНИ ЛИДЕРСКИ ПРАКТИКИ

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Резюме: Докладът разглежда трансформацията на лидерството в образованието като преход от йерархично управление към споделени лидерски практики, основани на сътрудничество, доверие и колективна отговорност. Анализира се промяната в ролята на образователния лидер — от централен носител на власт и контрол към инициатор на взаимодействие и създател на условия за активно участие на педагогическите специалисти в определянето на общи цели и вземането на решения. Акцент се поставя върху разпределянето на лидерски функции според компетентностите, професионалния опит и конкретните потребности на образователната общност. Обсъждат се предпоставките и ограниченията на този преход, включително организационната култура, готовността за участие и необходимостта от ясно определени отговорности. Споделеното лидерство се представя като възможност за насърчаване на професионалната инициативност, подкрепа на иновациите и устойчиво развитие на образователните институции.

Ключови думи: образователно лидерство, споделено лидерство, йерархично управление, организационна култура, сътрудничество.

THE TRANSFORMATION OF LEADERSHIP IN EDUCATION: FROM HIERARCHICAL MANAGEMENT TO SHARED LEADERSHIP PRACTICES

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Abstract: The paper examines the transformation of leadership in education as a transition from hierarchical management to shared leadership practices grounded in collaboration, trust, and collective responsibility. It analyses the changing role of the educational leader—from a central figure exercising authority and control to a facilitator of interaction who creates conditions for the active involvement of educators in setting common goals and making decisions. Particular emphasis is placed on distributing leadership functions according to competencies, professional experience, and the specific needs of the educational community. The prerequisites and limitations of this transition are discussed, including organisational culture, readiness to participate, and the need for clearly defined responsibilities. Shared leadership is presented as an approach that can foster professional initiative, support innovation, and promote the sustainable development of educational institutions.

Keywords: educational leadership, shared leadership, hierarchical management, organisational culture, collaboration.

Кризисните проявления в сферата на нравствените ценности и обществения морал в съвременното българско общество поставят съществени въпроси пред образованието и неговата роля в личностното и гражданското формиране на младите хора. Те намират израз в напрежението между обществено утвърдени нравствени принципи и реални модели на поведение, както и в затрудненията при изграждането на споделени критерии за справедливост, отговорност и обществено благо. В този контекст социалните трансформации следва да бъдат осмисляни и чрез отражението им върху ценностните ориентири, нравствената култура и отношенията между личността, общността и институциите.

Преходът между различни обществени системи предполага преосмисляне на установени авторитети, норми и представи за допустимо поведение. Съпътстващото го многообразие от ценностни позиции разширява възможностите за личен избор, но същевременно поставя изисквания към способността на човека да оценява тези позиции и да аргументира собствените си решения. Педагогическото предизвикателство се състои в създаването на условия, при които свободата на избора се съчетава с разбиране на неговите нравствени основания и последици за другите.

В процеса на личностно формиране стремежът към истина, добро, красота, любов и справедливост заема значимо място в духовните търсения на младите хора. Чувствителността към тези ценности насочва вниманието им към начина, по който те се проявяват в ежедневните отношения и в поведението на значимите за тях личности. Несъответствието между заявени нравствени принципи и конкретни действия може да породи критичност, разочарование и нетърпимост към неискреността, лицемерието и несправедливостта. Подобни преживявания участват във формирането на ценностните ориентации и влияят върху психологическите нагласи в юношеската и младежката възраст (Нунев, 2008).

От тази гледна точка приемането на правилата и нормите на поведение зависи и от възприемането им като смислени, справедливи и последователно прилагани. Когато нравствената им обосновка остава неясна или противоречи на наблюдаваните практики, младият човек може да ги възприеме като формални ограничения. Особено значимо е поведението на възрастните, които изискват спазването на тези норми. Разминаването между техните послания и действия поставя под съмнение убедителността на изискванията и може да отслаби доверието в педагогическия и институционалния авторитет.

Когато институционалните форми на съвместен живот и нормите на обществения ред не се подкрепят от споделени ценности, последователно прилагани в социалната практика, сред младите хора може да се формира усещане за ценностна неопределеност и отчуждение. Разминаването между обществено заявените идеали и действителните отношения затруднява разпознаването на убедителни нравствени ориентири и може да отслаби доверието в институциите. В подобни условия търсенето на алтернативни форми на духовност, културна принадлежност и общностно участие може да бъде израз на стремеж към смисъл, признание и личностна изява.

Тези процеси поставят пред образователното лидерство необходимостта от задълбочено разбиране на ценностите, убежденията, представите и очакванията на младите хора. Ефективното педагогическо взаимодействие предполага познаване на начина, по който учениците осмислят своя опит, възприемат авторитета и оценяват отношенията в образователната среда. Съобразяването с тези особености позволява формулирането на разбираеми и значими за тях послания и подкрепя осъзнатото им участие в процеса на учене.

Утвърждаването на определени ценности като личностни идеали и основания за действие влияе върху избора на цели, характера на социалното участие и отношението към

другите. Ценностните предпочитания намират израз в решенията и поведението, но тяхното практическо осъществяване зависи и от конкретните възможности, ограничения и отговорности на личността. Ето защо разбирането на ценностната система изисква внимание както към заявените убеждения, така и към начина, по който те се проявяват в реални ситуации.

Ценностната система съчетава относителна устойчивост с възможност за развитие и преосмисляне. Устойчивостта се свързва с трайната значимост на ценности като мир, знание, справедливост, демокрация и свобода. Динамичността се изразява в промяната на тяхната относителна тежест и в начина на интерпретирането им под въздействието на политическите, икономическите и социалните условия. В различни обстоятелства различна значимост могат да придобиват конформизмът, традицията, универсализмът, себеутвърждаването и властта (Нунев, 2008).

За образователното лидерство тази взаимовръзка има непосредствено практическо значение. Тя предполага създаване на пространство за диалог, в което индивидуалните ценностни позиции могат да бъдат изразявани и обсъждани във връзка с общите правила и цели. Споделените ориентири се изграждат чрез аргументиране, личен пример и справедливо взаимодействие. Така педагогическата среда може да подкрепя едновременно личностната автономия и отговорността към общността, които са съществени предпоставки за развитието на споделени лидерски практики.

Разбирането на взаимовръзката между устойчивостта и изменението на ценностните ориентации има съществено значение за образователното лидерство. То предполага съчетаване на трайни нравствени принципи с чувствителност към променящите се потребности и житейски опит на учениците. В тази перспектива диалогът и уважението към личностните различия създават основа за изграждане на споделени ценностни ориентири. Тяхното утвърждаване изисква последователно прилагане в педагогическите отношения, така че доверието, сътрудничеството и отговорността да се превърнат в практически измерения на училищния живот.

Подобен лидерски подход придобива особено значение в мултикултурната образователна среда, в която взаимодействат ученици с различна етническа, религиозна и езикова принадлежност, социален статус и семейна история. Културното многообразие поставя изисквания към организацията на обучението, общуването и участието в училищната общност. То същевременно предоставя възможности за разширяване на познавателния опит, за обмен на различни гледни точки и за развитие на умения за съвместна дейност. Реализирането на този потенциал зависи от способността на образователните лидери да създават справедливи условия за участие и да подкрепят взаимното разбиране.

Управлението на взаимодействията в подобна среда изисква внимание към културните особености и към индивидуалните различия във всяка общност. Етническата, религиозната или езиковата принадлежност сама по себе си не определя ценностите, способностите и очакванията на конкретния ученик. Педагогическата преценка следва да се основава на непосредствено познаване на личността, нейния опит и потребности. Това позволява да се избегнат стереотипни интерпретации и да се изграждат отношения, основани на равнопоставеност и уважение към човешкото достойнство.

Децата и техните семейства участват в образователния процес със своите традиции, ценностни ориентири и модели на общуване. Културата може да бъде разглеждана като динамична система от споделени значения, норми и практики, чрез които хората осмислят своя опит и организират отношенията си с другите. Тя влияе върху представите за авторитет, отговорност, успех и допустимо поведение, както и върху очакванията към училището и

учителя. Тези представи се развиват във взаимодействие със социалната среда и могат да бъдат преосмисляни чрез нов опит и диалог.

Познаването на семейния и културния контекст подпомага педагогическите специалисти при разбирането на индивидуалните потребности на учениците. То има значение за избора на подходи към обучението, за преодоляването на комуникационни затруднения и за изграждането на партньорство с родителите. Такова партньорство предполага достъпна комуникация, ясно представяне на образователните цели и възможности семействата да споделят своите очаквания и опасения. По този начин училището може да създаде по-пълна представа за условията, които подкрепят или затрудняват участието на всяко дете.

В контекста на споделеното лидерство приобщаването се осъществява чрез съвместния принос на ръководството, учителите, учениците и родителите. Включването им в обсъждането на правила, инициативи и решения създава възможности различните позиции да бъдат чути и съотнесени към общите образователни цели. Задачата на лидера е да организира този процес, да гарантира справедливостта на взаимодействието и да поддържа ясни отговорности. Така културното многообразие може да се превърне в ресурс за развитие на училищната общност, а споделените ценности — в основа за принадлежност, сътрудничество и отговорно участие.

Интеркултурното възпитание и образование подпомагат разширяването на културния хоризонт на учениците и развитието на способности за общуване и сътрудничество в многообразна социална среда. Тяхното значение се свързва с формирането на нагласи за взаимно уважение, разбиране на различни гледни точки и осмисляне на собствената културна принадлежност в отношенията с другите. Подобна подготовка създава предпоставки за пълноценно участие както в училищната общност, така и в международни образователни и социални взаимодействия.

В тази перспектива класната стая следва да функционира като пространство за диалог, личностна изява и съвместно учене. Педагогическото взаимодействие трябва да насърчава увереността, инициативността, любознателността и самодисциплината, като предоставя възможности за задаване на въпроси, аргументиране на позиции и поемане на отговорности. Положителните модели на поведение и високите очаквания, съчетани с подкрепа според индивидуалните потребности, подпомагат мотивацията за постижения и увереността в собственото развитие. Съществено място заема партньорството между ученика, семейството и училищната общност, което укрепва чувството за достойнство, принадлежност и лична значимост (Бузов, 2008).

Осъществяването на тези цели предполага развитие на лидерски компетентности както у директорите, така и у всички педагогически специалисти. Учителят упражнява лидерско влияние чрез организацията на учебния процес, личния пример, формулирането на общи цели и подкрепата за ученическа активност. Неговата роля включва посредничество между различни позиции, насърчаване на сътрудничеството и създаване на условия за отговорно участие. Следователно лидерската подготовка има непосредствено отношение към качеството на педагогическото взаимодействие и към изграждането на приобщаваща образователна среда.

Когато квалификационните програми са съсредоточени преимуществено върху ръководните кадри и управлението на педагогическите колективи, съществува риск лидерските измерения на работата с учениците да останат недостатъчно развити. Това обосновава необходимостта обучението по лидерство да бъде разглеждано като съществен компонент на професионалната квалификация на всеки учител, независимо от преподавания учебен предмет. Включването му като задължителен компонент може да

бъде аргументирано с потребността от системна подготовка за мотивиране, ефективно общуване, етично вземане на решения и работа в културно многообразна среда.

Подобна подготовка следва да съчетава теоретични знания с анализ на педагогически ситуации, практически задачи и рефлексия върху собствения професионален опит. Особено значение имат уменията за разпределяне на отговорности, подкрепа на инициативи и съвместно решаване на проблеми. По този начин развитието на учителските лидерски компетентности създава основа за споделени лидерски практики, при които приносът на различните участници се координира около общи ценности и образователни цели.

Съпоставката между лидерските качества и компетентностите, необходими за осъществяването на учителската мисия, разкрива съществени сходства в техните мотивационни, комуникативни и нравствени измерения. Сред тях се откроява способността за формулиране и споделяне на ясна визия за бъдещето, която придава смисъл на съвместните усилия и очертава перспективи за развитие. В образователната среда тази визия придобива практическа значимост, когато се свързва с разбираеми цели, конкретни възможности за действие и активно участие на учениците.

При затруднения и несигурност подкрепящата роля на учителя има особено значение. Тя се изразява в подпомагане на учениците да осмислят препятствията, да разпознават наличните ресурси и да избират подходящи стратегии за справяне. Увереността в собствените възможности се изгражда чрез постижими задачи, последователни усилия и обратна връзка, която прави напредъка видим. Подобен подход насърчава разбирането, че способностите и уменията подлежат на развитие, а трудностите могат да бъдат повод за учене и преосмисляне на използваните подходи.

Като значима фигура в образователния опит на учениците учителят влияе върху тяхната мотивация, устойчивост и самооценка. Неговото лидерско въздействие се проявява в създаването на среда, в която високите очаквания се съчетават с внимание към индивидуалните потребности и възможности. Съществена задача е учениците постепенно да развиват самостоятелност при поставянето на цели, оценяването на собствените резултати и поемането на отговорност за своето развитие.

Обща характеристика на педагогическата и лидерската дейност е устойчивият ангажимент към израстването на другите. Той предполага готовност за инвестиране на време, знания и усилия в подкрепа на индивидуалния и колективния напредък. От тази перспектива лидерството има и измерение на служене, при което решенията се ръководят от потребностите на участниците и общите цели. В учителската практика това се изразява в последователна грижа за развитието на учениците, справедливо отношение и създаване на възможности всеки да разгърне своя потенциал.

Поддържането на подобна ангажираност изисква решимост, професионална отговорност и осъзната мотивация. Отдадеността предполага разумно съчетаване на подкрепата за другите с грижа за собствените професионални ресурси и способност за определяне на приоритети. Убедеността в смисъла на педагогическата мисия може да поддържа постоянството, но устойчивото ѝ осъществяване се нуждае и от колегиално сътрудничество и институционална подкрепа. Така грижата за развитието се превръща в споделена отговорност на образователната общност и в основа за последователни лидерски практики.

Мотивацията и вдъхновението представляват съществени измерения на педагогическата дейност и лидерското взаимодействие. Тяхното значение се проявява в способността да се свържат индивидуалните стремежи с общите цели и да се поддържа осъзнато участие в съвместната дейност. Признаването на усилията, конструктивната обратна връзка и предоставянето на възможности за развитие подпомагат увереността и

готовността за поемане на инициатива. Ефективността на тези подходи зависи от разбирането на личните мотиви, интереси и потребности, както и от съобразяването на общуването с конкретния контекст.

В образователната среда мотивационното въздействие на учителя се свързва с разкриването на смисъла на ученето и с насърчаването на активното отношение към собственото развитие. Съществено място заема личният пример, чрез който отговорността, постоянството и уважението придобиват конкретен поведенчески израз. Когато учителят демонстрира готовност да учи, да обсъжда различни позиции и да признава собствените си грешки, той създава условия учениците да възприемат тези практики като част от своето израстване. По този начин вдъхновението се основава на последователно и убедително поведение.

Педагогическата и лидерската практика предполагат съчетаване на ясно ръководство със сътрудничество и участие. Поставянето на разбираеми изисквания и определянето на отговорности осигуряват необходимата организираност, а диалогът позволява решенията да бъдат осмислени и съобразени с различните гледни точки. Преценката за степента на самостоятелност следва да отчита характера на задачата, възрастта, подготовката и индивидуалните потребности на участниците. В този процес учителят постепенно разширява възможностите на учениците да правят избори и да оценяват последствията от тях.

Поведението на учителя и лидера служи като ориентир за начина, по който се упражнява авторитет и се разрешават противоречия. Наблюдавайки това поведение, учениците и членовете на екипа изграждат представи за отговорността, уважението и допустимите форми на взаимодействие. Ето защо мотивацията, сътрудничеството и почтеността следва да се разглеждат като взаимосвързани основания на образователното лидерство. Тяхното последователно осъществяване подкрепя култура, в която инициативата се насърчава, отговорностите се споделят и общите цели се постигат чрез доверие.

Ясното, последователно и двустранно общуване представлява съществено условие за ефективното педагогическо и лидерско взаимодействие. Чрез него се изгражда общо разбиране за целите, очакванията и отговорностите на участниците в образователния процес. Комуникативната компетентност на учителя включва активно слушане, разбираемо изразяване и готовност за изясняване на различните гледни точки. Особено значение има чувствителността към затрудненията, които учениците невинаги могат да формулират непосредствено. Тяхното разпознаване предполага внимателно наблюдение и диалог, чрез който първоначалните предположения да бъдат проверени и уточнени.

Своевременната и конструктивна обратна връзка подпомага осмислянето на постигнатите резултати и определянето на следващи стъпки за развитие. Тя следва да бъде конкретна, аргументирана и насочена към действията и възможностите за подобрение, като съхранява достойнството на ученика. Същевременно двустранният характер на общуването предполага учителят да приема обратна връзка за собствените си подходи и да отчита начина, по който неговите послания се разбират. Така комуникацията създава условия за взаимно учене и за по-активно участие в съвместната дейност.

Емоционалната интелигентност допълва комуникативните компетентности чрез осъзнаване на собствените преживявания, способност за саморегулация и чувствителност към емоционалните състояния на другите. В педагогическата практика тези способности подпомагат разграничаването между непосредствената емоционална реакция и професионално обоснованото действие. Самопознанието и рефлексията позволяват на учителя да разпознава собствените си нагласи и факторите, които влияят върху неговата преценка. Емпатията създава възможност поведението на ученика да бъде осмислено в контекста на неговите потребности, преживявания и конкретни обстоятелства.

При напрежение или конфликт емоционалната саморегулация подпомага запазването на уважителен тон, изясняването на причините за противоречието и търсенето на приемливи решения. Тя предполага осъзнато управление на начина, по който емоциите се изразяват и влияят върху взаимодействието. Чрез собственото си поведение учителят предоставя модел за справяне с несъгласие, разочарование и несигурност. Готовността да признае грешка, да обясни решение и да възстанови диалога има значение за развитието на подобни способности у учениците.

Конструктивното отношение и гъвкавостта позволяват тези компетентности да бъдат прилагани съобразно конкретната ситуация. Гъвкавостта се проявява в адаптирането на методите, темпа и формите на подкрепа при съхраняване на ясни цели и справедливи критерии. Достъпността и уважението създават психологически сигурна среда, в която учениците могат да задават въпроси, да споделят затруднения и да изразяват аргументирано несъгласие. Подобна среда насърчава инициативността и същевременно поддържа отговорността за собственото поведение и за отношенията с другите.

При кризи и неуспехи педагогическата подкрепа следва да съчетава признаване на преживяваните емоции с ориентиране към реалистични възможности за действие. Това включва съвместно изясняване на проблема, определяне на постижими стъпки и проследяване на напредъка. В перспективата на споделеното лидерство комуникацията, емоционалната интелигентност и гъвкавостта подпомагат разпределянето на отговорности според подготовката и възможностите на участниците. По този начин учителят създава условия учениците постепенно да развиват увереност, самостоятелност и готовност за сътрудничество в променяща се образователна среда.

Автентичността представлява съществено нравствено основание на педагогическото и лидерското въздействие. Тя се проявява в съответствието между осъзнатите лични ценности, заявените принципи и поведението в конкретни ситуации. В образователната среда това съответствие придава убедителност на учителския авторитет и подпомага изграждането на доверие. Решенията, начинът на общуване и отношението към учениците показват доколко утвърждаваните ценности намират реално приложение в ежедневната практика.

Автентичното поведение предполага самопознание, критична рефлексия и готовност за поемане на отговорност за собственото влияние. То включва способност за преразглеждане на дадена позиция, когато нови обстоятелства или аргументи разкриват нейните ограничения. Нравствената последователност се съхранява чрез открито обяснение на основанията за подобна промяна. Същевременно личните убеждения на учителя следва да бъдат осмисляни във връзка с професионалните му отговорности, уважението към различията и правото на учениците да изграждат собствена аргументирана позиция.

Разминаването между провъзгласени принципи и действителни действия може да породи съмнение в справедливостта на педагогическите изисквания и да отслаби доверието в образователната институция. Поради това автентичността има значение и за организационната култура на училището. Нейното утвърждаване предполага прозрачност на решенията, последователно прилагане на общите правила и възможности за обсъждане на възникнали противоречия. Тези условия подкрепят споделеното лидерство, като позволяват участието и отговорността да се основават на взаимно доверие.

Практическото осъществяване на подобна подготовка предполага използване на етични казуси, дискусии, съвместни проекти и задачи за самооценка. Чрез тях учениците могат да свързват абстрактните нравствени категории с конкретния си опит в семейството, училището и отношенията с връстниците. Възможностите за избор и участие следва да бъдат съобразени с възрастта и да се съпровождат от ясни критерии за отговорност. Така

развитието на лидерски компетентности се обвързва с изграждането на обоснована самооценка, самоуважение и уважение към другите.

Изучаването на аксиологията може да подкрепи формирането на нравствена култура, ориентирана към хуманистичен обществен идеал. Негови основни измерения са човешкото достойнство, взаимната отговорност, уважението, взаимопомощта и стремежът към интелектуално и духовно развитие. Образованието, основано на тези ценности, създава предпоставки за изграждане на личности с творческа и гражданска позиция и с осъзнат ангажимент към общото благо (Бузов, 2008). Реализирането на този потенциал изисква ценностите да бъдат последователно въплъщавани в отношенията, решенията и възможностите за участие в училищната общност.

В подобна образователна перспектива училището създава условия за ориентиране в сложна социална и информационна среда. Критичната преценка предполага оценяване както на достоверността на информацията, така и на ценностните послания, които тя съдържа. Обсъждането на въпроси за справедливостта, свободата, достойнството и отговорността позволява тези категории да бъдат свързани с ежедневния опит на учениците. По този начин обучението и възпитанието подкрепят самостоятелното мислене и способността за осъзнато участие в обществения живот.

Свързването на познавателните, емоционалните и ценностните измерения на ученето позволява личностното развитие да бъде разглеждано като цялостен процес. Знанието придобива личностна значимост, когато ученикът разбира неговото приложение, осмисля отношението си към него и оценява възможните последици от използването му. В тази перспектива интерактивните пространства за общуване, обмен на знания и партньорство могат да бъдат разглеждани като среда за разширяване на образователния опит и за неформално учене (Зохар, 2003).

Образователното въздействие на пространствата за общуване и съвместна дейност се осъществява както чрез непосредствените социални взаимодействия, така и във виртуалната среда. В тях младите хора обменят знания, съпоставят позиции и усвояват модели на поведение, които участват във формирането на личностните им нагласи. Потенциалът на тези пространства за диалог и сътрудничество зависи от качеството на комуникацията, критичната преценка на съдържанието и яснотата на правилата за участие. Съществено значение има възможността всеки участник да изразява позицията си, да бъде чут и да поема отговорност за собственото си влияние върху другите.

В тази перспектива основна цел на обучението по лидерство е развитието на осъзнато отношение към личния избор и собственото бъдеще. Подготовката следва да подпомага младите хора да разпознават възможностите си за действие, да определят приоритети и да формулират реалистични цели. Същевременно тя трябва да отчита, че личностното развитие протича в конкретни социални условия, които предоставят възможности, но поставят и ограничения. Отговорното отношение към бъдещето предполага както инициативност и постоянство, така и способност за търсене на подкрепа, сътрудничество и преразглеждане на избраните стратегии.

Особено място в лидерската подготовка заема разбирането за доверието като основа на устойчивите отношения с родители, учители и връстници. То се изгражда чрез последователно поведение, изпълнение на поетите ангажименти и открито общуване. Съответствието между намеренията, заявените убеждения и действията придава убедителност на личната позиция. Признаването на грешки и готовността за тяхното поправяне също имат значение за съхраняването на доверието, тъй като показват осъзната отговорност към отношенията с другите.

Лидерското обучение предполага развитие на способност за критично осмисляне на установените модели на мислене и поведение. Това включва изследване на техните

основания, приложимост и последствия, както и готовност за обсъждане на алтернативи. Формулирането на лични ценностни ориентири и визия за развитие се обвързва със самодисциплина, аргументираност и нравствена смелост. Отстояването на убежденията придобива зрял характер, когато се съчетава с откритост към нови знания и уважение към различните гледни точки.

Практическото развитие на тези способности може да се осъществява чрез съвместни проекти, анализ на казуси и рефлексия върху конкретни решения. Участието в планирането, разпределянето на задачи и оценяването на резултатите позволява на учениците да осмислят връзката между личния принос и общото постижение. По този начин обучението по лидерство създава условия за постепенно изграждане на инициативност, самостоятелна преценка и отговорно участие. Тези качества подкрепят споделените лидерски практики, при които влиянието се основава на компетентност, доверие и ангажимент към общите цели.

Историко-философски основания на разбирането за лидерството като единство на компетентност и нравствена отговорност могат да бъдат открити в представеното от Иванов тълкуване на Питагоровата концепция за съвкупната добродетелност на лидера. В тази интерпретация политическите, гражданските и държавническите измерения на добродетелността се разглеждат като взаимосвързани характеристики на личността, която поема отговорност за общите дела. Съотнесена към съвременните условия, тази идея насочва към необходимостта управленските способности да се съчетават с гражданска ангажираност, нравствена зрялост и ориентация към общественото благо (Иванов, 2014).

Въпросът за възможността лидерската добродетелност да бъде развивана чрез обучение и възпитание поставя в центъра на вниманието връзката между личностните предпоставки, социалния опит и целенасоченото педагогическо въздействие. Иванов (2014) разглежда нейното формиране чрез междупоколенческо предаване на ценности и модели на поведение, както и чрез организирана етико-педагогическа подготовка. В този контекст приемствеността може да бъде осмислена като процес на усвояване, критична оценка и обновяване на опита, чрез който нравствените ориентири придобиват значение за конкретните условия на обществен живот.

Посочените от автора образователни примери — от Аристотеловия Лицей до Висшето училище по администрация в Париж — илюстрират трайния интерес към подготовката на личности за обществени и управленски отговорности. Тяхното съпоставяне позволява да се открои общият въпрос за отношенията между знанието, способността за действие и нравствената преценка, като същевременно се отчитат различията в историческия контекст и образователните цели. От тази перспектива лидерската подготовка предполага развитие на способност за оценяване на целите, средствата и последствията от упражняваното влияние.

Приложено към образованието, това разбиране обосновава необходимостта практическите лидерски компетентности да бъдат развивани във връзка с нравствената отговорност към другите. Уменията за организиране, мотивиране и вземане на решения придобиват педагогическа значимост, когато се основават на справедливост, уважение към човешкото достойнство и готовност за отчитане на различни позиции. Развитието на лидерска добродетелност изисква възможности тези принципи да бъдат прилагани в конкретни ситуации, а решенията да бъдат подлагани на аргументирана оценка и самооценка.

В контекста на споделеното лидерство нравствената подготовка се свързва и със способността за съвместно определяне на цели, разпределяне на отговорности и признаване на приноса на всеки участник. Лидерското влияние се осмисля като отговорност за условията, в които другите могат да действат самостоятелно и да развиват своите

способности. Така историко-философската перспектива предоставя основание съвременното обучение по лидерство да бъде разглеждано като цялостен процес, обединяващ знания, практически умения и ценностно ориентирано поведение.

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Geographic Sciences

Görünməyən Sərhədlər: Şəhərlərdə Sosial-İqtisadi Seqreqasiya və Urban İnfrastrukturun Transformasiyas

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Müasir urbanizasiya prosesləri yalnız demoqrafik və memarlıq baxımından deyil, həm də dərin sosial-məkan parçalanmaları ilə xarakterizə olunur. Sosial-iqtisadi seqreqasiya — müxtəlif gəlir qruplarına aid insanların şəhər mühitində bir-birindən coğrafi olaraq təcrid olunmuş məkanlarda məskunlaşması fenomenidir. Bu məqalədə şəhərlərdə zəngin və kasıb məhəllələrin formalaşmasının coğrafi qanunauyğunluqları, bu "görünməyən sərhədlərin" yaranma mexanizmləri və şəhər infrastrukturunun (nəqliyyat, yaşıl zonalar, kommunal xidmətlər) bu bölgüyə uyğun olaraq necə asimmetrik formalaşdığı akademik çərçivədə təhlil edilir. Məqalə həmçinin beynəlxalq və yerli keyslər vasitəsilə bərabərsizliyin məkan ölçülərini və gələcək inklüziv planlaşdırma modellərini araşdırır.

1. Giriş və Nəzəri Çərçivə

Şəhər sadəcə binaların və yolların cəmi deyil; o, sosial münasibətlərin məkanda maddi forma almış təzahürüdür. Coğrafi məkanda sinfi ayrılma prosesi şəhər sosiologiyası və humanitar coğrafiyanın ən fundamental mövzularından biridir. Sənaye inqilabından bu yana kapitallaşma meylləri insan qruplarının gəlirlərinə görə yerləşdirərkən məkanın fiziki xüsusiyyətlərindən bir filtr kimi istifadə etmişdir.

Sosial-məkan seqreqasiyasının öyrənilməsində üç əsas nəzəri yanaşma mövcuddur:

Çikaqo Məktəbinin Ekoloji Modeli (Robert Park, Ernest Burgess): Şəhərin böyüməsini "konsentrik dairələr" şəklində izah edir. Bu modelə görə, müxtəlif sosial qruplar iqtisadi imkanlarına uyğun olaraq şəhərin müəyyən zonalarına təbii şəkildə "sıxı" və rəqabət nəticəsində məkanlar ixtisaslaşır. Zaman keçdikcə daxili həlqələr mərkəzi biznes rayonundan uzaqlaşdıqca gəlir səviyyəsinin dəyişməsini əks etdirir.

Radikal (Marksist) Coğrafiya (David Harvey, Neil Smith): Seqreqasiyanı təbii bir proses deyil, kapitalın məkanda qeyri-bərabər toplanmasının və torpaq rentasının nəticəsi kimi görür. Zəngin zonaların investisiya alması, yoxsul zonaların isə dezinvestisiyaya (maliyyə qıtlığına) məruz qalması sistemli siyasətdir. Harvey vurğulayır ki, şəhər məkanı kapitalın təkrar istehsalı üçün daimi olaraq yenidən qurulur və bu, mütləq bərabərsizlik doğurur.

Məkan Məhrumiyyəti İndeksi: Müasir coğrafiyaçıların tətbiq etdiyi bu indeks, ərazinin təhsil, səhiyyə və təmiz mühitə çıxış imkanlarını ölçərək görünməyən sərhədləri xəritələşdirir. Bu yanaşma çoxölçülü yoxsulluq konsepsiyasına əsaslanır və maddi gəlirdən əlavə, məkanın təqdim etdiyi imkanların keyfiyyətini meyara çevirir.

2. Zəngin və Kasıb Məhəllələrin Coğrafi Paylanma Mexanizmləri

Şəhərlərdə sosial qrupların qütbləşməsi təsadüfi xarakter daşımır. Burada müəyyən coğrafi və iqtisadi drayverlər rol oynayır:

A. Təbii-Coğrafi Amillər (Topoqrafiya və Ekologiya)

Yüksəklik və Relyef: Tarixən və bu gün bir çox şəhərlərdə zəngin təbəqə şəhərin daha yüksək, mənzərəli, havası təmiz və sel/daşqın riskindən uzaq olan hissələrində (məsələn, Los-Ancelesdə Beverli Hills, Bakıda Badamdar və ya Dağüstü zonalar) məskunlaşır. Yoxsul təbəqə isə adətən dərələrə, sənaye zonalarına yaxın alçaq ərazilərə sıxışdırılır. Bu geomorfoloji asimmetriya landşaftın sosial təbəqələşməsini birbaşa diktə edir.

Külək İstiqaməti (Sənaye İrsi): Avropanın bir çox sənaye şəhərlərində (məsələn, London və Mançester) üstünlük təşkil edən qərb külәkləri sənaye tüstüsünü şərqə doğru aparırdı. Nəticədə şəhərlərin West End (Qərb hissəsi) zənginlərin, East End (Şərq hissəsi) isə fəhlə sinfinin məskəninə çevrildi. Bu coğrafi irs bu gün də daşınmaz əmlakın qiymət strukturunda özünü qabarıq göstərir.

B. İqtisadi və Hüquqi Mexanizmlər

Gentrifikasiya (Məkanın Soysoylulaşdırılması): Əvvəllər yoxsul və ya fəhlə sinfinin yaşadığı mərkəzi məhəllələrin kapital qoyuluşu ilə modernləşdirilməsi, nəticədə daşınmaz əmlak qiymətlərinin və vergilərin artması ilə yerli yoxsul əhalinin şəhər kənarına (periferiyaya) sıxışdırılması prosesidir. Bu proses məkanın sinfi xarakterini kökündən dəyişdirərək mədəni irsi kommersiyalaşdırır.

Qapalı Yaşayış Kompleksləri (Gated Communities): Yüksək gəlirli təbəqənin şəhərin ümumi xaosundan, cinayətkarlıqdan təcrid olunmaq üçün divarlarla, kameralarla və xüsusi mühafizə ilə əhatə olunmuş "ağıllı və lüks" anklavlar yaratması. Bu, məkanda fiziki və görünən bir sərhəd formalaşdırır və ictimai məkan anlayışını məhdudlaşdırır.

3. İnfrastrukturun Asimmetrik Transformasiyası

Sosial-iqtisadi seqreqasiya sadəcə evlərin keyfiyyətində deyil, şəhər infrastrukturunun paylanmasında özünü kəskin şəkildə büruzə verir. Bu fenomen akademik ədəbiyyatda "İnfrastruktur Aparteidi" və ya "Məkan Ədalətsizliyi" adlanır. İnfrastruktur şəbəkələri neytral mühəndislik layihələri deyil; onlar siyasi-iqtisadi prioritetlərin coğrafi əksidir.

1. Nəqliyyat İnfrastrukturu və "Nəqliyyat Səhraları" (Transit Deserts)

Zəngin məhəllələr adətən geniş magistrallara, sürətli metro xətlərinə və mikromobillik (velosiped yolları) infrastrukturuna birbaşa çıxışı olan ərazilərdə yerləşir. Əksinə, yoxsul məhəllələr və qeyri-formal məskunlaşma yerləri (gecəqondular, şəhərətrafı qəsəbələr) kütləvi nəqliyyat şəbəkəsindən məhrum olur. İnsanların iş yerlərinə çatmaq üçün saatlarla vaxt itirməsi onların iqtisadi mobilliyini də məhdudlaşdırır (Məkan uyğunsuzluğu hipotezi). Bu vəziyyət fərdlərin əmək bazarına daxil olmasını çətinləşdirərək yoxsulluq dövrəsini qapalı saxlayır.

2. Yaşıl İnfrastruktur və Ekoloji Ədalətsizlik

Peyk görüntüləri üzərində aparılan coğrafi analizlər (məsələn, NDVI - Normallaşdırılmış Fərq Vegetasiya İndeksi) göstərir ki, şəhərlərdə yaşıl örtüyün (parklar, xiyabanlar) sıxlığı birbaşa əhalinin gəlir səviyyəsi ilə korrelyasiya təşkil edir. Zəngin məhəllələr zəngin yaşıl infrastruktura malik olduğu üçün burada "Şəhər istilik adası" effekti az olur, hava daha təmizdir. Kasıb məhəllələrdə isə betonlaşma yüksək, ağac sayı azdır ki, bu da yay aylarında temperaturun süni şəkildə 4-5 dərəcə daha isti olmasına və tənəffüs yolu xəstəliklərinin artmasına səbəb olur.

3. Kommunal və Rəqəmsal İnfrastruktur

Kommunal Bərabərsizlik: Dünyanın bir çox inkişaf etməkdə olan ölkələrində (məsələn, Latın Amerikası və Afrika şəhərlərində) su təchizatı, kanalizasiya sistemləri və zibil yığılması xidmətləri zəngin məhəllələrə fasiləsiz verildiyi halda, yoxsul məhəllələrdə bu sistemlər ya yoxdur, ya da qəza vəziyyətindədir. Açıq kanalizasiya xətləri və təmizlənməyən məişət tullantıları bu zonaları epidemioloji risk mərkəzinə çevirir.

Rəqəmsal Seqreqasiya (Digital Divide): Sürətli fiber-optik internet xətləri, 5G stansiyaları ilk növbədə kommersiya mərkəzlərinə və elitar yaşayış zonalarına çəkilir, yoxsul

zonalar isə rəqəmsal izolyasiyada qalır. Bu, təhsil və distant iş imkanlarında bərabərsizliyi daha da dərinləşdirir.

4. Qlobal və Regional Keys Araşdırmaları

A. Rio-de-Janeyro (Braziliya): Favelalar və Asfalt Şəhər

Braziliyanın bu meqapolisində seqreqasiya vizual olaraq ən kəskin formadadır. "Asfalt şəhər" (asfalto) zənginlərin yaşadığı, hər cür infrastruktura malik sahilboyu əraziləri əhatə edir. Dərhal onların arxasındakı dik yamaclarda isə "favelalar" yerləşir. Favelalar rəsmi xəritələrdə uzun müddət boşluq kimi göstərilmiş, dövlət infrastruktur xidmətlərindən tamamilə məhrum edilmişdir. Bu iki məkan arasında cəmi bir neçə metr məsafə olsa da, sosial və infrastruktur uçurumu keçilməzdir.

B. Nyu-York (ABŞ): Redlining və Getto hekayəsi

XX əsrin ortalarında ABŞ-da tətbiq edilən "redlining" (qırmızı xətt çəkmə) siyasəti federal xəritələrdə yoxsul və azlıqların yaşadığı məhəllələri riskli zona elan edərək bura bank kreditlərinin və infrastruktur investisiyalarının qoyulmasını bloklamışdır. Nəticədə Harlem və Bruklinin bəzi hissələri infrastruktur baxımından çökərək gethoya çevrilmişdir. Gentrifikasiya bu gün həmin sərhədləri yenidən formalaşdırır.

C. Bakı (Azərbaycan): Suburbanizasiya və Şəhərətrafı Qəsəbələr

Bakı şəhərinin məkan dinamikasında da bənzər elementləri müşahidə etmək mümkündür. Paytaxtın mərkəzi və dənizkənarı hissələri (məsələn, Ağ Şəhər, premium yaşayış kompleksləri) mükəmməl yaşıl infrastruktur, yeraltı kommunikasiya və nəqliyyat şəbəkəsi ilə təmin olunduğu halda, Abşeron yarımadasının bəzi şəhərətrafı qəsəbələrində və qeyri-formal məskunlaşma zonalarında mərkəzləşdirilmiş kanalizasiya, müntəzəm su təchizatı və daxili yolların asfalt örtüyü hələ də tam formalaşmamışdır. Bu, şəhərin iqtisadi nüvəsi ilə periferiyası arasında fərqli xidmət səviyyələri yaradır.

5. Sosial-Məkan Seqreqasiyasının Nəticələri

Bu görünməyən sərhədlərin qalınlaşması şəhər ekosistemi üçün ciddi risklər yaradır:

Sosial Qütbləşmə və Radikallaşma: Məkanca ayrılmış insanlar arasında ortaq şəhər mədəniyyəti və empatiya hissi itir. "Biz" və "Onlar" sindromu yaranır, bu isə sosial gərginliyi artırır.

Cinayətkarlığın Məkan Konsentrasiyası: İnfrastruktur və təhsil imkanlarından məhrum olan getholarda kriminal mühit qaçılmaz olaraq inkişaf edir. Məkanın fiziki baxımsızlığı cinayətə meylliliyi stimullaşdırır (Sınmış pəncərələr nəzəriyyəsi).

İqtisadi Səmərəsizlik: Şəhərin bir hissəsinin funksional olaraq iflic olması ümumi şəhər iqtisadiyyatının məhsuldarlığını aşağı salır. İşçi qüvvəsinin mərkəzə daşınma xərcləri və zaman itkisi makroiqtisadi itkilərə yol açır.

6. Nəticə və Davamlı Urban Planlaşdırma Həlləri

Şəhərlərdəki "görünməyən sərhədləri" tamamilə yox etmək bazar iqtisadiyyatı şəraitində çətin olsa da, urbanistlər və coğrafiyaçılar bu uçurumu azaltmaq üçün Məkan Ədaləti (Spatial Justice) konsepsiyasını irəli sürürlər.

Bu çərçivədə atılmalı olan addımlar:

İnklüziv Zonalaşdırma (Inclusive Zoning): Yeni tikilən hər bir böyük yaşayış kompleksində müəyyən faiz kvotanın sosial (aztəminatlı) mənzillər üçün ayrılmasının məcburiləşdirilməsi. Bu, müxtəlif gəlir qruplarının eyni məkanda inteqrasiyasına kömək edir.

Transit-Oriented Development (TOD): İctimai nəqliyyat xətlərinin məhz yoxsul və periferik məhəllələrin mərkəzə inteqrasiyası istiqamətində inkişaf etdirilməsi. Nəqliyyat əlçatanlığı sosial bərabərliyin ən birinci şərtidir.

Taktiki Urbanizm və Yaşıl Bərabərlik: Parkların və sosial obyektlərin şəhər xəritəsində mərkəzləşdirilmiş şəkildə deyil, "hər kəs üçün 15 dəqiqəlik piyada məsafədə" prinsipi ilə ədalətli

paylanması. Yerli icmaların abadlıq layihələrinə cəlb edilməsi məkan mənsubiyyətini gücləndirir.

Nəticə etibarilə, davamlı gələcək şəhərləri divarlarla bölünmüş anklavlar deyil, infrastrukturun hər bir vətəndaş üçün əlçatan olduğu, məkanca ədalətli və inteqrasiya olunmuş coğrafi sistemlər olmalıdır. Urban planlaşdırma sadəcə iqtisadi mənfəəti deyil, insan ləyaqətini və məkan ədalətini rəhbər tutmalıdır.

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Political Studies

Қазақстандағы урбанизациялық процестер: тенденциялар мен келешегі

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Кіріспе

Зерттеудің өзектілігі мен жалпы контексті:

Соңғы онжылдықтарда жаһандық дамудың басты экономикалық және демографиялық драйверлерінің бірі – урбанизация процесі болып табылады. Қазақстан Республикасында да бұл үрдіс соңғы жылдары айтарлықтай серпін алып, елдің әлеуметтік-экономикалық және кеңістіктік келбетін түбегейлі өзгертуде. Ресми статистикалық деректерге сәйкес, 2018–2022 жылдар аралығында елдегі қала халқының үлесі 57,6%-дан 61,5%-ға дейін өссе, соңғы көрсеткіштер бойынша урбанизация деңгейі 63,1%-ға жетіп, қала тұрғындарының саны 12,8 млн адамды, ал ауыл халқы 7,5 млн адамды құрады. Демографиялық және еңбек ресурстарын дамыту орталығы сарапшыларының болжамды есептеулеріне қарағанда, бұл қарқын сақталған жағдайда 2030 жылға қарай қала халқының үлесі 64,2%-ға, ал 2050 жылға қарай 69,4%–70%-ға дейін ұлғаймақ.

Урбанизацияның өсуі заманауи индустрияландыру мен сервистік экономиканың дамуымен тығыз байланысты болғанымен, бұл процестің қарқыны мен бағыты Қазақстан өңірлерінде біркелкі жүрмей отыр. Қалалану ағыны негізінен елдің үш ірі мегаполисіне – Астана, Алматы және Шымкент қалаларына бағытталған. Мәселен, Алматы қаласының халық саны соңғы 10 жылда 42,8%-ға өсіп, 2,3 млн адамнан асса, Алматы агломерациясының жалпы халық саны 3,8 млн адамнан асып түсті.

Ғылыми және әлеуметтік-экономикалық проблеманың қойылуы:

Бүгінгі таңда Қазақстандағы урбанизациялық процестер бірқатар терең демографиялық, экономикалық және инфрақұрылымдық сын-қатерлермен сүйемелденуде:

Өңіраралық және демографиялық диспропорциялар: Елдегі ішкі көші-қон сальдосы тек мегаполистерде оң көрсеткіш көрсетіп, солтүстік, шығыс және орталық облыстарда халық санының жүйелі түрде азаюына әкелуде. Еңбек және халықты әлеуметтік қорғау министрлігінің болжамы бойынша, қалыптасқан тенденциялар сақталса, 2050 жылға қарай солтүстік өңірлерде халық саны 600 мың адамға кеміп, ал оңтүстік өңірлерде (Алматы мен Шымкентті есептемегенде) 1,6 млн адамға артады, бұл оңтүстік пен солтүстік арасындағы халық тығыздығының 4 еселік алшақтығын тудырады.

«Жалған урбанизация» (Pseudo-urbanization) мен сервистік экономика шектеулері: Ауылдық жерлерден жаппай қоныс аудару халықты сапалы әрі өнімді жұмыс орындарымен қамтамасыз ету жылдамдығынан озып кетті. Қалаға келген мигранттардың басым бөлігі өзін-өзі бейресми қамту, курьерлік қызмет, такси немесе шағын сауда салаларында шоғырланып, еңбек өнімділігінің өсуіне толыққанды серпін бере алмай отыр.

Моноқалалардың стагнациясы мен инфрақұрылымның тозуы: Елдегі 27 моноқалада 1,4 млн адам тұрады (ел халқының 8%-ы), олар өнеркәсіп өнімінің 40%-ға жуығын өндіргенімен, кадрлардың кетуі, кен орындарының сарқылуы және коммуналдық

желілердің (су, жылу, электр) 55%–61%-дан 85%–90%-ға дейін тозуы сияқты күрделі түйткілдерге тап болуда.

Мегаполистердегі инфрақұрылымдық және экологиялық салмақ: Астана мен Алматы агломерацияларында ретсіз субурбанизация, тұрғын үй тапшылығы, әлеуметтік мекемелерге (мектептер, ауруханалар) салмақ түсуі және экологиялық жағдайдың нашарлауы байқалуда

Зерттеудің мақсаты мен міндеттері

Осы мақаланың басты мақсаты – Қазақстандағы урбанизациялық процестердің заманауи үрдістері мен факторларын, өңірлік демографиялық диспропорцияларды және моноқалалардың даму ерекшеліктерін кешенді талдау негізінде елдің аумақтық-кеңістіктік дамуы мен демографиялық саясатын оңтайландыру бойынша ғылыми негізделген ұсынымдар әзірлеу болып табылады.

Осы мақсатқа жету үшін мынадай зерттеу міндеттері қойылды:

Соңғы жылдардағы қала халқының динамикасы мен өңіраралық көші-қон ағындарының негізгі траекторияларын саралау.

Үш мегаполиске (Астана, Алматы, Шымкент) шоғырлану дәрежесін және «жалған урбанизация» белгілерін бағалау.

Солтүстік және оңтүстік өңірлер арасындағы демографиялық алшақтықтардың экономикалық тәуекелдерін анықтау.

Моноқалалардың әлеуметтік-инфрақұрылымдық жағдайын және оларды топтастыру бойынша мемлекеттік саясат шараларын талдау.

Ауылдық аумақтарды тұрақты дамыту мен агломерацияларды теңгерімді басқарудың тетіктерін ұсыну.

Деректер мен әдістер

Кез келген ауқымды әлеуметтік-экономикалық және демографиялық зерттеудің ғылыми негізділігі мен нәтижелерінің объективтілігі оның ақпараттық базасы мен таңдап алынған әдіснамалық аппаратының сапасына тікелей тәуелді. Қазақстан Республикасындағы урбанизациялық процестердің трансформациясын, агломерациялар мен моноқалалардың даму серпінін, сондай-ақ халықтың көші-қоны мен еңбек нарығындағы өзгерістерді зерттеу мақсатында кешенді методологиялық тәсілдер жүйесі құрылды. Зерттеудің дизайн-құрылымы бір-бірін толықтыратын сандық статистикалық, математикалық және сапалық институционалдық, концептуалдық әдістердің синтезіне негізделген. Мұндай тәсіл Қазақстанның кеңістіктік дамуындағы күрделі диспропорцияларды анықтап қана қоймай, олардың себеп-салдарлық байланыстарын терең түсінуге мүмкіндік береді.

Зерттеудің сенімділігі мен репрезентативтілігін қамтамасыз ету мақсатында ресми статистикалық, институционалдық, аналитикалық және нормативтік дереккөздердің көпдеңгейлі жүйесі пайдаланылды. Зерттеудің іргетасы ретінде Қазақстан Республикасы Стратегиялық жоспарлау және реформалар агенттігі Ұлттық статистика бюросының ресми мәліметтер базасы алынды. Атап айтқанда, 2014 жылдан 2025 жылға дейінгі уақыт кезеңін қамтитын динамикалық қатарлар талданды. Бұл хронологиялық шеңбер Қазақстандағы жаңа экономикалық циклдерді, пандемияға дейінгі және одан кейінгі миграциялық толқындарды, сондай-ақ ірі мегаполистердің институционалдық құрылу кезеңдерін толық қамтиды. Осы базадан қала және ауыл халқының саны, олардың пайыздық арақатынасының өзгеру серпіні, туу мен өлім-жітім көрсеткіштерінің өңірлік кесіндісі және өңіраралық, өңірішілік көші-қон ағындарының матрицалары іріктеліп алынды. Бұл мәліметтер ауылдан қалаға көшу тенденцияларының масштабтарын нақты математикалық түрде айқындауға қызмет етті.

Өткен кезеңдерді талдаумен шектелмей, болашақ тенденцияларды болжау үшін ҚР Еңбек және халықты әлеуметтік қорғау министрлігіне қарасты «Еңбек ресурстарын дамыту орталығы» АҚ сарапшылары әзірлеген ұзақ мерзімді аналитикалық есептер қолданылды. Бұл ақпарат көзі арқылы 2023–2030 жылдарға және 2050 жылға арналған демографиялық құрылым мен еңбек нарығының базалық және пессимистік сценарийлері зерттелді. Базалық сценарий ағымдағы трендтер сақталғандағы демографиялық жүктемені көрсетсе, келеңсіз сценарий экономикалық шоктар мен көші-қон ағындарының теріс сальдосы күшейген жағдайдағы өңірлік теңсіздіктердің өсу қаупін бағалауға мүмкіндік берді. Урбанизация процесі тек ірі қалалармен шектелмейтіндіктен, шағын және өнеркәсіптік қалалардың жағдайын бағалау үшін Экономикалық зерттеулер институтының жалпы халқы 1,4 миллион адамды құрайтын жиырма жеті моноқала бойынша жүргізген талдамалық шолулары тартылды. Бұл зерттеулер моноқалалардағы демографиялық депопуляция қарқынын, инженерлік-коммуникациялық инфрақұрылымның тозу деңгейін және жергілікті экономиканың қала құраушы ірі кәсіпорындарға тәуелділік индексін терең талдауға негіз болды. Сонымен қатар, нақты процестердің мемлекеттік бағдарламалармен сәйкестігін анықтау үшін ҚР Көші-қон саясатының 2022–2026 жылдарға арналған тұжырымдамасы, ҚР Аумақтық-кеңістіктік дамуының 2030 жылға дейінгі болжамды схемасы және Мемлекет басшысының моноқалалар мен агломерацияларды дамыту жөніндегі тапсырмалары контент-талдаудан өткізілді [1].

Алынған ауқымды эмпирикалық мәліметтерге терең ғылыми түсініктеме беру үшін халықаралық экономикалық география мен урбанистика ғылымдарында мойындалған классикалық және заманауи теориялар басшылыққа алынды. Ең алдымен, Х. Гейер мен Т. Контулидің сараланған урбанизация теориясы қолданылды. Бұл тұжырымдама бойынша мемлекеттің кеңістіктік дамуы бастапқы урбанизация, поляризацияның кері қайтуы және

контрурбанизация кезеңдерінен тұрады. Қазақстанның тәжірибесіне және Дж. Джиббстің эволюциялық модельдеріне бейімделген бұл теория еліміздің халық тым көп шоғырланған ірі агломерациялар мен демографиялық донорға айналып, тұрғындарын жоғалтып жатқан орташа және шағын қалалар арасындағы өтпелі кезеңде тұрғанын ғылыми тұрғыдан түсіндіреді. Оған қоса, елдегі қалалық елді мекендердің халық саны бойынша таралу үйлесімділігін және қалалар каркасының сапасын анықтау үшін Дж. Ципфтің «ранг-көлем» заңдылығы мен Ципф қисықтары қолданылды. Осы математикалық модель арқылы Қазақстандағы ірі мегаполистердің шектен тыс гипертрофиялық өсуі және орташа қалалар институтының дамымай қалуы математикалық дәлдікпен дәлелденді. Сапалық урбанизацияны бағалауда шынайы және жалған (псевдо) урбанизация концепциялары іске қосылды. Зерттеу барысында мигранттардың қалаға көшіп келгенімен, инфрақұрылымсыз шеткі аудандарда шоғырлануы осы жалған урбанизацияның белгісі ретінде қарастырылды. Бұл құбылыс халық өскен сайын өнімділік артатын «қала-өндіруші» және керісінше, тек әлеуметтік-инфрақұрылымдық салмақ көбейетін «қала-тұтынушы» модельдері аясында сарапталды [9].

Теориялық базаны эмпирикалық деректермен ұштастыру барысында бір-бірін толықтыратын кешенді сандық және сапалық әдістер жүйесі қолданылды. Ретроспективті және салыстырмалы статистикалық талдау арқылы қала халқы үлесінің 57,1 пайыздан 63,1 пайызға дейін өсу серпініне декомпозиция жасалып, Алматы, Астана және Шымкент мегаполистеріндегі он жылдық демографиялық динамика салыстырылды. Кеңістіктік қозғалыстың масштабтарын өлшеу үшін көші-қон сальдосы мен қарқындылық коэффициенттері есептелді. Бұл өңіраралық және өңірішілік көші-қон ағындарының бағыттарын, оң сальдосы бар магнит-өңірлер мен теріс сальдосы бар донор-өңірлердің аражігін ажыратуға көмектесті. Кеңістіктік диспропорцияларды сандық бағалау мақсатында демографиялық және еңбек ресурстық модельдеу әдісі қолданылды. Когорталық-компоненттік әдіс негізінде солтүстік өңірлерде халықтың шамамен 600 мың адамға азаюы және оңтүстік өңірлерде 1,6 миллион адамға артуы нәтижесінде екі макроөңір арасындағы халық орналасу тығыздығының төрт еселік алшақтығы дәлелденді. Сонымен қатар, урбанизацияның зардаптары мен моноқалалардың жай-күйін өлшеу үшін инфрақұрылымдық және сапалық индекстік бағалау әдістері тартылды. Моноқалалардағы энергетикалық, жылу және сумен жабдықтау желілерінің тозу пайызына жасалған макроэкономикалық талдау олардың критикалық деңгейге жеткенін көрсетсе, ірі агломерациялардағы еңбек өнімділігі мен күрделілік индекстері жаңадан қосылған тұрғындардың экономикалық тиімділігін айқындап берді. Осылайша, жинақталған дереккөздер мен озық теориялық тұжырымдамаларды нақты талдау әдістерімен біріктіру Қазақстандағы урбанизация мен өңірлік даму процестерін объективті, терең әрі көпөлшемді түрде бағалауға толыққанды ғылыми-әдіснамалық негіз қалады.

Нәтижелер

Кешенді түрде жүргізілген сараптамалық және статистикалық талдау нәтижелері Қазақстан Республикасындағы урбанизация процесінің соңғы онжылдықта бұрын-соңды болмаған қарқынмен дамып, көптеген мемлекеттік бағдарламаларда көрсетілген болжамды нормативтерден әлдеқайда озып кеткенін анықтап берді. Урбанизация – бұл тек қала халқы санының механикалық өсуі ғана емес, ол бүкіл қоғамның әлеуметтік-экономикалық құрылымын, еңбек нарығын және кеңістіктік орналасу жүйесін түбегейлі өзгертетін күрделі құбылыс. Ұлттық статистика бюросының ресми мәліметтеріне сүйенсек, соңғы он жылдың бедерінде елдегі қала халқының үлесі 57,1 пайыздан 63,1 пайызға дейін, яғни толық 6 пайыздық тармаққа ұлғайған. Осылайша, қала тұрғындарының абсолюттік саны 12,8 миллион адамға жетсе, ауыл халқы 7,5 миллион адам деңгейінде қалды. Бұл көрсеткіштер Қазақстанның аграрлық-индустриялық қоғамнан толыққанды постиндустриялық, қалалық қоғамға өту фазасының белсенді кезеңінде тұрғанын көрсетеді. Әсіресе, 2018–2022 жылдар аралығындағы ретроспективті динамиканы талдау барысында қала халқының қысқа мерзім ішінде 1,5 миллион адамға немесе 14,7 пайызға күрт көбейгені байқалды. Бұл феноменалды өсім екі негізгі демографиялық фактордың синергиясы есебінен қалыптасты: біріншіден, қалалық жерлердегі жас отбасылар есебінен қамтамасыз етілген жоғары табиғи өсім, екіншіден, ауылдық аймақтардан үздіксіз ағылған оң көші-қон сальдосы. Мәселен, тек 2022 жылдың өзінде қалалық елді мекендердің көші-қон сальдосы 60,1 мың адамды құрап, рекордтық көрсеткішті көрсетсе, дәл осы кезеңде ауылдық жерлерде халық саны 193 мың адамға немесе 2,5 пайызға азайып, теріс көші-қон сальдосы минус 67 мың адамды құрады. Ауылдан қалаға бағытталған бұл бір бағытты (one-way) миграциялық ағын болашақта да тоқтамайтындығын сарапшылардың ұзақ мерзімді болжамдары растайды. Еңбек ресурстарын дамыту орталығының демографиялық модельдеу сценарийлеріне сәйкес, ағымдағы базалық трендтер сақталған жағдайда қала халқының үлесі 2030 жылға қарай 64,2 пайызға немесе 14 миллион адамға, ал 2050 жылға қарай 70 пайызға жуықтап, 19,3 миллион адамға жетеді деп күтілуде. Алып аумағы бар мемлекет үшін халықтың 70 пайызының қалалық жерлерге шоғырлануы инфрақұрылымға, экологияға және азық-түлік қауіпсіздігіне тікелей әсер ететін үлкен сын-қатер болып табылады [2].

Алайда, зерттеу барысында анықталған ең басты мәселе – урбанизация процесінің ел аумағында біркелкі жүрмеуі. Өңіраралық көші-қон ағындарын кеңістіктік саралау нәтижесінде Қазақстанда демографиялық және еңбек ресурстарының өте қауіпті асимметриясы мен диспропорциясы қалыптасқаны дәлелденді. Ішкі көші-қонның бағыттарын талдау көрсеткендей, ел тұрғындары барлық қалаларға бірдей көшіп жатқан жоқ. Көші-қон сальдосының тұрақты оң көрсеткіштері тек республикалық маңызы бар үш ірі мегаполисте – Астана, Алматы, Шымкент қалаларында және Алматы облысында ғана тіркелген. Бұл аймақтар экономикалық, білім беру және әлеуметтік ресурстарды өзіне тартатын қуатты «гравитациялық орталықтарға» (growth poles) айналған. Елдің қалған барлық дерлік облыстарында созылмалы теріс көші-қон сальдосы байқалады, яғни бұл аймақтар мегаполистер үшін тек демографиялық донор рөлін атқарып отыр. Халықтың ең көп сыртқа кетуі экономикасы негізінен ауыл шаруашылығына негізделген оңтүстік облыстарда байқалады. Мәселен, Түркістан облысынан бір жыл ішінде 18,1 мың адам кеткен болса, олардың негізгі ағыны Шымкент, Алматы қалалары мен Алматы облысына бағытталған. Дәл осы тенденция Жамбыл облысында (минус 10,3 мың адам) және Жетісу облысында (минус 8,9 мың адам) байқалады. Бұл аймақтардағы аграрлық сектордағы жұмыссыздық пен жалақының төмендігі жастарды ірі қалаларға қоныс аударуға мәжбүрлейтін басты итермелеуші (push) факторлар болып табылады. Еңбек және халықты әлеуметтік қорғау министрлігінің перспективалық есептеулері қазіргі миграциялық

векторлар сақталған жағдайда 2050 жылға қарай елдің демографиялық картасы түбегейлі өзгеретінін ескертеді. Бұл өзгерістер ең алдымен солтүстік өңірлердегі терең демографиялық депопуляциядан көрініс табады. Солтүстік Қазақстан, Қостанай, Павлодар, Шығыс Қазақстан және Абай облыстарының халық саны алдағы онжылдықтарда жалпы алғанда 600 мың адамға дейін азаю қаупінің алдында тұр. Базалық сценарий бойынша Солтүстік Қазақстан облысы өз халқының 34 пайызын, Қостанай облысы 22 пайызын, ал Шығыс Қазақстан мен Абай облыстары 15–16 пайызын жоғалтпақ. Бұл стратегиялық маңызы бар, шекаралас және астықты аймақтардағы адами капиталдың сарқылуы тек экономикалық емес, ұлттық қауіпсіздікке де тікелей әсер ететін фактор. Ал дәл осы уақытта оңтүстік облыстардың халқы (Алматы мен Шымкент мегаполистерін есептемегеннің өзінде) 1,6 миллион адамға артады. Мұндай қарама-қайшы динамиканың нәтижесінде солтүстік пен оңтүстік макроөңірлер арасындағы халық орналасу тығыздығының диспропорциясы 4 еседен астам ұлғайып, оңтүстікте су және жер ресурстарына, әлеуметтік инфрақұрылымға түсетін салмақ сын көтермес деңгейге жетеді [3].

Урбанизацияның орташа қалалар мен өңірлік орталықтардың есебінен емес, тек ірі агломерациялардың шектен тыс, гипертұтынушылық өсуі есебінен жүзеге асып жатқаны зерттеудің басты ғылыми жаңалығының бірі болып саналады. Бұл үрдіс, әсіресе, Алматы қаласының мысалынан айқын көрінеді. Соңғы он жыл ішінде Алматы халқы 42,8 пайызға өсіп, 1,6 миллионнан 2,3 миллион адамға жетті. Ал қалаға күнделікті жұмыс істеуге немесе оқуға келіп-кететін, бірақ ресми тіркелмеген маятниктік еңбек мигранттарын қоса есептегенде, Алматы агломерациясының нақты күндізгі халық саны 3,8 миллион адамды құрайды. Сарапшылардың бағалауы бойынша, бұл көрсеткіш 2030 жылға қарай 4,5 миллион адамға жетуі әбден мүмкін. Осындай ауқымды экономикалық және демографиялық талдау барысында Қазақстандағы қалалану процесінде классикалық даму заңдылықтарынан ауытқу, яғни «жалған урбанизация» (pseudo-urbanization) және қаланың экономикалық драйвер емес, «қала-тұтынушы» (city-consumer) моделі басым екендігі анықталды. Жалған урбанизацияның бірінші себебі әкімшілік-аумақтық факторларға тікелей байланысты. Статистикалық қала халқының өсуі көбінесе экономикалық дамудан емес, қала маңындағы халық тығыз орналасқан ауылдық елді мекендерге қала мәртебесін беру немесе оларды қала аумағына қосу есебінен жасанды түрде жүзеге асты. Мұның ең жарқын мысалы – Астана қаласының іргесіндегі бұрынғы Қосшы, Қараөткел сияқты ауылдардың ресми қалалық статусқа ие болуы. Адамдар қала тұрғыны атанғанымен, олардың өмір сүру сапасы, инфрақұрылыммен қамтылуы қалалық стандарттарға толық сай келмейді. Бұған қоса, мегаполистердегі еңбек өнімділігінің стагнациясы псевдоурбанизацияның екінші, ең қауіпті симптомын ашты. Дәстүрлі экономикалық теория бойынша (қала-өндіруші моделі), халықтың қалаға шоғырлануы еңбек бөлінісін тереңдетіп, инновациялар мен өндіріс көлемін арттыруы тиіс еді. Алайда, талдау нәтижелері көрсеткендей, Алматы қаласындағы еңбек өнімділігінің индексі 2024 жылы 2019 жылғы деңгеймен салыстырғанда 99,9 пайызды ғана құраған. Бұл соңғы бес жылда жүз мыңдаған жаңа тұрғындардың қалаға қосылғанына қарамастан, әрбір жұмыскердің өндіретін қосылған құнының мүлдем өспегенін білдіреді. Жаңадан келген ішкі мигранттардың басым көпшілігі экономиканың нақты секторында, өңдеуші өнеркәсіпте немесе жоғары технологиялық салаларда жұмыс істемейді. Олар керісінше, өнімділігі өте төмен, бейресми қамту секторларында: такси қызметінде, курьерлік жеткізуде, көтерме-бөлшек саудада және қызмет көрсету саласында шоғырланған. Бұл адами капиталдың деградациясына әкеліп, қаланың инфрақұрылымына, жол желілеріне, экологиясына және әлеуметтік жүйесіне (мектептер мен ауруханаларға) орасан зор тұтынушылық жүктеме түсіреді. Осы тұрғыдан алғанда, Алматы агломерациясындағы шамадан тыс жүктемені жеңілдету, инфрақұрылымдық және экологиялық коллапстың алдын алу мақсатында жаңа «ақылды» (smart) Алатау қаласын салу бастамасы тек қала құрылысы

жобасы емес, елдің макроэкономикалық және демографиялық тұрақтылығын сақтап қалуға бағытталған маңызды кеңістіктік шешім ретінде бағалануы тиіс.

Мегаполистердің шектен тыс ісініп, өсуі аясындағы тағы бір өткір контраст – Қазақстандағы моноқалалардың қазіргі әлеуметтік-инфрақұрылымдық және демографиялық дағдарысы. Еліміздегі барлық 89 қаланың 27-сі немесе толықтай 30 пайызы моноқала мәртебесіне ие. Бұл қалаларда 1,4 миллион адам немесе ел халқының 8 пайызы тұрады және олар еліміздегі өнеркәсіп өнімінің 40 пайызға жуығын өндіретін стратегиялық маңызды индустриялық орталықтар болып табылады. Бірақ, нақты секторда байлық өндіріп отырған осы қалалар терең құлдырау кезеңін бастан кешіруде. Моноқалаларды кешенді талдау барысында бірнеше жүйелі проблемалардың беті ашылды. Бірінші кезекте – халықтың жүйелі түрде азаюы және қартаюы. 1999 жылдан бергі уақыт аралығында моноқалалардың жалпы халқы 3 миллионнан 1,5 миллион адамға дейін, яғни екі есеге қысқарған. Жастардың білім іздеп немесе жақсы жұмыс іздеп ірі қалаларға жаппай кетуі салдарынан бұл аумақтарда демографиялық қартаю процесі қатты үдеген: мұнда қарт адамдардың үлесі 11 пайыздан асады (республика бойынша орташа деңгей 7,8 пайызды құрайды). Екінші, өте күрделі мәселе – кеңес заманында салынған инженерлік инфрақұрылымның толықтай моральдық және физикалық тозуы. Су құбыры мен канализация желілерінің тозуы орташа есеппен 61 пайызды құраса, Арқалық, Балқаш, Шахтинск, Теміртау сияқты ірі өнеркәсіптік орталықтарда бұл көрсеткіш апаттық деңгейге – 90 пайызға дейін жеткен. Жылу және электр желілерінің тозуы орташа 55 пайызды, ал жекелеген қалаларда (Арқалық, Серебрянск, Шахтинск) 85 пайызды құраса, автомобиль жолдарының кемінде 40 пайызы қанағаттанарлықсыз жағдайда. Бұл инфрақұрылымдық коллапс моноқалалардағы тіршілік ету ортасының сапасын күрт төмендетіп, көші-қонды одан әрі ушықтыруда. Үшіншіден, қалалардың өміршеңдік цикліне тікелей әсер ететін табиғи фактор – Жаңаөзен, Арқалық, Риддер, Хромтау, Балқаш сияқты қалалардағы пайдалы қазбалар мен шикізат базасының бірте-бірте сарқылуы және қала құраушы ірі кәсіпорындардағы жұмыс орындарының объективті түрде қысқаруы. Бұл экономикалық базаның тарылуы жергілікті тұрғындар арасында әлеуметтік шиеленіс тәуекелдерін геометриялық прогрессиямен арттыруда. Осы түйінді мәселелерді шешу үшін мемлекеттік саясат бірыңғай тәсілден бас тартып, моноқалаларды даму әлеуетіне қарай үш топқа саралауды бастады. Экономикалық келешегі төмен, шикізаты таусылған шағын моноқалалардан (Арқалық, Ақсай, Абай, Жаңатас, Қаратау және т.б.) халықты ерікті түрде ішкіоблыстық және өңіраралық көшіру стратегиясы қолға алынды. Бұл мақсатта «Отбасы банк» арқылы жастар мен мамандарға 10 пайыз бастапқы жарнамен және 2–5 пайыздық өте төмен мөлшерлемемен арнайы жеңілдетілген ипотекалық бағдарламалар ұсыну тетіктері енгізіліп жатыр. Сонымен қатар, даму әлеуеті сақталған Кентау және Екібастұз сияқты қалаларда экономиканы бір салаға тәуелділіктен арылту (әртараптандыру) мен кешенді даму жоспарларын енгізу алғашқы оң нәтижелерін бере бастады. Қорыта келгенде, Қазақстандағы урбанизация процесі бір жағынан агломерациялардың экономикалық мүмкіндігінен асып түсетін жаппай шоғырлануын, екінші жағынан индустриялық базаның тірегі болып табылатын моноқалалар мен солтүстік өңірлердің қаңырап босап қалуын қатар алып жүрген өте күрделі әрі қарама-қайшылықты эволюциялық кезеңді бастан өткеруде. Осы зерттеудің нәтижелері елдің аумақтық-кеңістіктік саясатын шұғыл түрде қайта қарап, реттелетін және сапалы урбанизация парадигмасына көшудің қажеттілігін бұлтартпас статистикалық және аналитикалық фактілермен негіздеп берді.

Талқылау

Зерттеу нәтижелерінен алынған ауқымды эмпирикалық және статистикалық мәліметтерді кешенді түрде талқылау Қазақстандағы урбанизация процесінің тек сандық қана емес, терең сапалық, құрылымдық және институционалдық қайшылықтарға толы екенін көрсетеді. Елімізде қала халқының үлесі 63,1 пайыздан асып, өсу қарқыны бұрынғы болжамды нормативтерден айтарлықтай озып кеткенімен, бұл көрсеткіштерді халықаралық ғылыми теориялар мен парадигмалар, соның ішінде Дж. Джиббс, Х. Гейер және Т. Контулидің тұжырымдамалары аясында сараптау барысында ұлттық қалалану үрдісінің біркелкі еместігі, тіпті белгілі бір деңгейде деформацияланғаны айқын көрініс табады. Ғылыми және сараптамалық қоғамдастықта Қазақстандағы бұл құбылыс көбінесе «жалған урбанизация» немесе псевдоурбанизация терминімен сипатталады. Классикалық түсініктегі шынайы урбанизация өнеркәсіптік индустрияландырумен, технологиялық дамумен және жоғары өнімді жұмыс орындарының құрылуымен қатар жүруі тиіс болса, біздің жағдайда қала халқының күрт өсуі көбінесе ауылдық жерлердегі инфрақұрылымның шектеулігінен, жұмыссыздықтан және аграрлық сектордағы тоқыраудан қашқан ішкі көші-қонның ретсіз ағынымен сүйемелденіп отыр.

Бұл «жалған урбанизацияның» тағы бір айқын көрінісі – статистикалық иллюзия, яғни қала халқы үлесінің артуы тек демографиялық көшумен ғана емес, әкімшілік-аумақтық реформалардың нәтижесімен де байланысты болуы. Мәселен, Астана мен Шымкент сияқты мегаполистердің іргесінде орналасқан, халық тығыз қоныстанған Қосшы немесе Қараөткел сияқты ауылдық елді мекендерге қала мәртебесін беру немесе оларды қала шекарасына қосу арқылы статистикалық көрсеткіштер жасанды түрде жақсартылды. Алайда, атаудың өзгеруі тұрғындардың өмір сүру сапасын, инженерлік инфрақұрылымның дамуын немесе олардың еңбек нарығындағы статусын бірден қалалық стандарттарға жеткізе алмайды. Соның салдарынан Алматы сияқты ірі орталықтарда еңбек өнімділігі индексінің 2019 жылғы деңгейде қатып қалуы (стагнациялануы, яғни 99,9 пайызды көрсетуі) байқалады. Бұл өте қауіпті макроэкономикалық сигнал. Ол ірі мегаполистердің ұлттық экономиканы алға сүйрейтін «қала-өндіруші» (city-producer) моделінен шығып, тек дайын игіліктерді тұтынатын «қала-тұтынушы» (city-consumer) моделіне біржола ойысқанын айғақтайды. Ауылдан немесе шағын қалалардан үлкен шаһарға қоныс аударған мигранттардың басым көпшілігі өңдеуші өнеркәсіпте, IT немесе жоғары технологиялық салаларда емес, керісінше, еңбек өнімділігі өте төмен, қосылған құны аз бейресми секторда, атап айтқанда такси қызметінде, курьерлік жеткізуде, құрылыста және шағын көтерме-бөлшек саудада шоғырланады. Бұл «прекариат» (тұрақсыз жұмыспен қамтылғандар) тобының артуына әкеліп, қаланың экономикалық әлеуетін төмендетеді [4].

Көші-қон ағындарын талқылау барысында еліміздің кеңістіктік дамуындағы ауыр теңгерімсіздіктер назар аудартады. Оң сальдо тек үш республикалық маңызы бар қалада (Астана, Алматы, Шымкент) ғана қалыптасып, қалған өңірлік орташа қалалар мен ауылдардың қансырап, жүйелі түрде сиреп бара жатқаны байқалады. Бұл үрдіс ірі агломерациялар үшін орасан зор инфрақұрылымдық және экологиялық шиеленістерді туындатып отыр. Жыл сайын жүз мыңдаған жаңа тұрғындардың қосылуы тұрғын үй тапшылығын тудырып, бағаның негізсіз өсуіне (көпіршіктерге), қала көшелеріндегі шешілмейтін көлік кептелісіне, мектептер мен ауруханаларға түсетін сын көтермес салмаққа және экологиялық апатқа (қара түтін, смог) алып келуде. Бұл тәуекелдерді теңгерімдеу, мегаполистердің тұншығуына жол бермеу үшін мемлекет тарапынан жаңа серіктес қалаларды (мәселен, Алматы маңындағы Алатау «smart city» немесе G4 City жобалары) дамытудың, оларды тек «ұйықтайтын аудандар» емес, толыққанды өндірістік әрі сервистік орталықтар ретінде қалыптастырудың маңызы зор.

Осы алып агломерациялардың жарқыраған фасадының көлеңкесінде Қазақстан өнеркәсібінің күретамыры саналатын 27 моноқаланың тағдыры өте күрделі институционалдық тұйыққа тіреліп отыр. Елдегі өнеркәсіп өнімінің 40 пайызын өндіретін, 1,4 миллион адам тұратын бұл аумақтар қазіргі таңда терең әлеуметтік-экономикалық құлдырауды бастан кешіруде. 1999 жылдан бері олардың жалпы халқының үш миллионнан бір жарым миллионға дейін, яғни екі есеге азаюы – бұл жай ғана статистика емес, бұл тұтас бір өндірістік мәдениеттің жоғалуы. Жастар мен білікті мамандардың бұл қалалардан жаппай кетуі демографиялық қартаюды жеделдетіп, қарт адамдардың үлесін 11 пайыздан асырып жіберді. Оған қоса, кеңес дәуірінен мұраға қалған коммуналдық, су және жылу желілерінің тозу деңгейінің 61 пайыздан 90 пайызға дейін жетуі тіршілік ету ортасының қауіпсіздігіне тікелей қатер төндіреді. Ең үлкен қауіп – Жаңаөзен, Арқалық, Риддер сияқты қалалардағы негізгі қала құраушы кәсіпорындардың кен орындарының бірте-бірте сарқылуы. Жұмыс орындарының қысқаруы мен баламалы экономиканың жоқтығы моноқалаларды әлеуметтік шиеленіс пен наразылықтардың потенциалды ошақтарына айналдыру тәуекелін өте жоғары деңгейге көтереді [5].

Қалалану процесі қалалардың ғана емес, ауылдық аумақтардың да болмысын түбегейлі өзгертеді. Урбанизацияның өсуі халықтың демографиялық репродуктивті мінез-құлқы мен дәстүрлі отбасылық құндылықтарының трансформациялануымен өте тығыз байланысты. Ауылдан қалаға көшу адамның экономикалық статусын ғана емес, оның дүниетанымын да өзгертеді. Урбанистік ортада әйелдердің білім деңгейінің артуы, олардың еңбек нарығындағы экономикалық белсенділігінің жоғарылауы, қалалық пәтерлердегі тұрғын үй ауданының шектеулігі және ең бастысы, «бір баланың құны» (cost of raising a child) түсінігінің қалыптасуы (балабақша, сапалы білім, үйірмелер ақысы) көпбалалы отбасы моделінен бас тартуға және бала туу көрсеткішінің біртіндеп төмендеуіне тікелей ықпал етеді. Алайда, демографиялық ауысу бірден жүзеге аспайды. Ауылдан көшіп келген бірінші ұрпақ өкілдері өздерінің дәстүрлі репродуктивті көзқарасын қала ортасында да белгілі бір уақыт аралығында сақтайтындықтан, табиғи өсім күрт төмендеп кетпейді, бұл мегаполистердегі демографиялық бумды уақытша ұстап тұрған негізгі фактор болып табылады [7].

Осы ретте, соңғы жылдары ауылдық аумақтарда халық санының күрт азаюы және 500-ден астам (нақтырақ айтқанда 582) ауылдың толықтай жабылуы қоғамда ұлттық азық-түлік қауіпсіздігіне төнетін қауіп ретінде жиі талқыланады. Дегенмен, экономикалық талдау мен дамыған елдердің тәжірибесіне сүйенсек, бұл үрейдің ғылыми негізі шамалы. Мәселен, АҚШ, Германия немесе Беларусь сияқты елдерде ауыл шаруашылығының жоғары өнімділігі ауыл халқының басым болуына немесе қол еңбегіне емес, заманауи агротехнологияларға, механикаландыруға және ірі агрохолдингтердің тиімді менеджментіне тікелей тәуелді. Қазақстандағы негізгі проблема – ауылда адамның аздығы емес, ауыл шаруашылығының тым бөлшектеніп кетуі, ұсақ шаруа қожалықтарының басым болуы. Бұл еңбек өнімділігін тежейді, жаңа технологияларды (нақты егіншілік, тамшылатып суару, GPS-навигация) енгізуге кедергі келтіреді. Сондықтан, урбанизация жағдайында сапалы агроөнеркәсіптік кешенді ірілендіру, оларды мақсатты түрде субсидиялау мен толық цифрландыру мемлекеттің стратегиялық басымдығына айналуы тиіс. Халық саны аз болса да, технологиялық жағынан жарақтандырылған ауыл ғана елді азық-түлікпен қамтамасыз ете алады [8].

Урбанизация мен демографиялық үрдістердің осындай күрделі, көпқабатты мәселелерін оңтайлы басқару үшін мемлекеттік реттеу саясатын түбегейлі жаңғырту және жаңа институционалдық тәсілдерді енгізу өмірлік қажеттілікке айналып отыр. Мемлекет стихиялық көші-қонды бақылаусыз қалдыра алмайды. Бұл бағыттағы ең өзекті қадамдардың бірі – моноқалаларды олардың нақты экономикалық және даму әлеуеті бойынша қатаң саралау. Мемлекет басшысының тапсырмасына сәйкес моноқалаларды үш топқа бөлу

саясаты қолға алынды. Осыған орай, экономикалық әлеуеті төмен, шикізаты таусылған және қайта жаңғырту мүмкін емес шалғай елді мекендерден (Арқалық, Жаңатас, Қаратау, Абай сияқты қалалар) халықты шығаруды, яғни басқарылатын құлдырауды (managed decline) жүзеге асыру қажет. Бұл процесс міндетті түрде ерікті негізде, тұрғындарды экономикалық жағынан ынталандыру арқылы өтуі тиіс. Ол үшін «Отбасы банк» сияқты қаржы институттары арқылы қоныс аударушыларға небәрі 10 пайыз бастапқы жарнамен және 2-5 пайыздық өте төмен мөлшерлемемен арнайы жеңілдетілген ипотекалық несиелер ұсыну, сондай-ақ қомақты көтерме жәрдемақылар беру тетіктерін кеңейту ұсынылады [6].

Бұдан бөлек, геосаяси және экономикалық тұрғыдан аса қауіпті құбылыс – өңірлік демографиялық депопуляцияны еңсеру мәселесі кезек күттірмейді. 2050 жылға қарай солтүстік өңірлерде халықтың 600 мыңға азаюы және ресурстары шектеулі оңтүстікте 1,6 миллионға өсу қаупі елдің біртұтас кеңістіктік дамуына үлкен қатер. Бұл теңгерімсіздікті жою үшін бұған дейін жүзеге асырылған «Солтүстік–Оңтүстік» өңіраралық көші-қон бағдарламаларын қателіктерден сабақ ала отырып, қайта пішімдеу қажет. Мемлекеттік квоталармен шектелмей, корпоративтік мобильділік тетіктерін нығайту, яғни солтүстікке баратын инвесторларға салықтық преференциялар жасау арқылы жұмыс орындарын құру басты назарда болуы керек. Ал Астана, Алматы және Шымкент агломерацияларының инфрақұрылымдық жүктемесін жеңілдету үшін іргелес жатқан серіктес қалаларды толыққанды дамытуға басымдық берілуі қажет. Сонымен қатар, экономикалық әлеуеті сақталған, бірақ инфрақұрылымы тозған моноқалаларды апаттан аман алып қалу үшін 61-90 пайыз тозған су, жылу, электр желілерін кешенді жаңғыртуға ауқымды инвестициялар тарту талап етіледі. Қала құраушы кәсіпорындардың өмірін ұзарту үшін Риддер, Хромтау, Жезқазған, Теміртау, Балқаш сияқты индустриялық орталықтардың маңында мемлекеттік қолдаумен терең геологиялық барлау жұмыстарын жүргізіп, жаңа шикізат базаларын ашу – бұл қалалардың тек сақталып қалуының ғана емес, жаңа индустриялық серпіліс жасауының бірден-бір кепілі болмақ. Осылайша, Қазақстандағы урбанизация мен кеңістіктік даму саясаты жалаң сандық көрсеткіштерді қуудан арылып, сапалық, теңгерімді және әр өңірдің ерекшелігін ескеретін прагматикалық деңгейге көтерілуі тиіс [10].

Қорытынды

Жүргізілген кешенді ғылыми-сараптамалық, макроэкономикалық және демографиялық талдаулардың нәтижелерін қорытындылай келе, Қазақстан Республикасындағы урбанизациялық процестердің өте серпінді, жылдам қарқынмен жүріп жатқанын, алайда аумақтық, құрылымдық және сапалық тұрғыдан өте теңгерімсіз, қайшылықты сипатқа ие екендігін бұлтартпас фактілермен тұжырымдауға болады. Тәуелсіздік жылдарынан бастау алған, әсіресе соңғы онжылдықта күрт үдеген қалалану үрдісі елдің әлеуметтік-экономикалық ландшафтын, еңбек нарығының құрылымын және ұлттық кеңістіктік орналасу жүйесін түбегейлі трансформациялады. Зерттеу барысында жинақталған эмпирикалық мәліметтер, математикалық модельдеулер мен институционалдық бағалаулар бұл процестің тек сандық қана емес, терең саяси-экономикалық салдары бар екенін көрсетті. Осыған орай, зерттеу жұмысының түйінді қорытындылары мен мемлекеттік саясатқа бағытталған стратегиялық ұсынымдары біртұтас ғылыми пайым ретінде төмендегідей жүйеленіп, тарқатылады.

Бірінші кезекте, қалалану серпіні мен демографиялық болжамдардың ауқымын кеңінен бағамдау қажет. Ресми статистикалық деректерге сүйенсек, соңғы онжылдықта Қазақстандағы қала халқының үлесі 57,1 пайыздан 63,1 пайызға дейін өсіп, абсолюттік мәнде қала тұрғындарының саны 12,8 миллион адамға жетті. Бұл 6 пайыздық тармаққа өсу көрсеткіші өзінің тарихи және экономикалық салмағы бойынша орасан зор құбылыс болып табылады, өйткені ол миллиондаған адамның дәстүрлі ауылдық өмір салтынан индустриялық және постиндустриялық қалалық ортаға ауысқанын білдіреді. Демографиялық болжамдар мен когорталық-компоненттік модельдеу нәтижелері бұл қарқынның болашақта бәсеңдемейтінін, керісінше, жаңа серпінмен жалғасатынын айқын көрсетеді. Ағымдағы демографиялық трендтер мен көші-қон ағындары сақталған жағдайда, қала халқының үлесі 2030 жылы 64,2 пайызды (немесе 14 миллион адамды) құраса, 2050 жылға қарай бұл көрсеткіш 69,4–70 пайыздық (19,3 миллион адам) межеге жететін болады. Ел халқының жетпіс пайызының қалалық аумақтарда шоғырлануы мемлекеттік жоспарлау жүйесі үшін мүлдем жаңа сын-қатерлерді – тұрғын үймен қамтамасыз ету, энергетикалық қуат көздерін еселеп арттыру, экологиялық қауіпсіздік пен азық-түлік логистикасын қайта құру қажеттілігін тудырады.

Алайда, осы жаппай қалалану үрдісінің ең үлкен көлеңкелі тұсы – өңіраралық терең диспропорциялар мен соған байланысты туындайтын ұлттық деңгейдегі демографиялық тәуекелдер. Зерттеу дәлелдегендей, ішкі көші-қон ағыны ел аумағына біркелкі таралмай, негізінен үш ірі агломерациялық орталыққа – Астана, Алматы және Шымкент мегаполистеріне ғана бағытталып отыр. Осы тартылыс орталықтарының (growth poles) гравитациялық күші қалған өңірлердің, әсіресе солтүстік және шығыс облыстардың адами капиталын сорып алуда. Егер қалыптасқан осы стихиялық үрдістер мемлекет тарапынан пәрменді түрде реттелмесе, 2050 жылға қарай демографиялық карта танымастай өзгереді. Болжамдарға сәйкес, солтүстік өңірлерде халық саны 600 мың адамға дейін күрт азайып, тұтастай аудандар мен елді мекендердің қаңырап босап қалуына, шекаралық қауіпсіздіктің әлсіреуіне және астықты аймақтардағы жұмыс күшінің дефицитіне алып келеді. Ал дәл осы уақытта аумағы мен су ресурстары шектеулі оңтүстік облыстарда халық саны қосымша 1,6 миллион адамға артып, әлеуметтік инфрақұрылымның коллапсына әкелуі ықтимал. Бұл процестердің нәтижесінде оңтүстік пен солтүстік арасындағы халық орналасу тығыздығының 4 еселік алшақтығы туындайды, бұл біртұтас мемлекеттің экономикалық кеңістігін сақтап қалу үшін өте қауіпті тенденция болып саналады.

Сонымен қатар, зерттеу барысында анықталған ең өзекті макроэкономикалық қайшылық – Қазақстандағы қалалануды классикалық даму жолынан ауытқып, «жалған

урбанизация» (pseudo-urbanization) сипатына ие болуы. Ауылдан қалаға жаппай қоныс аудару процесі жоғары технологиялық, өнімді жұмыс орындарының құрылуымен, яғни шынайы индустрияландырумен толық сүйемелденген жоқ. Керісінше, қалаға келген жүз мыңдаған ішкі мигранттар экономиканың нақты секторына емес, еңбек өнімділігі төмен, әлеуметтік кепілдіктері жоқ бейресми қамту салаларына және қарапайым сервистік секторға (сауда, көлік, курьерлік қызмет) шоғырланды. Бұл ірі қалалардағы ЖӨӨ өсімінің сапасын төмендетіп, еңбек өнімділігінің стагнациясына әкеліп соқтырды. Бұған қоса, «жалған урбанизацияны» үдеткен тағы бір фактор – статистикалық манипуляциялар, яғни қала маңындағы халық тығыз қоныстанған ауылдық елді мекендерді әкімшілік шешімдермен қала аумағына қосу немесе оларға қала мәртебесін беру тәжірибесі. Бұл қадамдар статистикалық есепте қала халқының үлесін жасанды түрде өсіргенімен, шын мәнінде ол аймақтарда қалалық өмір сүру сапасын, толыққанды инфрақұрылымды және жоғары табысты еңбек нарығын қалыптастыра алған жоқ.

Осы алып мегаполистерге назар ауған тұста, ел экономикасының нақты индустриялық тірегі болып табылатын моноқалалардың қасіретті жағдайы назардан тыс қалмауы тиіс. Еліміздегі 27 моноқала ұлттық өнеркәсіп өндірісінің 40 пайызына жуығын қамтамасыз етіп отырғанымен, бүгінде олар жүйелі әрі өте қауіпті инфрақұрылымдық және экономикалық дағдарысты бастан кешіруде. Кеңес одағынан мұраға қалған инженерлік желілердің (су құбырлары, кәріз, жылу және электр желілері) амортизациялық тозу деңгейі 61 пайыздан бастап, кейбір қалаларда критикалық 90 пайызға дейін жеткен. Бұл кез келген уақытта ауқымды техногендік апаттарға әкелуі мүмкін екендігін білдіреді. Оның үстіне, көптеген моноқалалардың (мысалы, Арқалық, Жаңаөзен, Риддер) экономикалық базасы саналатын кен орындарының сарқылуы олардың монопрофильді экономикасын тығырыққа тіреп, жұмыссыздықтың өсуіне және халықтың, әсіресе жастардың жаппай көшуіне себеп болуда. Бұл қалаларды өздігінен сауығады деп күту үлкен қателік, сондықтан олар шұғыл түрде мемлекеттік араласуды қажет етеді.

Жоғарыда аталған түйінді мәселелер мен қайшылықтарды шешу, сондай-ақ стихиялық урбанизацияны басқарылатын, сапалы экономикалық өсім көзіне айналдыру мақсатында зерттеу тарапынан келесідей стратегиялық сараптамалық ұсынымдар (Policy Recommendations) әзірленді.

Біріншіден, аумақтық-кеңістіктік дамуды реттеу саясатын түбегейлі қайта қарау қажет. Үш ірі агломерацияға (Астана, Алматы, Шымкент) түсіп отырған орасан зор демографиялық, экологиялық және инфрақұрылымдық салмақты жеңілдету үшін полицентрлік даму моделіне көшу ұсынылады. Бұл ретте мегаполистердің іргесінен шағын серіктес қалаларды (satellite cities) немесе орташа қалаларды жедел әрі кешенді түрде дамыту стратегиясы іске қосылуы тиіс. Серіктес қалалар тек тұрғын үй массивтері (ұйықтайтын аудандар) ретінде емес, өз алдына тәуелсіз экономикалық базасы, индустриялық аймақтары және әлеуметтік инфрақұрылымы бар толыққанды өндірістік-сервистік хабтар ретінде жоспарлануы қажет. Бұл көші-қон ағынын мегаполистің орталығына емес, оның перифериясына бағыттап, агломерациялық жүйенің теңгерімін сақтауға мүмкіндік береді.

Екіншіден, моноқалаларды экономикалық және әлеуметтік сауықтыру бойынша өте прагматикалық әрі дифференциалданған саясат жүргізу талап етіледі. Барлық 27 моноқаланы бірдей құтқару мүмкін еместігін мойындай отырып, оларды нақты экономикалық даму әлеуеті бойынша саралау (триаж) қажет. Шикізаты толық таусылған, инфрақұрылымын қалпына келтіру экономикалық тұрғыдан тиімсіз, әлеуеті төмен шалғай моноқалалардан халықты басқа өңірлерге немесе даму нүктелеріне ерікті түрде қоныс аударуын мемлекеттік деңгейде жүйелі түрде ұйымдастыру қажет. Бұл процесті ауыр әлеуметтік соққысыз өткізу үшін «Отбасы банк» желісі арқылы қоныс аударушыларға арналған арнайы жеңілдетілген ипотекалық өнімдерді (бастапқы жарнасы төмен, жылдық

мөлшерлемесі 2–5 пайыз көлемінде) жаппай енгізу және оларға жаңа жерде орналасу үшін лайықты көтерме жәрдемақылар төлеу механизмін заңнамалық түрде бекіту ұсынылады. Ал әлеуеті бар моноқалалар үшін экономиканы әртараптандыру және инфрақұрылымды толық жаңғырту бағдарламаларын күшейту қажет.

Үшіншіден, урбанизация салдарынан ауылдық жерлерде халық санының күрт азаюы фонында ұлттық азық-түлік қауіпсіздігін қамтамасыз ету мақсатында ауыл шаруашылығын толықтай индустрияландыру бағдарламасын қолға алу стратегиялық маңызға ие. Ауылда жұмыс қолының азаюын трагедия ретінде емес, агроөнеркәсіптік кешенді технологиялық жаңғыртуға берілген мүмкіндік ретінде қарастырған жөн. Бұл бағытта ескірген, өнімділігі төмен ұсақ шаруашылықтардан бас тартып, заманауи агротехнологияларды (нақты егіншілік, автоматтандыру, тамшылатып суару) кеңінен қолданатын ірі агрохолдингтер мен кооперацияларды дамытуға мемлекеттік субсидияларды бағыттау қажет. Жоғары технологиялар мен қуатты техникалармен жабдықталған ауыл шаруашылығы ғана аз адам ресурсымен жоғары еңбек өнімділігін көрсетіп, елдің ішкі сұранысын ғана емес, экспорттық әлеуетін де қамтамасыз ете алады.

Қорытындылай айтқанда, Қазақстандағы қалалану процесі кері қайтымсыз тарихи және эволюциялық заңдылық. Мемлекеттің басты міндеті – бұл процесті тоқтату немесе тежеу емес, оны дұрыс арнаға бұрып, стихиялық көші-қоннан сапалы, экономикалық негізделген, инфрақұрылымдық жағынан қамтамасыз етілген және барлық өңірлердің мүддесін теңгерімді түрде ескеретін «ақылды урбанизацияға» (smart urbanization) көшу болып табылады. Осы зерттеу барысында ұсынылған шараларды кешенді түрде іске асыру еліміздің кеңістіктік дамуын жаңа сапалық деңгейге көтеріп, экономикалық тұрақтылық пен ұлттық қауіпсіздіктің берік іргетасын қалауға толыққанды негіз бола алады.

Пайданылған әдебиеттер

1. Қазақстан Республикасы Стратегиялық жоспарлау және реформалар агенттігі Ұлттық статистика бюросы (БНС АСПиР РК). Қазақстан Республикасының демографиялық жылнамалығы және халықтың көші-қоны (2014–2025 жж. статистикалық жинақтары).
2. «Еңбек ресурстарын дамыту орталығы» АҚ (ЦРТР) / ҚР Еңбек және халықты әлеуметтік қорғау министрлігі. Қазақстан Республикасының ұлттық демографиялық және еңбек ресурстарының 2030 және 2050 жылдарға арналған ұзақ мерзімді болжамдары.
3. «Экономикалық зерттеулер институты» АҚ (ERI). Қазақстанның моноқалаларының әлеуметтік-экономикалық дамуы және инфрақұрылымдық жағдайы бойынша талдамалық шолулар.
4. Қазақстан Республикасының Үкіметі. Қазақстан Республикасының Көші-қон саясатының 2022–2026 жылдарға арналған тұжырымдамасы.
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ҚАЗІРГІ ХАЛЫҚАРАЛЫҚ ҚАТЫНАСТАР ЖҮЙЕСІНДЕГІ ҚАЗАҚСТАН: ЖЕРГІЛІКТІ БАСҚАРУДЫ ЦИФРЛАНДЫРУ – ЖАҺАНДЫҚ ИНТЕГРАЦИЯ МЕН БӘСЕКЕГЕ ҚАБІЛЕТТІЛІК ҚҰРАЛЫ РЕТІНДЕ

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Аңдатпа

Бұл мақалада Қазақстанның қазіргі халықаралық қатынастар жүйесіндегі орны жергілікті басқару жүйесін цифрландыру призмасы арқылы қарастырылады. Жаһандану дәуірінде мемлекеттің сыртқы саяси беделі мен инвестициялық тартымдылығы оның ішкі, әсіресе жергілікті деңгейдегі басқару тиімділігімен тікелей байланысты. Зерттеу барысында жергілікті өзін-өзі басқаруды цифрландырудың (Smart City, e-gov) Қазақстанның халықаралық рейтингтердегі позициясына, халықаралық ұйымдармен (БҰҰ, ЭЫДҰ) ынтымақтастығына және «GovTech» (үкіметтік технологиялар) дипломатиясын қалыптастыруына тигізер ықпалы талданады. Әлемдік тәжірибеге (Эстония, Оңтүстік Корея) сүйене отырып, мақала цифрлық трансформацияның Қазақстан үшін тек ішкі даму құралы ғана емес, сонымен қатар «жұмсақ күш» (soft power) құралы екенін дәлелдейді.

Кілт сөздер: халықаралық қатынастар, цифрлық дипломатия, жергілікті басқару, GovTech, Smart City, e-Government, жаһандық интеграция.

Аннотация

В данной статье исследуется место Казахстана в современной системе международных отношений через призму цифровизации системы местного управления. В эпоху глобализации внешнеполитический имидж и инвестиционная привлекательность государства напрямую связаны с эффективностью внутреннего управления, особенно на местном уровне. В ходе исследования анализируется влияние цифровизации местного самоуправления (Smart City, e-gov) на позиции Казахстана в международных рейтингах, его сотрудничество с международными организациями (ООН, ОЭСР) и формирование дипломатии в сфере «GovTech» (государственных технологий). Опираясь на мировой опыт (Эстония, Южная Корея), статья доказывает, что цифровая трансформация для Казахстана является не только инструментом внутреннего развития, но и эффективным инструментом «мягкой силы» (soft power).

Ключевые слова: международные отношения, цифровая дипломатия, местное управление, GovTech, Smart City, e-Government, глобальная интеграция.

Abstract

This article explores Kazakhstan's place in the modern system of international relations through the prism of local governance digitalization. In the era of globalization, the foreign policy prestige and investment attractiveness of a state are directly linked to the efficiency of internal governance, particularly at the local level. The study analyzes the impact of local self-government

digitalization (Smart City, e-gov) on Kazakhstan's positions in international rankings, its cooperation with international organizations (UN, OECD), and the formation of "GovTech" (government technologies) diplomacy. Drawing on global experience (Estonia, South Korea), the article proves that digital transformation is not only an internal development tool for Kazakhstan, but also an effective instrument of "soft power".

Keywords: international relations, digital diplomacy, local governance, GovTech, Smart City, e-Government, global integration.

Кіріспе

Қазіргі халықаралық қатынастарда мемлекеттің жаһандық ықпалы тек экономикалық немесе әскери қуатпен емес, технологиялық дамумен және «цифрлық дипломатиямен» де өлшенеді. Осы орайда Қазақстанның әлемдік аренадағы беделі оның ішкі, әсіресе жергілікті басқару жүйесін цифрландыру деңгейіне тікелей тәуелді. Бұл мақаланың басты мақсаты – жергілікті өзін-өзі басқаруды цифрландырудың елдің халықаралық позициясына, жаһандық интеграциясына және геосаяси салмағына тигізетін әсерін ғылыми тұрғыдан көрсету.

Бір қарағанда ішкі әкімшілік мәселе болып көрінетін жергілікті басқаруды цифрландыру іс жүзінде бірнеше ауқымды халықаралық міндетті шешеді. Біріншіден, ол аймақтардағы әкімшілік кедергілер мен жемқорлықты жойып, транспаренттілікті арттыру арқылы шетелдік инвесторлар үшін қолайлы халықаралық климат қалыптастырады (инвесторлар көбіне нақты аймақ әкімдіктерімен жұмыс істейді). Екіншіден, жергілікті қызметтердің электронды экожүйесі БҰҰ мен Дүниежүзілік банк сияқты ұйымдардың рейтингтерінде Қазақстанның жаһандық сенімділігін бекітеді. Үшіншіден, бұл үрдіс Қазақстанға Орталық Азиядағы цифрлық көшбасшы ретінде өз технологияларын шетелге ұсынуға мүмкіндік беріп, мемлекеттің жаңа «GovTech» дипломатиясы мен «жұмсақ күш» (soft power) саясатын қалыптастырады.

Зерттеу әдістемесі

Осы ғылыми зерттеудің мақсаттары мен міндеттерін толыққанды жүзеге асыру үшін бір-бірін логикалық тұрғыдан толықтыратын кешенді ғылыми әдіснамалық аппарат қолданылды. Зерттеудің іргетасы ретінде салыстырмалы-тарихи талдау әдісі таңдалды. Бұл әдіс Қазақстанның жергілікті басқару жүйесін цифрландыру эволюциясын осы саладағы танылған әлемдік көшбасшылардың тәжірибесімен терең ұштастыра отырып қарастыруға мүмкіндік берді. Атап айтқанда, муниципалды қызметтерді толықтай электронды форматқа көшіріп, орталықтандырылмаған басқарудың озық үлгісін көрсеткен Эстонияның «e-Estonia» экожүйесі мен қалалық дипломатияны цифрлық технологиялар арқылы жаһандық деңгейде дамытқан Оңтүстік Кореяның Сеулдегі «Smart City» жобалары эталондық үлгі ретінде алынды. Бұл салыстыру Қазақстандағы «e-gov» және «Ашық үкімет» жобаларының даму динамикасын, олардың институционалдық артықшылықтары мен кемшіліктерін, сондай-ақ шетелдік тәжірибенің отандық басқару моделіне бейімделу деңгейін тарихи ретроспективада бағалауға жол ашты.

Теориялық тұжырымдардың нақтылығын, сенімділігін және объективтілігін қамтамасыз ету мақсатында эмпирикалық мәліметтерді талдау әдісі кеңінен қолданылды. Зерттеу барысында халықаралық ұйымдардың ресми сандық және сапалық есептеріне терең контент-талдау жасалды. Негізгі дереккөз ретінде Біріккен Ұлттар Ұйымының (БҰҰ) электрондық үкіметті дамыту индексі (EGDI), оның ішінде тікелей муниципалитеттердің дамуын өлшейтін жергілікті деңгейдегі онлайн-қызметтердің көрсеткіштері (Local Online Service Index – LOSI) алынды. Бұған қоса, Швейцариядағы IMD зерттеу орталығының Жаһандық бәсекеге қабілеттілік рейтингінің (IMD World Competitiveness Ranking) мемлекеттік басқарудың тиімділігі, ашықтығы мен транспаренттілігіне қатысты

индикаторлары сарапталды. Осы статистикалық деректерді өңдеу арқылы жергілікті әкімдіктер қызметін цифрландырудың Қазақстанның халықаралық инвестициялық тартымдылығына және жаһандық сенімділігіне тигізетін тікелей әсері өлшенді.

Жалпыұлттық статистика мен жаһандық индекстерден бөлек, макродеңгейдегі трансформацияның микродеңгейде, яғни нақты аймақтарда қалай жүзеге асып жатқанын дәлелдеу үшін тәжірибелік зерттеуге негізделген кейс-стади әдісі арнайы қолданылды. Зерттеу нысаны ретінде еліміздің екі ірі мегаполисіндегі цифрлық жобалар таңдап алынды. Біріншісі – Астана қаласы әкімдігінің жанынан құрылған «iKOMEK» бірыңғай байланыс орталығы. Бұл орталықтың қала басқарудағы халықаралық ISO стандарттарын енгізу тәжірибесі және оның шетелдік делегациялар үшін GovTech бағытындағы тәжірибе алмасу хабына айналу процесі егжей-тегжейлі зерттелді. Екіншісі – Алматы қаласындағы «Smart Almaty» жобасы аясындағы инвесторларға жер телімдерін бөлу мен қала құрылысын басқарудың геоақпараттық жүйелері (ГАЖ). Осы екі нақты кейсті талдау барысында олардың тек жергілікті тұрғындардың тұрмысын жеңілдетіп қана қоймай, сондай-ақ БҰҰ Даму бағдарламасының «Тұрақты қалалар» (SDG 11) мақсаттарымен және ЕҚЫҰ-ның жемқорлыққа қарсы стандарттарымен қаншалықты интеграцияланғаны жан-жақты ашып көрсетілді. Жинақталған бұл әдіснамалық кешен мақаланың ғылыми негіздемесін күшейтіп, жергілікті басқаруды цифрландыру халықаралық қатынастардың пәрменді құралы екендігі туралы ұсынылған гипотезаның өміршеңдігін дәлелдеуге толық мүмкіндік берді.

Нәтижелер

Жүргізілген кешенді зерттеу барысында Қазақстанның жергілікті басқару жүйесін цифрландыру үрдісінің халықаралық қатынастарға тигізетін ықпалын айқындайтын бірқатар маңызды ғылыми және практикалық нәтижелер алынды. Ең алдымен, бұл үрдіс мемлекеттің жаһандық рейтингтердегі позициясын түбегейлі жақсартуға ықпал еткені анықталды. Біріккен Ұлттар Ұйымының 2022-2024 жылдарға арналған «Электрондық үкімет» (E-Government Survey) жаһандық зерттеуінің қорытындысына сәйкес, Қазақстан әлемнің 193 елінің ішіндегі бәсекелестікте өте жоғары позицияларды иеленіп, соңғы деректер бойынша электрондық басқаруды дамыту жөніндегі алғашқы 30 мемлекеттің қатарына сенімді түрде енді. Зерттеу көрсеткендей, бұл ауқымды халықаралық жетістікке жетуде тек орталық министрліктердің жұмысы ғана емес, ең бастысы – жергілікті атқарушы органдар қызметтерінің бірыңғай «e-Gov» порталына және мобильді қосымшаларға толық интеграциялануы шешуші рөл атқарған. Тұрғындар мен бизнеске ең жақын орналасқан муниципалитеттердің қызметін автоматтандыру транспаренттілікті күрт арттырды. Әсіресе, отандық «Ашық әкімдік» және «Ашық бюджет» порталдарының жұмысы Экономикалық ынтымақтастық және даму ұйымының (ЭЫДҰ) сарапшылары тарапынан жіті зерттеліп, азаматтық қоғамды жергілікті өзін-өзі басқару ісіне тікелей тартудың, сыбайлас жемқорлық тәуекелдерін төмендетудің халықаралық эталоны ретінде жоғары бағаланды.

Бұл институционалдық жетістіктер құрғақ статистикалық сандармен ғана шектелмейді, олар мемлекеттің халықаралық инвестициялық тартымдылығына тікелей әсер ететін прагматикалық нәтижелерге ұласты. Зерттеу нәтижесі көрсеткендей, жергілікті басқаруды цифрландыру тікелей шетелдік инвестициялардың (ТШИ) көлемі мен сапасына тығыз байланысты. Өйткені трансұлттық корпорациялар мен ірі шетелдік инвесторлар жаңа нарыққа кірер кезде орталық биліктің мәлімдемелерінен гөрі, нақты аймақтардағы жергілікті бюрократияның деңгейіне, инфрақұрылымға қосылудың ашықтығына баса назар аударады. Осы орайда Астана мен Алматы қалаларында толыққанды енгізілген «Smart City» (Ақылды қала) цифрлық экожүйелері шетелдік бизнес үшін әкімшілік кедергілерді барынша азайтты. Атап айтқанда, коммерциялық нысандар құрылысына рұқсат алу процестерін толық цифрландыру, инвестициялық мақсаттағы жер телімдерін бөлудің геоақпараттық жүйелерін

(ГАЖ) іске қосу жергілікті билік пен шетелдік инвесторлар арасындағы қатынастарды мейлінше ашық әрі болжамды етті. Мұның айқын көрінісі ретінде Астана қаласының цифрлық басқару моделін атап өтуге болады. Ол Біріккен Ұлттар Ұйымының Тұрақты даму мақсаттарына (әсіресе, SDG 11: «Тұрақты қалалар мен елді мекендер» индикаторына) толықтай сай келетіндіктен, Дүниежүзілік банк тарапынан бүкіл Орталық Азия аймағы үшін үлгілі муниципалды модель ретінде ресми танылды. Бұл Қазақстанның аймақтарын халықаралық капитал үшін сенімді хабқа айналдыруда.

Сонымен қатар, зерттеу барысында анықталған ең концептуалды және халықаралық қатынастар теориясы үшін маңызды жаңалық – Қазақстанның жергілікті өзін-өзі басқаруды цифрландырудағы озық тәжірибесін халықаралық аренада өзіндік «жұмсақ күш» құралы ретінде сәтті қолдана бастауы болды. Егер бұрын цифрлық жүйелер тек ішкі тәртіпті реттеу үшін ғана қызмет етсе, енді ол Қазақстанның сыртқы саясатының белсенді элементіне айналды. Мәселен, 2023-2024 жылдар аралығында Қазақстан өзінің толықтай пилоттық сынақтан өткен «E-gov», жергілікті әкімдіктерге арналған электрондық құжат айналымы және «Smart Data Ukimet» технологияларын Тәжікстан мен Қырғызстан мемлекеттеріне, сондай-ақ Африка құрлығындағы бірқатар дамушы елдерге экспорттау туралы стратегиялық келісімдерге қол қойды. Бұл нәтижелер мемлекеттің жаңа цифрлық дипломатиясының (GovTech экспорт) қалыптасқанын көрсетеді. Жергілікті басқару технологияларын экспорттау Қазақстанның халықаралық қатынастардағы дәстүрлі рөлін түбегейлі өзгертіп, оны жай ғана қазба байлықтары мен шикізат экспорттаушы мемлекет деңгейінен, басқа елдердің мемлекеттік аппаратын жаңғыртуға көмектесетін интеллектуалдық цифрлық шешімдерді провайдер-мемлекет деңгейіне дейін көтергенін ғылыми түрде дәлелдейді.

Талқылау

Осы зерттеу аясында алынған нәтижелерді талқылау барысында Қазақстанның жергілікті басқаруды цифрландыру тәжірибесінің әлемдік озық үлгілермен қаншалықты сабақтасатыны, сондай-ақ қандай бірегей институционалдық ерекшеліктерге ие екендігі айқын көрініс тапты. Мәселен, мемлекеттің халықаралық имиджін қалыптастырудағы Эстонияның тәжірибесін алсақ, бұл ел өзінің «e-Residency» бағдарламасы арқылы цифрлық жергілікті қызметтерді әлемнің кез келген нүктесіндегі шетелдік азаматтар мен кәсіпкерлерге ұсыну арқылы жаһандық кеңістіктегі бәсекеге қабілеттілігін арттыра алды. Қазақстан да дәл осы стратегиялық бағытты ұстана отырып, Астана халықаралық қаржы орталығы (АХҚО) мен «Astana Hub» инновациялық экожүйесінің мүмкіндіктерін пайдалана отырып, шетелдік IT-мамандар мен инвесторлар үшін жергілікті тіркеу, салық төлеу және визалық қызметтерді толықтай цифрландырды. Бұл қадам ішкі жергілікті басқару жүйесінің құралдары қалайша ауқымды халықаралық қатынастардың пәрменді тетігіне айнала алатындығының айқын мысалы болып табылады. Сонымен қатар, қалалық дипломатияның (paradiplomacy) дамуына Оңтүстік Кореяның тәжірибесі зор ықпал еткенін ерекше атап өткен жөн. Сеул қаласының әкімдігі Дүниежүзілік ақылды қалалар ұйымын (WeGO) құрып, халықаралық деңгейде жергілікті басқару жүйелерін цифрландыру саясатын тікелей басқарып, өзінің технологиялық ықпалын жүргізіп отыр. Осы жаһандық үрдіске сәйкес, Қазақстанның Астана және Алматы сияқты ірі мегаполистері де аталған халықаралық ұйымдарға толыққанды мүше бола отырып, өздерінің дербес қалалық дипломатиясын белсенді түрде дамытуда. Яғни, бүгінгі таңда сыртқы саясат тек орталық министрліктер деңгейінде ғана емес, жоғары деңгейде цифрланған әкімдіктер мен муниципалитеттер арқылы да тікелей жүзеге асырылуда.

Дегенмен, жергілікті басқару жүйесін жаппай цифрландырудың халықаралық қатынастар мен ұлттық қауіпсіздік тұрғысынан өзіндік жасырын сын-қатерлері де жоқ емес екенін ескеру қажет. Бұл бағыттағы ең өткір мәселелердің бірі – киберқауіпсіздік және

геосаяси тәуекелдер. Жергілікті деректер базасы, оның ішінде азаматтардың жеке мәліметтері мен стратегиялық маңызы бар қалалық инфрақұрылым туралы мәліметтер (сумен, жылумен, электр қуатымен жабдықтау жүйелері) түрлі геосаяси мүдделер қақтығысы кезінде трансшекаралық хакерлік топтардың немесе кибершабуылдардың басты нысанына айналуы әбден мүмкін. Бұған қоса, технологиялық тәуелділік мәселесі де халықаралық аренадағы белгілі бір осалдықты тудырады. Жергілікті басқару жүйелерін цифрлық форматқа көшіру барысында Қазақстан көбінесе Америка Құрама Штаттары, Қытай немесе Еуропалық Одақ елдерінің жетекші вендорлары ұсынатын бағдарламалық қамтамасыз ету платформалары мен аппараттық кешендеріне тәуелді болып қалуда. Бұл жағдай жаһандық технологиялық бәсекелестік немесе санкциялық текетірестер ушыққан сәтте мемлекеттің цифрлық егемендігіне нұқсан келтіруі ықтимал фактор ретінде ғылыми ортада қызу талқылануда.

Алайда, осы аталған технологиялық және геосаяси қауіптерге қарамастан, жергілікті басқаруды цифрландыру Қазақстанның көпвекторлы сыртқы саясатының жаңа әрі аса тиімді басымдығына айналып үлгерді. Бұл құрал мемлекеттік аппараттың, соның ішінде аймақтық биліктің жоғары деңгейдегі транспаренттілігін қамтамасыз ете отырып, батыс демократияларымен және Дүниежүзілік банк, Азия даму банкі сияқты ірі халықаралық қаржы институттарымен барынша сенімді, ашық диалог орнатуға берік негіз қалайды. Жергілікті әкімдіктердің инфрақұрылымдық және әлеуметтік жобаларға бөлінген бюджетті қалай игеріп жатқаны туралы мәліметтердің «Ашық деректер» (Open Data) порталдары арқылы кез келген уақытта жаһандық бақылаушылар мен инвесторларға қолжетімді болуы Қазақстанды заманауи халықаралық қатынастар жүйесінде жауапты, ашық әрі сенімді стратегиялық әріптес ретінде айшықтайды. Мұндай ашықтық өз кезегінде елдің инвестициялық рейтингін көтеріп, оның жаһандық экономикалық және саяси процестерге интеграциялануын жеделдете түседі.

Қорытынды

Қорыта келгенде, осы ғылыми зерттеудің нәтижелері жергілікті басқару жүйесін цифрландыру тек мемлекеттің ішкі бюрократиялық процестерін оңтайландыратын немесе халыққа қызмет көрсету сапасын жақсартатын техникалық құрал ғана емес екендігін толықтай дәлелдеп отыр. Қазіргі күрделі халықаралық қатынастар жүйесінде бұл үрдіс Қазақстанның жаһандық кеңістікке тиімді интеграциялануының, шетелдік капитал үшін инвестициялық тартымдылығын арттырудың және ең бастысы, «GovTech» дипломатиясы арқылы өзіндік «жұмсақ күшін» ілгерілетудің аса маңызды стратегиялық элементіне айналды. Мемлекеттің халықаралық беделі бұдан былай тек макроэкономикалық көрсеткіштермен немесе табиғи ресурстардың көлемімен ғана емес, жергілікті деңгейдегі әкімдіктер мен муниципалитеттердің азаматтар мен инвесторларға қаншалықты транспарентті, ашық және цифрлық тұрғыда қолжетімді қызмет көрсете алатындығымен де тікелей өлшенеді.

Бұл тұжырымды әлемдік озық тәжірибе де толық растайды. Эстония, Оңтүстік Корея және Сингапур сияқты дамыған мемлекеттердің тарихи тәжірибесі көрсеткендей, жергілікті өзін-өзі басқару экожүйесін тиімді цифрландыру арқылы бұл елдер әлемдік саясаттағы өздерінің геосаяси және экономикалық салмағын геометриялық прогрессиямен арттыра алды. Қазақстан үшін де бұл бағыт стратегиялық басымдыққа ие, себебі цифрлық трансформацияны өңірлік деңгейде сәтті жүзеге асыру еліміздің Орталық Азия аймағындағы технологиялық және дипломатиялық көшбасшылығын сақтап қалудың басты кепілі болып табылады. Отандық IT-компаниялар мен мемлекеттік органдардың біріккен жобалары көршілес елдердің нарығына шығып, Қазақстанды технологиялық экспорттаушы мемлекет ретінде жаңа деңгейге көтеріп үлгерді.

Болашақта Қазақстанның халықаралық позициясын одан әрі нығайту және жоғарыда аталған сын-қатерлерге төтеп беру үшін бірқатар стратегиялық қадамдарды жүзеге асыру қажет. Біріншіден, жергілікті цифрлық жүйелер мен аймақтық инфрақұрылымдық деректер базасын сыртқы кибершабуылдардан қорғау мақсатында халықаралық киберқауіпсіздік одақтарымен интеграцияны барынша күшейту талап етіледі. Екіншіден, отандық IT-шешімдерді, электрондық үкімет платформаларын және "Smart City" технологияларын халықаралық нарыққа (әсіресе, дамушы елдерге) экспорттау бағытын Қазақстан Республикасының мемлекеттік сыртқы саясатының ресми доктринасының бір бөлігі ретінде заңнамалық деңгейде бекіту ұсынылады. Бұл қадамдар Қазақстанның заманауи халықаралық қатынастардағы цифрлық дипломатиясының әлеуетін толық ашып, ұлттық мүддені жаһандық деңгейде қорғауға сенімді негіз қалайды.

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Agricultural Sciences

Determination of Irrigation Regime and Optimization of Hydromodule Schedule for Forest Nursery

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Abstract
The article discusses the detailed methodology for designing irrigation systems, determining the irrigation regime, and optimizing the hydromodule schedule for a forest nursery. The research object is a 23-hectare nursery divided into four main sections. Based on soil-climatic parameters and active layer depth, irrigation norms and hydromodules were calculated for each section. Analysis of the uncompleted hydromodule schedule showed a peak discharge of 0.508 l/s/ha. Through optimal rescheduling of irrigation periods, the maximum hydromodule was reduced to 0.300 l/s/ha (a 41% reduction), and the maximum water intake (Q_gross) of the farm decreased from 156 l/s to 93 l/s.
Keywords: Irrigation regime, hydromodule, completed schedule, nursery, water demand, evapotranspiration.

Introduction and Theoretical Foundations

The irrigation regime of agricultural and forestry crops forms the basis for the design and efficient operation of irrigation systems. It covers the following main issues: determination of total water demand, establishment of irrigation and watering norms, and determination of watering schedules and multiplicity.

Total Water Demand (Evapotranspiration): Moisture is removed from the soil in two ways — physical evaporation (from the surface) and plant transpiration. Their sum constitutes the total

water demand (E) of the crop. Physical evaporation dominates at the initial stage of plant development, while transpiration dominates in later phases.

1. A. Kostiakov's empirical formula (determining water demand by yield):

$$E = K_m \times Y$$

Where: E — crop water demand over the entire vegetation period (m³/ha); Y — projected yield (t/ha); K_m — water demand coefficient (m³/t).

2. Prof. I. Chkhenkeli's formula (for Georgian conditions):

$$E = K_{ch} \times \sum d$$

Where: ∑d — sum of air humidity deficits (in mm) during the calculation period; K_ch — bioclimatic water demand coefficient (from field experiments).

Calculation Parameters of the Forest Nursery

When calculating the parameters of the forest nursery (total area 23 ha), the nursery is divided into 4 main sections:

1. Seeding / Cutting section: F = 6.9 ha (30%), active layer depth H = 0.6 m;
2. Growing section: F = 9.2 ha (40%), active layer depth H = 0.7 m;
3. Mother plantation: F = 2.3 ha (10%), active layer depth H = 0.8 m;
4. Landscaping (decorative): F = 4.6 ha (20%), active layer depth H = 0.6 m.

Initial soil-physical calculation parameters:

- Soil field capacity: r_fc = 32.5%;
- Soil bulk density: α = 1.27 g/cm³;
- Pre-irrigation allowable moisture: r_lim = 26.0%;
- Replenishable moisture deficit: Δr = 6.5%.

Irrigation norm (m) is calculated using Kostiakov's formula:

$$m = 100 \times H \times \alpha \times (r_{fc} - r_{lim})$$

Calculated irrigation norms by section:

- Seeding and cutting (H = 0.6 m): m = 100 × 0.6 × 1.27 × 6.5 = 495.3 ≈ 550 m³/ha;
- Growing section (H = 0.7 m): m = 100 × 0.7 × 1.27 × 6.5 = 577.85 ≈ 650 m³/ha;
- Mother plantation (H = 0.8 m): m = 100 × 0.8 × 1.27 × 6.5 = 660.4 ≈ 700 m³/ha;
- Landscaping (decorative) (H = 0.6 m): m = 100 × 0.6 × 1.27 × 6.5 = 495.3 ≈ 550 m³/ha.

Hydromodule (q) represents the water discharge (l/s) required to irrigate 1 ha of area per unit of time:

$$q = (m \times 1000) / (T \times 86400) \times \alpha\%$$

Where: T — irrigation duration in days; α% — section relative area (fraction); 86400 — number of seconds in a day.

Uncompleted Hydromodule Schedule and Analysis

Table 1: Data for Uncompleted Hydromodule Schedule

N	Sections	Area (ha)	Area (%)	Irrig. N	Start	End	Days	Irrig. Norm (m^3/ha)	q (per ha)	q (per % area)
1	Seeding	6.9	30	1	1.06	10.06	10	550	0.636	0.190
				2	5.07	10.07	5		1.273	0.381
				3	10.08	20.08	10		0.636	0.190
2	Growing	9.2	40	1	10.04	25.04	15	650	0.501	0.200
				2	5.05	15.05	10		0.752	0.300
				3	10.06	20.06	10		0.752	0.300
				4	10.07	20.07	10		0.752	0.300
				5	20.08	30.08	10		0.752	0.300
3	Mother	2.3	10	1	10.04	25.04	15	700	0.540	0.054
				2	5.05	15.05	10		0.810	0.081
				3	10.06	20.06	10		0.810	0.081
				4	20.07	30.07	10		0.810	0.081
				5	20.08	30.08	10		0.810	0.081
4	Landscape	4.6	20	1	20.06	30.06	10	550	0.636	0.127
				2	20.07	30.07	10		0.636	0.127
				3	20.08	30.08	10		0.636	0.127

Analysis of the uncompleted schedule: The graph is constructed by summing hydromodule values over time. When irrigation of several sections coincides, ordinates are summed (e.g., in decade IV: growing 0.200 + mother plantation 0.054 = 0.254 l/s/ha; at the end of decade VIII: growing 0.300 + mother 0.081 + landscaping 0.127 = 0.508 l/s/ha). Such uneven peaks require sizing the irrigation network for maximum discharge (0.508 l/s/ha), which significantly increases capital construction costs.

Figure 1: Uncompleted Hydrograph (Peak: 0.508 l/s/ha)

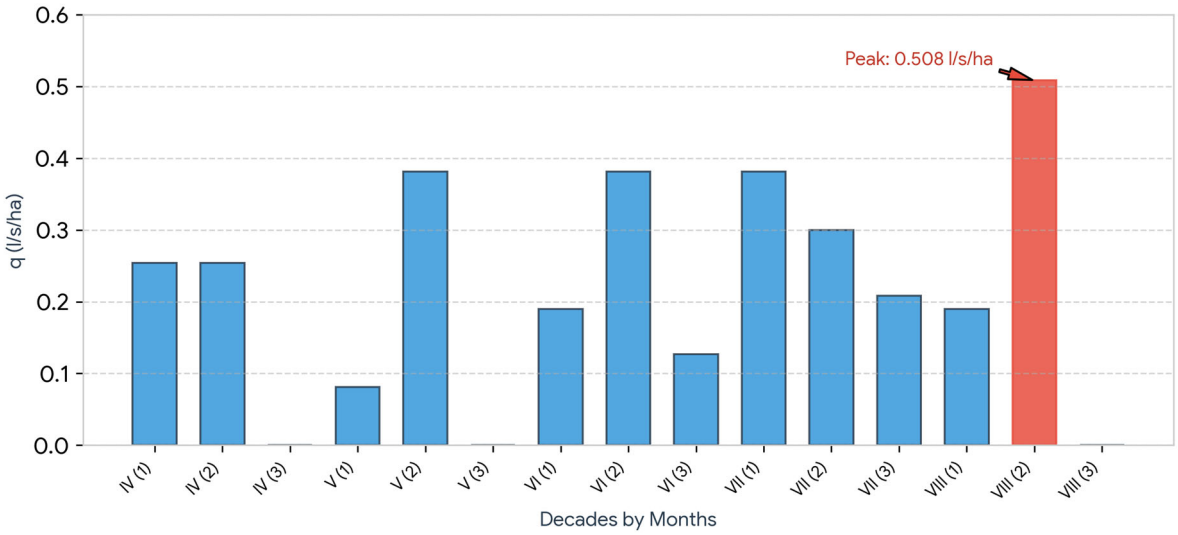


Figure 1: Uncompleted Hydromodule Schedule (Peak Discharge: 0.508 l/s/ha)

Optimization of Hydromodule Schedule (Completed)

To complete and optimize the schedule, irrigation periods were shifted by ±(5–6) days:

• In May, mother plantation irrigation shifted to May 1–10, growing section to May 10–20;

• In June, seeding and mother plantation schedules were compressed/shifted;
• In August–September, mother plantation and landscaping irrigation extended until September 5.

The optimized water demand and completed hydromodule data are presented in Table 2.

Table 2: Optimized Water Demand and Hydromodules of the Nursery

N	Start	End	q Max (l/s/ha)	Q_net (l/s)	Q_gross (l/s)	Eff. (η)
1	10.04	25.04	0.200	46	61	0.75
2	1.05	10.05	0.081	18	24	0.75
3	10.05	20.05	0.300	70	93	0.75
4	25.05	5.06	0.190	44	59	0.75
5	5.06	10.06	0.162	37	49	0.75
6	10.06	20.06	0.300	70	93	0.75
7	20.06	30.06	0.127	29	39	0.75
8	1.07	10.07	0.190	44	59	0.75
9	10.07	20.07	0.300	70	93	0.75
10	20.07	30.07	0.162	37	49	0.75
11	5.08	15.08	0.190	44	59	0.75
12	15.08	25.08	0.300	70	93	0.75
13	25.08	5.09	0.162	37	49	0.75

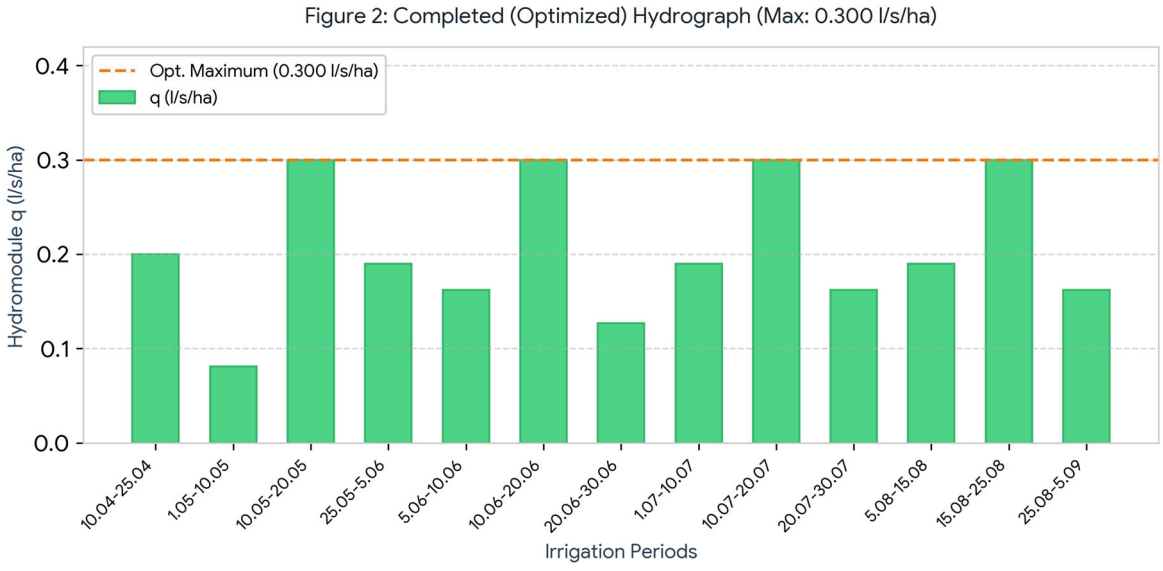


Figure 2: Completed (Optimized) Hydromodule Schedule (Max: 0.300 l/s/ha)

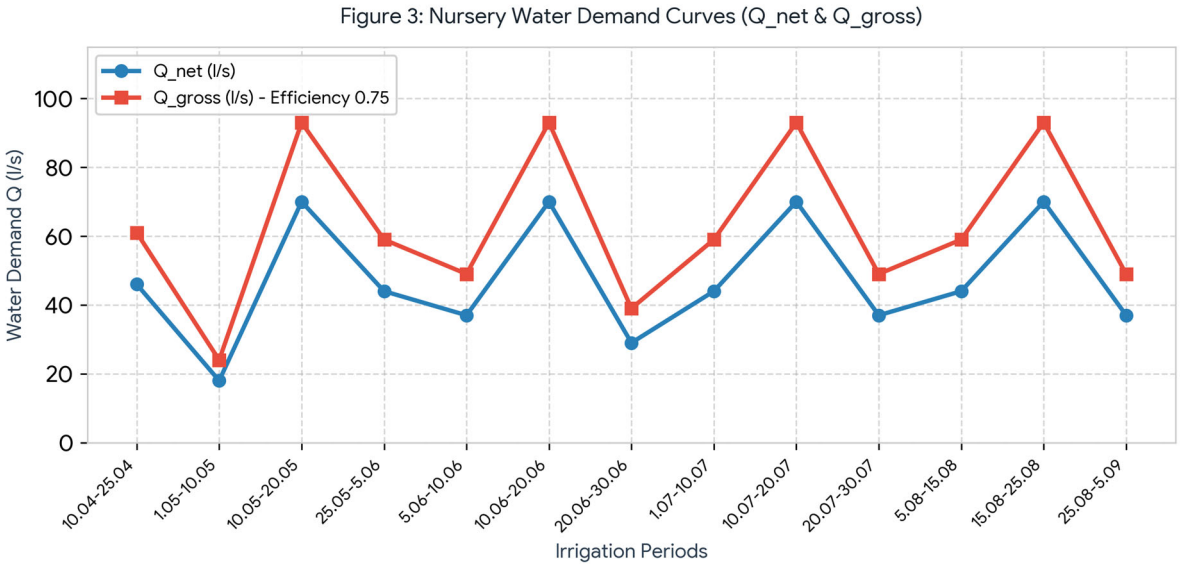


Figure 3: Nursery Water Demand Curves (Q_net & Q_gross)

Conclusion and Recommendations

As a result of completing the hydromodule schedule, the maximum ordinate decreased from 0.508 l/s/ha to 0.300 l/s/ha (a 41% reduction). Accordingly, the maximum water intake (Q_gross) required for the farm is 93 l/s instead of the initial 156 l/s.

This optimization allows to:

1. Reduce the design diameter/cross-section of irrigation canals and pipelines;
2. Lower capital construction costs of the irrigation system;
3. Ensure rational and even distribution of water resources throughout the vegetation period.

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Proceedings of the 14th International Scientific Conference «Foundations and Trends in Modern Learning» (October 8-9, 2026). Berlin, Germany, 2026. 285p

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