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ANALYSIS OF THE IMPACT OF HUMAN FACTORS ON TRAFFIC SAFETY AND RAILWAY TRANSPORT RELIABILITY

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Annotatsiya. Mazkur maqolada inson omili xatolarining salbiy ta'sirini minimallashtirish orqali temir yo'l transporti faoliyatining ishonchliligi va xatosizligini oshirish masalalari tadqiq etilgan. O'zbekiston Respublikasida ishlab chiqarishdagi jarohatlanishlar hamda poyezdlar harakati xavfsizligi buzilishlari bo'yicha statistik ma'lumotlarning tahlili asosida hodisalarning muhim qismi texnologik jihatdan mas'ul va muhim operatsiyalarni bajaruvchi xodimlar faoliyati bilan bog'liq ekanligi aniqlangan. Xavfsizlikni ta'minlashda asosan texnik vositalarga tayanilgan yondashuvdan inson–mashina tizimlarini kompleks boshqarishga o'tish zarurligi ilmiy jihatdan asoslab berilgan. Inson xatolarining yuzaga kelishiga olib keluvchi asosiy omillar aniqlanib, ularni temir yo'l transporti texnologik jarayonlarini loyihalash hamda amaliyotga joriy etish bosqichlarida kamaytirishning ustuvor yo'nalishlari belgilangan. Taklif etilgan ilmiy-amaliy yondashuvlarni joriy etish poyezdlar harakati xavfsizligi darajasini oshirishga, shuningdek temir yo'l transporti tizimining barqaror va ishonchli faoliyat yuritishini ta'minlashga xizmat qiladi.

Kalit so'zlar: temir yo'l transporti, harakat xavfsizligi, ishonchlilik, inson omili, inson xatolari, ishlab chiqarishdagi jarohatlanishlar, inson–mashina tizimi.

Аннотация. В статье рассматриваются вопросы повышения надежности и безошибочности работы железнодорожного транспорта путем минимизации влияния человеческих ошибок. На основе анализа статистических данных по производственному травматизму и нарушениям безопасности движения поездов в Республике Узбекистан

показано, что значительная часть инцидентов обусловлена действиями персонала, выполняющего критически важные технологические операции. Обоснована необходимость перехода от преимущественно технического обеспечения безопасности к комплексному управлению человеко-машинными системами. Выделены основные причины возникновения человеческих ошибок и определены направления их минимизации на этапах проектирования и реализации технологических процессов железнодорожного транспорта. Реализация предложенных подходов способствует повышению уровня безопасности движения и надежности функционирования железнодорожной системы.

Ключевые слова: железнодорожный транспорт, безопасность движения, надежность, человеческий фактор, человеческие ошибки, производственный травматизм, человеко-машинная система.

Abstract. The article discusses issues related to improving the reliability and accuracy of railway transport by minimizing the impact of human error. Based on an analysis of statistical data on occupational injuries and train safety violations in the Republic of Uzbekistan, it is shown that a significant proportion of incidents are caused by the actions of personnel performing critical technological operations. The need to move from predominantly technical safety measures to comprehensive management of human-machine systems is justified. The main causes of human error are identified and ways to minimize them at the design and implementation stages of railway transport technological processes are determined. The implementation of the proposed approaches contributes to improving traffic safety and the reliability of the railway system.

Keywords: rail transport, traffic safety, reliability, human factor, human error, occupational injuries, human-machine system.

Introduction

The transport industry is one of the industries with a high degree of risk in terms of injury hazards. An analysis of statistical data on occupational injuries and train safety violations shows that existing railway safety measures are largely focused on technical and regulatory aspects, while the human factor remains an insufficiently formalized and controllable element of the system [1]. The recurrence of accidents, the increase in the number of serious injuries and the steady increase in traffic safety violations indicate the need to develop scientifically based methods for minimizing human error. In these conditions, improving the reliability and accuracy of railway transport operations is impossible without a systematic analysis of human-machine processes, an assessment of the professional characteristics of personnel, and the introduction of methods for managing the human factor at the design and implementation stages of technological processes.

Research Methodology

According to information from the press service of the Ministry for Combating Poverty and Employment of the Republic of Uzbekistan, in the first six months of 2024,

416 workers were injured in 387 accidents, 303 suffered serious injuries and 12 suffered minor injuries. Unfortunately, 101 cases resulted in death (Table 1 and Figure 1) [2].

Table 1. Results of accident analysis by category.

Names of accidents	Years				
	2020	**2021**	**2022**	**2023**	**6 months of 2024**
Accidents	867	784	846	812	387
Victims	914	612	702	657	416
Serious injuries	498	594	635	598	303
Minor injuries	46	65	84	56	12
Death	165	98	194	235	101
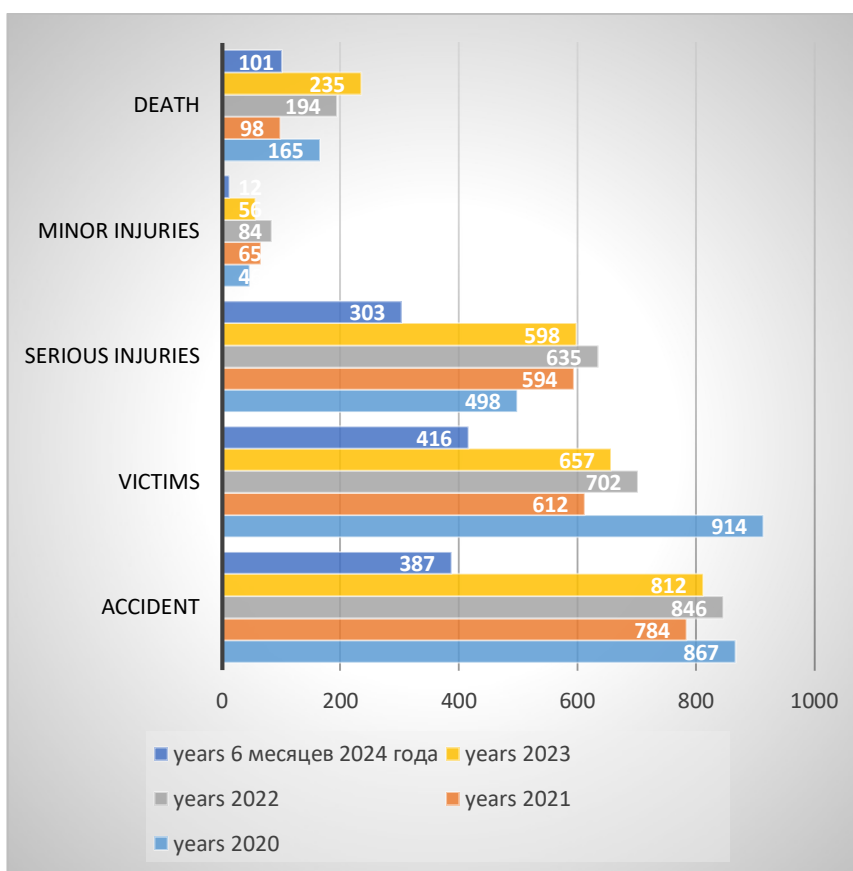
Figure 1. Dynamics of accidents at industrial facilities in the Republic of Uzbekistan.

The results of an analysis of accidents at industrial facilities in the Republic of Uzbekistan for the period 2020-2024 showed that the incidence of serious injuries has been increasing over the past five years. The main reasons for serious injuries to workers in production are employers' failure to comply with working conditions that meet safety and hygiene requirements in accordance with Article 211 of the Labor Code [3]. Moreover, the main sites of industrial accidents with serious injuries are in the transport sector of the country's economy. In this regard, cases of violations of train traffic safety at Uzbekistan Temir Yullari JSC for 2019-2023 were analyzed separately by economic sector (Figure 2 and Figure 3).
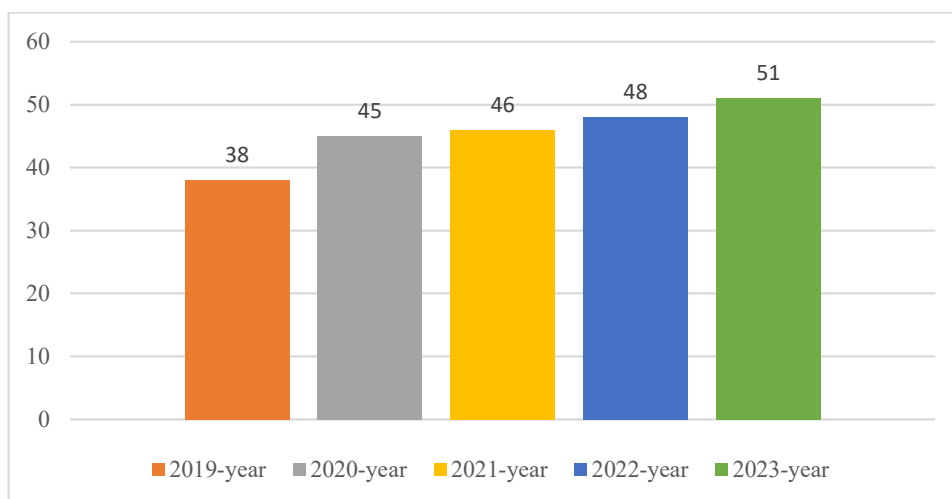
Figure 2. Train safety violations over the past five years at Uzbekistan Temir Yullari JSC.

An analysis of train safety violations over the past five years at Uzbekistan Temir Yullari JSC shows an average annual increase of 6.8% in this indicator.
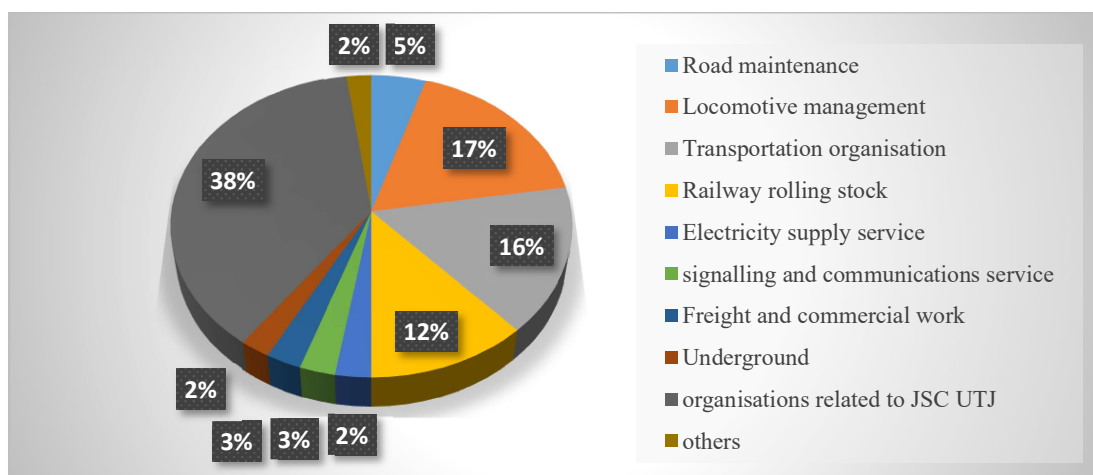
Figure 3. Train traffic safety violations by operating companies Uzbekistan Temir Yullari JSC.

Table 2. Analytical information on traffic safety violations in the area of regional railway junctions in 2019-2023 in the organisation of transport at regional railway junctions belonging to ministries and departments.

Areas where incidents occurred in the organisation of transport	Total number	Years				
		2019	2020	2021	2022	2023
Tashkent RRJ	20	3	4	2	5	6
Kokand RRJ	5	1	2	-	-	2
Bukhara RRJ	5	1	1	1	1	1
Kungrad RRJ	2	-	-	-	1	1
Karshi RRJ	1	-	-	-	-	1
Termez RRJ	3	-	1	1	-	1

An analysis of traffic safety violations at regional railway junctions in 2019-2023 on access roads belonging to ministries and departments shows that 41 incidents occurred on the branches adjacent to the territory of the Tashkent Railway Unitary Enterprise, and the total number of traffic safety violations amounted to 56%. On the railway access roads adjacent to the territory of the unitary enterprise "RRJ Kokand", 11 accidents occurred, which is 16% of the total number of accidents. There were 10

accidents on the railway sidings adjacent to the territory of the Bukhara Railway Unitary Enterprise, accounting for 12% of the total number of accidents. Four accidents occurred on the railway sidings adjacent to the territory of the RRJ Kungrad unitary enterprise, accounting for 4% of traffic safety violations [4]. On the railway branch adjacent to the territory of the RRJ Karshi unitary enterprise, on the contrary, there was one incident. Seven accidents occurred on the access roads adjacent to the territory of the Termez RRJ unitary enterprise, accounting for 10% of traffic safety violations. An analysis of these analytical data by year can be seen in Table 2.

The results of the analysis of safety violations by transport workers showed that about 82% of cases occurred during station work and 18% during cargo handling. The main parties responsible for safety violations by transport workers are station duty officers, fleet duty officers, train dispatchers, chief conductors, and train receivers [5].

Analyses of compliance with occupational safety requirements were carried out at UTJ JSC enterprises (Figure 4, Figure 5, and Table 3).
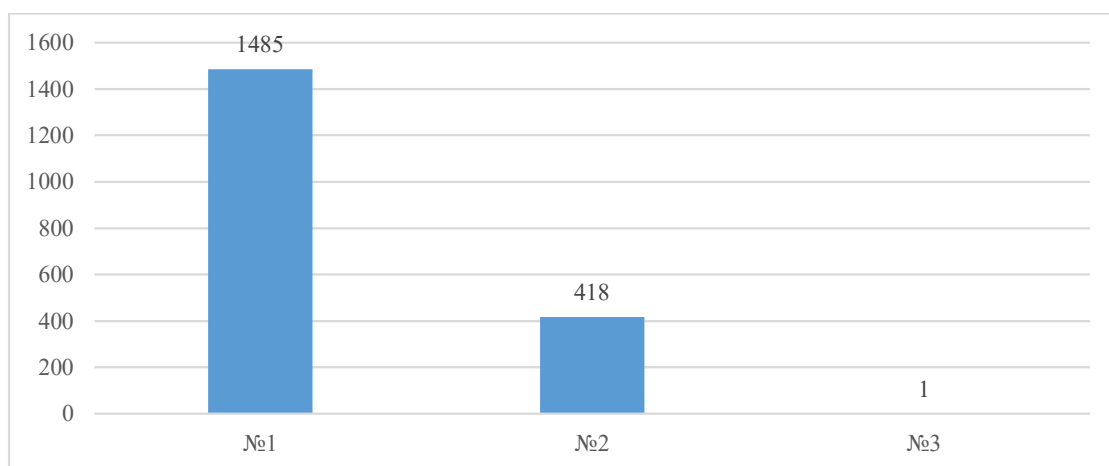
Figure 4. Graph showing the number of warning tickets issued by occupational health and safety officers in 2023.
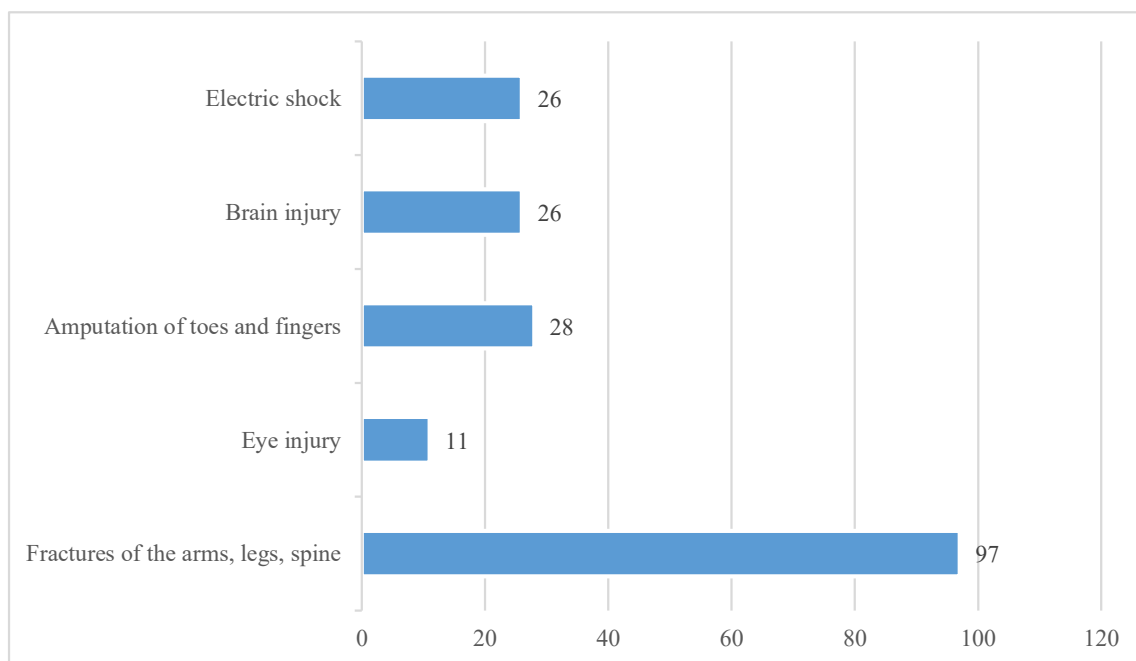
Figure 5. Recorded types of injuries sustained by employees of UTJ JSC at work**.**

Table 3. Types of accidents recorded at UTJ JSC enterprises in 2017–2023.

№	Accidents (year)	Total number of accidents	Of these:		
			Fatal accidents	Accidents involving serious injuries	Accidents with minor injuries
1	2017 year	34	6	19	9
2	2018 year	21	5	10	6
3	2019 year	30	5	18	7
4	2020 year	23	5	13	5
5	2021 year	23	6	14	3
6	2022 year	30	7	17	6
7	2023 year	27	9	11	7
Total:		188			

In Uzbekistan, occupational injuries on access roads and during the unloading of semi-wagons are a pressing issue linked to insufficient mechanisation and compliance with safety regulations. Risk factors include the use of manual labour on access roads, outdated equipment and low levels of mechanisation at many industrial enterprises, inadequate training and a weak system for monitoring compliance with safety standards. The main causes of injuries are: workers falling while unloading railcars, manual handling of cargo and equipment, which increases the likelihood of injury, and insufficient coordination between railway rolling stock operators and workers involved in unloading [6].

Despite ongoing reforms and modernisation, injuries still occur in Uzbekistan, especially at older or remote industrial stations. In particular, there is a high risk of injury during manual unloading or when working with outdated machinery.

One measure to improve the situation is to modernise equipment. In recent years, Uzbekistan has begun to actively modernise its railway infrastructure. Mechanised unloading systems, such as wagon tippers, are being installed at major junctions, reducing the involvement of people in dangerous processes. The Ministry of Labour and Social Protection, in conjunction with Uzbekistan Temir Yullari JSC, has launched a programme to train workers at industrial enterprises, particularly in the areas of safety compliance and working with modern machinery. The introduction of stricter safety requirements and the implementation of control and audit systems on industrial access roads also contributes to a reduction in occupational injuries.

It has been established that the following shortcomings in the field of occupational health and safety, technical and industrial safety are chronically repeated at the enterprises of JSC "UTY":

non-compliance with technological processes;

non-compliance by the head of the enterprise and the chief engineer with the basic provisions on occupational health and safety, insufficient consideration of occupational health and safety issues;

insufficient attention paid by middle managers to violations of occupational health and safety rules during working hours;

low level of knowledge of occupational health and safety among the enterprise's management and middle managers;

low quality of initial guidance and professional practice for newly hired employees;

newly hired employees are assigned to unqualified specialists and the work process remains uncontrolled;

employees involved in train traffic should not be dismissed from work even if they have not undergone periodic medical examinations within the established time limits;

Failure to carry out three-stage occupational health and safety checks in accordance with the requirements of Regulation on Occupational Safety Briefings–313, or superficial checks and non-participation of company managers, chief engineers and occupational health and safety representatives in these checks.

All kinds of occupational safety briefings for middle managers are conducted contrary to the requirements of Regulation on Occupational Safety Briefings–312.

Analysis and Results

The statistical data presented on occupational injuries in the Republic of Uzbekistan for the period 2020–2024 indicate a persistently high level of risk in the transport sector, which is traditionally one of the most injury-prone areas of the economy. Of particular concern is the increase in the number of serious injuries and fatalities, which points to systemic problems in ensuring occupational safety and the reliability of production processes.

An analysis of accidents shows that the transport industry ranks first in terms of the number of serious industrial injuries, which is directly related to the high complexity of technological operations, increased responsibility of personnel and a significant share of manual labour. These circumstances create conditions in which the human factor becomes one of the key risk elements affecting both the level of industrial injuries and the safety of train traffic.

An additional analysis of train safety violations at Uzbekistan Railways JSC for 2019–2023 shows a steady upward trend in the number of such violations, averaging 6.8% per year. This fact indicates a decline in the reliability of technological processes and points to the insufficient effectiveness of existing safety management mechanisms. At the same time, a significant proportion of violations are recorded in regional railway junctions, where traffic intensity and the complexity of interaction between participants in the transport process are particularly high.

The distribution of traffic safety violations by enterprise and type of work shows that approximately 82% of incidents occur during station operations, and the main perpetrators of violations are station duty officers, fleet duty officers, train dispatchers, chief conductors, and train receivers. These categories of employees are directly

involved in train traffic management and the performance of critical technological operations, which confirms the decisive role of the human factor in determining the level of safety and reliability of rail transport.

Conclusion

An analysis of accidents at Uzbekistan Railways JSC enterprises for the period 2017–2023 also confirms the persistent presence of injuries, including fatal and serious cases. This indicates chronic problems in the areas of occupational health and safety, technical and industrial safety, as well as the insufficient effectiveness of preventive measures. The recurring shortcomings identified – non-compliance with technological processes, a formal approach to occupational safety, low level of training of management and newly hired employees, weak control over compliance with safety requirements – are clearly organizational and human in nature.

Thus, the results of the analysis of industrial injuries and train traffic safety violations clearly demonstrate that human error is one of the key factors affecting the reliability and accuracy of railway transport operations. The high proportion of incidents related to staff actions confirms the need to move from a predominantly technical approach to safety to comprehensive management of human-machine systems.

In this regard, there is an urgent need to develop scientifically sound methods and models for minimizing the impact of human factors, aimed at improving the reliability of technological processes, reducing the likelihood of human error and ensuring the stable and safe operation of rail transport. Solving this problem is the basis of this study.

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DESIGN OF THE MECHANICAL MACHINING PROCESS FOR PARTS WITH COMPLEX GEOMETRY

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Annotatsiya. Ushbu maqolada murakkab konfiguratsiyaga ega detallarni mexanik ishlov berish jarayonini loyihalashning nazariy va amaliy jihatlari ko'rib chiqilgan. Zamonaviy CNC dastgohlari, CAD/CAM tizimlari hamda raqamli ishlab chiqarish texnologiyalaridan foydalanish orqali yuqori aniqlik va samaradorlikka erishish yo'llari tahlil etiladi. Texnologik jarayonni bosqichma-bosqich loyihalash, kesish rejimlarini tanlash va ishlab chiqarish sifatini oshirish masalalariga alohida e'tibor qaratilgan.

Kalit so'zlar: murakkab konfiguratsiya, mexanik ishlov berish, texnologik jarayon, CNC dastgohlar, CAD/CAM, aniqlik.

Аннотация. В данной статье рассмотрены теоретические и практические аспекты проектирования процесса механической обработки деталей сложной конфигурации. Проанализированы пути достижения высокой точности и эффективности за счёт использования современных станков с ЧПУ, систем CAD/CAM и цифровых производственных технологий. Особое внимание уделено поэтапному проектированию технологического процесса, выбору режимов резания и вопросам повышения качества производства.

Ключевые слова: сложная конфигурация, механическая обработка, технологический процесс, станки с ЧПУ, CAD/CAM, точность.

Abstract. This article examines the theoretical and practical aspects of designing the mechanical machining process for parts with complex geometry. The use of modern CNC machines, CAD/CAM systems, and digital manufacturing technologies to achieve high accuracy and efficiency is analyzed. Particular attention is paid to the step-by-step design of the technological process, selection of cutting parameters, and issues related to improving production quality.

Keywords: complex geometry, mechanical machining, technological process, CNC machines, CAD/CAM, accuracy.

Introduction

The current stage of development of the machine-building industry requires the production of products that meet high demands for accuracy, reliability, and

competitiveness. In particular, the manufacture of parts with complex geometry is considered one of the most responsible and technologically challenging areas of modern industry. Such parts have curved and spatially complex surfaces, and their production involves significantly higher requirements for accuracy, surface quality, and geometric stability. Therefore, the issue of scientifically sound and correct design of the mechanical machining process is of special importance.

Parts with complex shapes are widely used in aviation and aerospace engineering, automotive manufacturing, power engineering machinery, medical device manufacturing, and modern robotics. Components used in these fields typically operate under high loads, vibrations, and temperature effects. As a result, their dimensional accuracy and mechanical strength directly affect the reliability of the entire system. Under such conditions, machining on conventional universal machines often fails to provide sufficient efficiency.

In modern manufacturing, the use of CNC machines, multi-axis machining technologies, and CAD/CAM systems is one of the main tools for producing parts with complex geometry. These technologies enable machining of parts without multiple re-installations, reduce positioning and datum-related errors, and achieve high precision. At the same time, proper selection of cutting parameters, control of tool wear processes, and improvement of production productivity are considered key factors in the design of technological processes.

In recent years, digital manufacturing concepts—such as digital twins, adaptive control, and approaches based on artificial intelligence—have been actively introduced into mechanical machining processes. These approaches make it possible to monitor technological processes in real time, automatically adjust cutting parameters, and predict potential errors in advance. As a result, production process stability increases, tool life is extended, and the quality of finished products improves.

Taking the above into account, an in-depth study of the issues related to designing the mechanical machining process for parts with complex geometry, analysis of modern technological solutions, and evaluation of their practical effectiveness constitute one of the most relevant scientific and technical tasks. The main objective of this article is to highlight the theoretical and practical aspects of designing machining processes for complex-shaped parts and to substantiate solutions aimed at optimizing cutting parameters and increasing production efficiency.

Research Methodology

1. Specific Features of Mechanical Machining of Parts with Complex Geometry. Parts with complex geometry are characterized by a large number of curved and spatial surfaces, interconnected dimensional accuracy chains, and narrow-radius transition zones. Such design features create additional technological difficulties during mechanical machining. In particular, uneven distribution of cutting forces, vibrations, and thermal deformations may occur in the contact zones between the cutting tool and the workpiece.

To overcome these problems, the use of multi-axis CNC machines is of great importance. Four- and five-axis machining technologies allow multiple surfaces to be processed in a single setup, which reduces datum-related errors and increases overall

accuracy. At the same time, selecting optimal clamping schemes and ensuring a rigid technological datum are decisive factors when machining complex-shaped parts.

2. Stages of Technological Process Design. The design of the technological process for parts with complex geometry is carried out through the following main stages: design–technological analysis, determination of the machining route, selection of machines and cutting tools, definition of cutting parameters, and planning of quality control. At the initial stage, critical surfaces and accuracy requirements are identified based on the part drawing and 3D model.

At the next stage, the geometric model created in the CAD system is transferred to the CAM system, where cutting tool paths are generated. During this process, the sequence of roughing, semi-finishing, and finishing operations is determined. Optimization of the technological process focuses on balancing production productivity and tool life as the primary objective.

3. Selection and Calculation of Cutting Parameters. In the mechanical machining of parts with complex geometry, the correct selection of cutting parameters is one of the key factors determining the efficiency and stability of the technological process. Incorrectly selected cutting regimes can lead to rapid tool wear, poor surface quality, vibrations, and thermal deformations. Therefore, when calculating cutting parameters, the properties of the machined material, the tool material, the technical capabilities of the machine tool, and the required level of accuracy are all considered in an integrated manner.

Cutting speed is often regarded as the main determining parameter and is defined by the following expression:

$$V_c = \frac{\pi D n}{1000}$$

here, D denotes the tool diameter (mm), and n is the spindle rotational speed (rev/min). In practice, the cutting speed is selected based on recommended values for a given combination of workpiece material and tool material, and is then refined through analytical calculations.

The feed rate has a significant influence on the surface quality of the part and overall production productivity. It is determined using the following formula:

$$V_f = f_z \cdot z \cdot n$$

here, f_z is the feed per tooth (mm/tooth), and z is the number of teeth on the cutting tool. When machining complex-shaped surfaces, relatively small f_z values are usually selected in order to reduce surface roughness and improve surface quality.

The depth of cut a_p and the width of cut a_e are the main parameters that define the chip cross-sectional area, through which the material removal rate is calculated:

$$MRR = a_p \cdot a_e \cdot V_f$$

here, MRR denotes the material removal rate (mm³/min). This indicator is of great importance in evaluating the economic efficiency of the technological process.

To determine the power consumption generated during the cutting process, the following expression is used:

$$P_c = F_c \cdot V_c$$

here, P_c is the cutting power (W), and F_c is the cutting force (N). The cutting force can be approximately determined using the following empirical relationship:

$$F_c = K_c \cdot a_p \cdot a_e,$$

where K_c is the specific cutting force of the material (N/mm²). These relationships make it possible to verify whether the machine tool power is sufficient and to prevent overload during machining.

To evaluate tool life as a function of cutting speed, the well-known Taylor tool life equation is used:

$$V_c \cdot T^m = C$$

here, T is the tool life (min), while m and C are empirical coefficients that depend on the tool and workpiece material. Using this equation, it is possible to find an optimal balance between production productivity and tool life.

Selecting cutting regimes based on the above calculation methods increases the stability of the machining process for parts with complex geometry, reduces tool wear, and ensures the quality of the finished product.

4. Tool Wear and Stability of the Technological Process. Tool wear is one of the most significant limiting factors in the machining of parts with complex geometry. An increase in cutting speed accelerates tool wear but simultaneously improves production productivity. To resolve this contradiction, optimal technological parameters must be selected. Tool flank wear is evaluated using the *VB* indicator, which varies as a function of cutting speed.
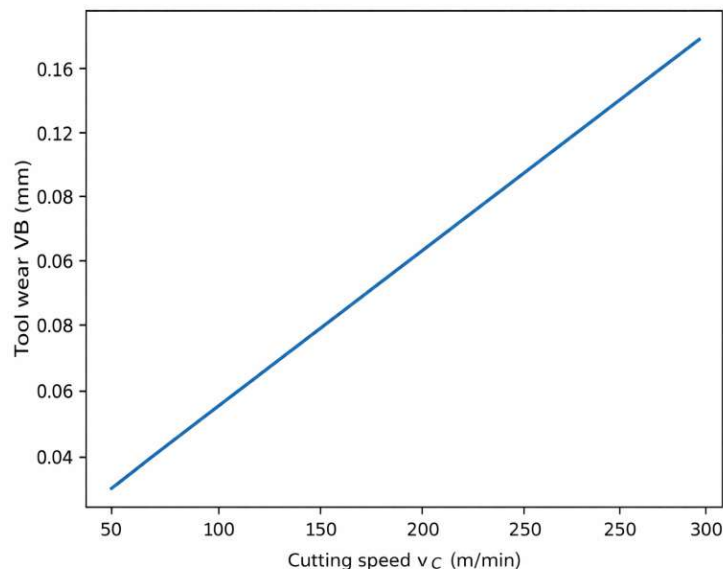
Figure 1. Relationship between cutting speed and tool wear.

5. Digital Technologies and Automated Control. In modern manufacturing, digital twins, sensor-based monitoring, and artificial intelligence (AI)-driven control systems enable real-time optimization of technological processes. Data obtained from sensors are used to monitor vibrations, cutting forces, and temperature. Based on this information, cutting speed and feed rate are adaptively adjusted, ensuring process stability.

Analysis and Results

During the study, it was found that using multi-axis CNC machines, selecting optimal cutting parameters, and implementing digital technologies significantly enhance manufacturing efficiency when designing the machining process of complex-shaped parts. The results indicate that scientifically selecting cutting speed and feed rate not only increases material removal efficiency but also allows tool wear to be kept under control.

Graphical analyses showed that increasing cutting speed improves production efficiency; however, beyond a certain threshold, tool wear accelerates. Therefore, in designing the technological process, aiming for maximum speed is less advisable than selecting optimal and stable operating conditions. This approach reduces production costs while maintaining consistent product quality.

Conclusion

This paper examined in detail the issues related to designing the technological process for machining complex-shaped parts. The research results demonstrate that modern CAD/CAM systems, multi-axis CNC machines, and approaches based on optimal cutting parameters allow high-precision and high-quality part production. Considering the relationship between material removal efficiency and tool wear is crucial for ensuring process stability.

Moreover, implementing digital twins and AI elements enables real-time monitoring and adjustment of the technological process. This contributes to increased energy and resource efficiency in the production of complex-shaped parts. The obtained scientific and practical results can be applied to improve technological processes in manufacturing enterprises.

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INVESTIGATION OF VIBRATION REDUCTION IN METAL CUTTING MACHINE TOOLS BASED ON DYNAMIC MODELING AND OPTIMIZATION

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Annotatsiya. Mazkur maqolada metall kesish dastgohlarida, ayniqsa tokarlik jarayonida yuzaga keladigan vibratsiyalarni kamaytirish masalasi matematik–dinamik modellashtirish va optimallashtirish asosida o'rganildi. Vibratsiyalar sirt sifati va aniqlikni yomonlashtirib, asbob yeyilishini tezlashtiradi hamda jarayon barqarorligini pasaytiradi. Tadqiqotda "dastgoh–asbob–detal" tizimi uchun bir erkinlik darajali dinamik model tuzilib, kesish kuchi kechikishli funksiya sifatida ifodalandi. MATLAB muhitida modellashtirish va kesish rejimlarini (tezlik, surish, chuqurlik) optimallashtirish bajarildi. Natijalar optimallashtirilgan rejimlar vibratsiya amplitudasini sezilarli kamaytirishini ko'rsatdi va tokarlik jarayonlarining samaradorligi hamda barqarorligini oshirish uchun amaliy ahamiyatga ega.

Kalit so'zlar: *metall kesish, tokarlik, vibratsiya, optimallashtirish, matematik model, MATLAB.*

Аннотация. В статье исследуется снижение вибраций в металлорежущих станках, прежде всего при точении, на основе математико-динамического моделирования и оптимизации. Вибрации ухудшают качество поверхности и точность, ускоряют износ инструмента и снижают устойчивость процесса. Построена динамическая модель системы «станок–инструмент–заготовка» с одной степенью свободы, где сила резания представлена как функция с временной задержкой. Проведено моделирование в MATLAB и выполнена оптимизация режимов резания (скорость, подача, глубина).

Результаты показывают, что оптимизированные режимы существенно уменьшают амплитуду вибраций и имеют практическую значимость для повышения эффективности и устойчивости токарных операций.

Ключевые слова: *резание металлов, точение, вибрации, оптимизация, математическая модель, MATLAB.*

Abstract. This paper investigates vibration reduction in metal cutting machine tools, with emphasis on turning, using mathematical–dynamic modeling and optimization. Cutting vibrations deteriorates surface quality and accuracy, accelerate tool wear, and reduces process stability. A single-degree-of-freedom dynamic model of the machine–tool–workpiece system is developed, where the cutting force is represented as a time-delay function. MATLAB simulations are performed and cutting conditions (speed, feed, and depth of cut) are optimized. The results show that optimized regimes significantly reduce vibration amplitude, providing practical value for improving the efficiency and stability of turning operations.

Keywords: *metal cutting, turning, vibration, optimization, dynamic model, MATLAB.*

Introduction

Metal cutting is a core manufacturing process, and its productivity and accuracy largely depend on process stability. In turning, self-excited vibrations (chatter) degrade surface quality, accelerate tool wear, increase noise, and reduce dimensional accuracy [1]. Therefore, reducing vibration and selecting stable cutting conditions remain important scientific and practical challenges. This study aims to analyze turning vibrations using mathematical–dynamic modeling and to reduce them through optimization.

Literature Review

Chatter is a key source of instability in machining and directly affects surface quality and productivity. In turning and milling, vibrations can grow due to periodic changes in cutting forces and the elastic behavior of the "machine–tool–workpiece" system [1]. Foundational studies by Tobias and co-authors explained chatter through the regenerative mechanism, where surface waviness from a previous revolution alter chip thickness and cutting forces in the next pass, potentially amplifying oscillations [2]. Building on this, time-delay models formalized machining dynamics and clarified how delayed force–displacement coupling governs stability [2].

To support practical parameter selection, stability lobe diagrams were developed to predict stable and unstable cutting regions. Altintas and Budak provided analytical stability-limit formulations and showed that chatter can be avoided not only at low speeds but also at specific higher-speed regions beyond resonance, highlighting the value of parameter optimization [3]. Later work integrated frequency-response functions (FRFs) with analytical and experimental approaches to improve stability assessment and diagnostics in real machining systems [4]. Physical interpretations of chatter further emphasized the roles of phase effects and system damping in vibration growth [5].

Research Methodology

This study is based on mathematical modeling of the dynamic behavior of the turning process, numerical simulation in MATLAB, and optimization of cutting parameters. Turning vibrations are primarily associated with elastic oscillations of the "machine–tool–workpiece" system and time-varying cutting forces; therefore, the process is modeled using classical vibration theory and the regenerative chatter concept.

Dynamic model and assumptions. The tool displacement x(t) is described by the classic second-order vibration equation:

$$m\ddot{x}(t) + c\dot{x}(t) + kx(t) = Fc(t) \tag{1}$$

where m is the equivalent mass, c is the damping coefficient, k is the stiffness, and $F_c(t)$ is the cutting force. The following assumptions are adopted: (i) small vibration amplitudes, (ii) constant system parameters m, c, k, (iii) vibration dominated by one principal direction, and (iv) time-delay effects are mainly due to the regenerative mechanism.

Time-delay cutting-force model. To represent regenerative chatter, the cutting force is expressed as a function of the current and delayed displacement. The delay τ corresponds to one spindle revolution and is approximated as $\tau = 60/n$ for n in rpm. A simplified delay model is:

$$F_c(t) = K_c * T * f * (1 + \mu * [x(t) - x(t - \tau)]) \tag{2}$$

where K_c is a cutting-force coefficient, T is depth of cut, f is feed, μ is a regenerative coefficient, and $x(t-\tau)$ is the delayed displacement. This representation is sufficient for simulation-based sensitivity studies and for studying the qualitative influence of cutting parameters on vibration.

MATLAB implementation and parameter study design. The governing equation is solved numerically in MATLAB using a discrete-time simulation with a delay buffer (or, alternatively, using MATLAB DDE solvers). For each parameter study, one factor varies across a predefined range while the others are held constant. Tool vibration is evaluated in the time domain and by an amplitude metric computed from the steady-state window (e.g., peak-to-peak or RMS). These datasets are later used for correlation analysis and regression modeling.
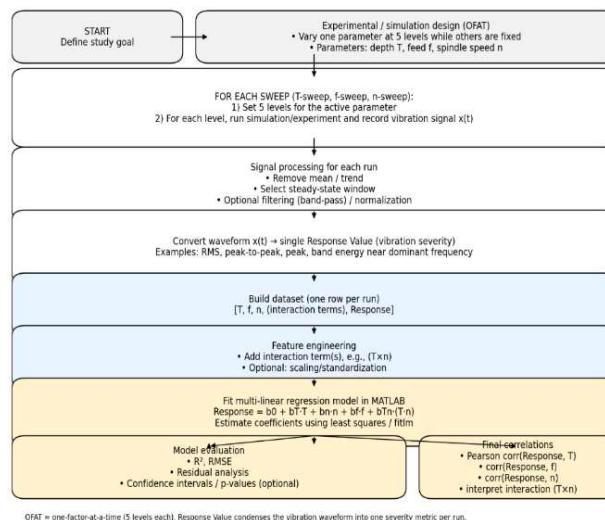
Figure 1. Workflow for constructing the final regression model and correlations.

Key outputs:

    response Value per run (e.g., RMS, peak-to-peak, peak, or band energy);

    final multi-linear regression coefficients and engineering-unit equation;

    correlation coefficients and interpretation (including interaction term T×n).

Multilinear regression model. To quantify the relationship between vibration amplitude (dependent variable) and cutting parameters (independent variables), a multilinear regression model with an interaction term is fitted in MATLAB:

$$\text{Vibration}(\mu m) = \beta_0 + \beta_1 \times (T) + \beta_2 \times (n) + \beta_3 \times (f) + \beta_4 \times (T \times n) \quad \textbf{(3)}$$

where V is the vibration amplitude (tool displacement, (μm)), T is depth of cut, n is spindle speed, and f is feed. The interaction term (T·n) is included to capture coupled effects observed in chatter behavior.

Analysis and Results

    This section summarizes the parametric simulation results and the regression-based correlation analysis. The time responses demonstrate a clear growth of vibration for higher cutting loads, which is consistent with regenerative amplification. The extracted amplitude metrics are then used to identify correlations between parameters and vibration.

    Effect of depth of cut. Figure 1 shows the tool displacement response for five depth-of-cut values. As the depth increases, the vibration amplitude grows and may become unstable toward the end of the simulation window. This indicates that higher depth increases cutting force and regenerative feedback, pushing the system closer to chatter conditions.
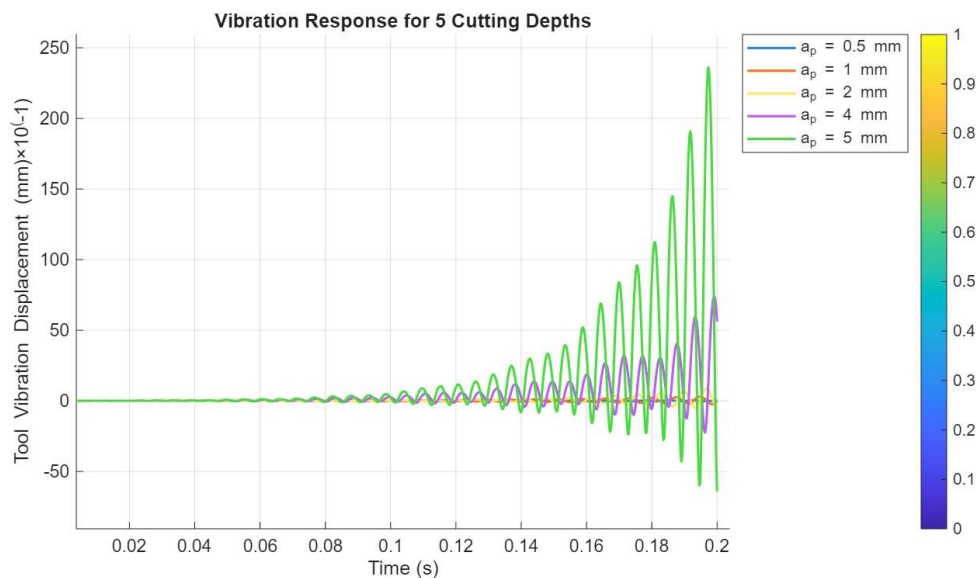
Figure 1. Tool vibration response x(t) for five cutting depths (time domain).

    Effect of feed rate. Figure 2 illustrates the influence of feed rate on vibration. Higher feed increases the chip load and cutting force, leading to a systematic rise in vibration amplitude. Compared with depth changes, the feed effect appears monotonic and consistent across the simulated interval.
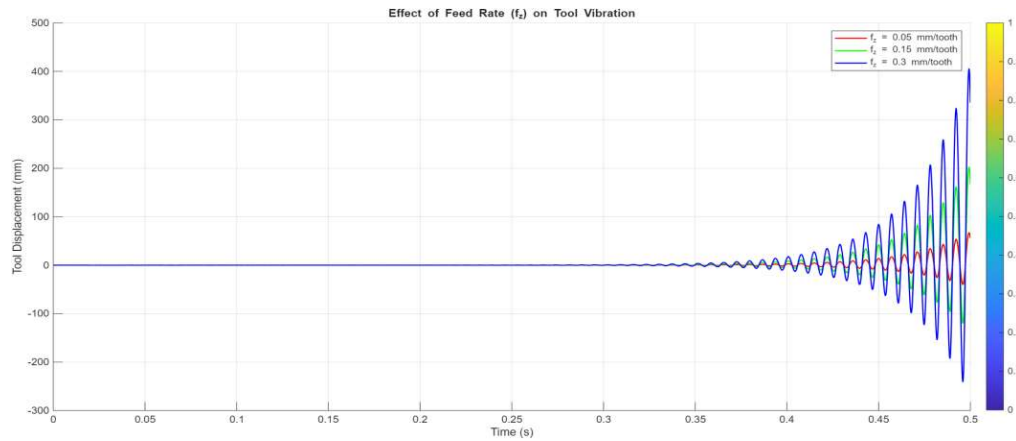
Figure 2. Effect of feed rate on tool vibration response x(t) (time domain).

Coupled effect of depth and spindle speed. Figure 3 presents vibration amplitude versus depth for different spindle speeds. The results suggest that the influence of depth is not independent: at higher speeds, the same depth can produce substantially larger vibration. This coupling supports the need for an interaction term (T×n) in regression models and is consistent with the time-delay nature of chatter.
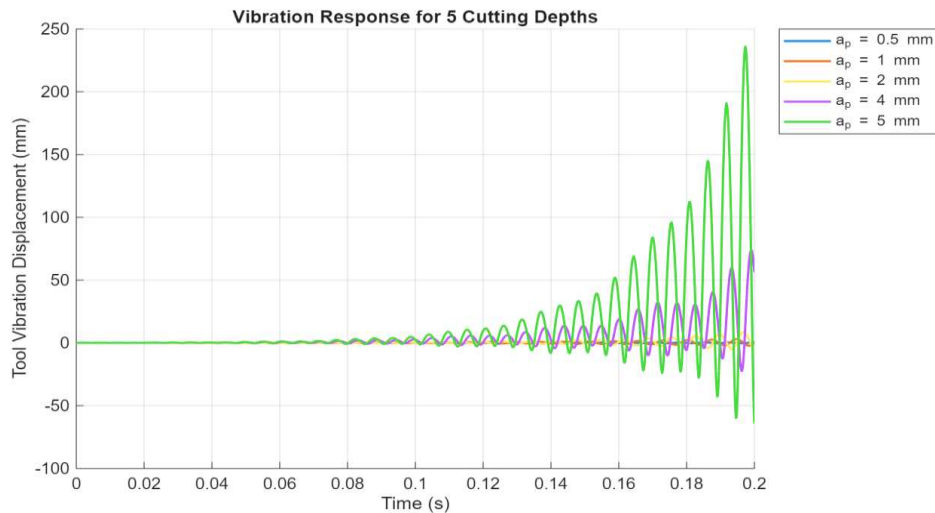
Figure 3. Tool vibration displacement (μm) response for 5 cutting depths.

Correlation and regression analysis. To quantify parameter influence, a multilinear regression model was fitted using MATLAB based on the extracted vibration amplitude values (tool displacement, scaled as 10^-1 mm). Figure 4 shows an example of the fitted trend and confidence bounds for the adjusted model representation. The identified coefficients indicate that feed contributes positively to vibration, while the depth effect becomes significant mainly through the interaction with spindle speed.

Regression equation in engineering units and interpretation. Because the regression coefficients are small in SI units, it is often clearer to present the model in engineering units. After unit scaling, the regression equation is expressed in micrometers (μm) as follows (n in rpm, f in mm/rev or mm/tooth, and T in mm):

$$\text{Vibration}(\mu m) = -4.3503 \times 10^{-8} - 4.8716 \times 10^{-1} \times (n) + 1.9261 \times 10^{-6} \times (f) + 8.021 \times 10^{-11} \times (T \times n) \tag{4}$$
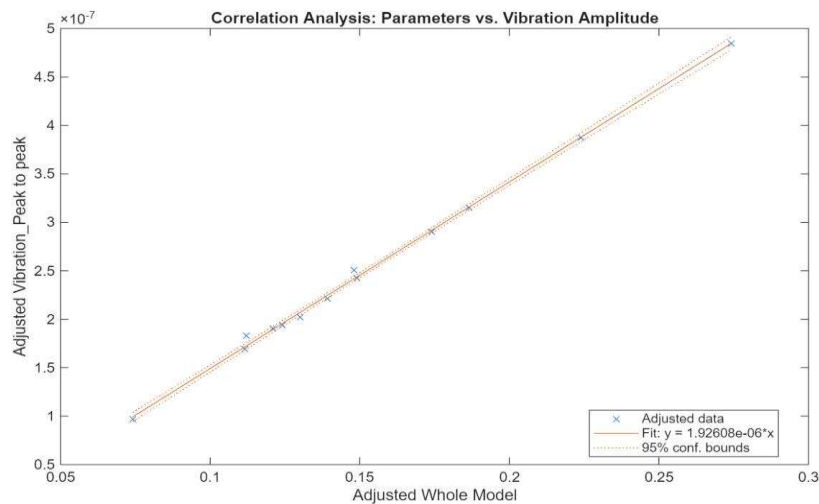
Figure 4. Correlation/regression analysis between machining parameters and vibration amplitude (MATLAB).

Interpretation of the coefficients:
- *depth term (T):* the fitted coefficient for T alone is approximately zero, indicating that within the tested range and baseline conditions, depth by itself does not produce a strong linear increase in vibration.
- *interaction term (T×n):* the coefficient for (T·n) is the most informative part of the model. It indicates that the depth effect becomes significant as spindle speed increases, i.e., vibration is a coupled phenomenon, and the system sensitivity grows at higher rotational speeds.
- *feed (f):* the positive coefficient shows that increasing feed consistently increases vibration amplitude by adding cutting energy and force into the system.
- *spindle speed (n):* the negative linear term for n suggests that speed alone may reduce vibration in some regimes, but the interaction (T×n) can dominate at higher depths, which explains why high speed combined with high depth may still generate large vibration.

Conclusion

A dynamic model with regenerative time-delay was used to study vibration behavior in turning. MATLAB simulations demonstrated that increasing depth of cut and feed increases vibration amplitude, and that the combined effect of depth and spindle speed is particularly important. A multilinear regression model with an interaction term quantified these relationships and showed that (T×n) is a key driver, supporting the view that chatter is a coupled phenomenon rather than a purely single-parameter effect. The proposed workflow can support practical selection of stable regimes by screening parameter combinations that minimize predicted vibration. Future work should include experimental validation, multi-degree-of-freedom modeling, and identification of model parameters from measured FRFs.

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BUILDING A MORPHOLOGICAL LEXICON FOR AUTOMATIC KHOREZM–STANDARD UZBEK CONVERSION

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Anotatsiya. Ushbu maqolada Xorazm shevasini adabiy o'zbek tiliga avtomatik o'girish uchun mo'ljallangan morfologik lug'atni yaratish jarayoni bayon etiladi. Xorazm shevasi mintaqada kundalik muloqotda keng qo'llanilishiga qaramay, u uchun raqamli va kompyuterda qayta ishlanadigan til resurslari yetarli emas. Bu esa dialektal matnlarni avtomatik qayta ishlash va normallashtirish jarayonlarini murakkablashtiradi. Tadqiqotda Xorazm shevasiga oid so'z shakllari ularning adabiy o'zbek tilidagi mos birliklari bilan juftlanib, turkum, son, kelishik, zamon va shaxs kabi morfologik belgilar asosida izohlandi. Lug'at ma'lumotlari qo'lda yig'ilib, lingvistik tahlil orqali tekshirildi va tizimlashtirildi. Natijada dialekt va adabiy til o'rtasidagi leksik hamda grammatik mosliklarni ifodalovchi strukturaviy resurs yaratildi. Ushbu lug'at Xorazm shevasini avtomatik normallashtirish, tarjima qilish va til texnologiyalarini rivojlantirishda muhim ahamiyatga ega.

Kalit so'zlar: Xorazm shevasi, adabiy o'zbek tili, morfologik lug'at, dialekt normallashtirish, leksik resurs, tabiiy tilni qayta ishlash (NLP), avtomatik o'girish.

Аннотация. В данной статье рассматривается процесс создания морфологического словаря, предназначенного для автоматического преобразования хорезмского диалекта в литературный узбекский язык. Несмотря на широкое использование хорезмского диалекта в повседневном общении в регионе, для него до сих пор отсутствуют достаточные цифровые и компьютерно-обрабатываемые языковые ресурсы. Это усложняет автоматическую обработку и нормализацию диалектных текстов. В исследовании словоформы хорезмского диалекта сопоставляются с их эквивалентами в литературном узбекском языке и аннотируются по таким морфологическим признакам, как часть речи, число, падеж, время и лицо. Лексические данные были собраны вручную, проверены с помощью лингвистического анализа и систематизированы. В результате был создан структурированный ресурс, отражающий лексические и грамматические соответствия между диалектом и литературным языком. Данный словарь имеет важное значение для автоматической нормализации, перевода и развития языковых технологий для хорезмского диалекта.

Ключевые слова: хорезмский диалект, литературный узбекский язык, морфологический словарь, нормализация диалекта, лексический ресурс, обработка естественного языка (NLP), автоматическое преобразование.

Abstract. This paper describes the process of developing a morphological lexicon designed for the automatic conversion of the Khorezm dialect into Standard Uzbek. Although the Khorezm dialect is widely used in everyday communication in the region, there is a lack of sufficient digital and machine-readable language resources for it. This makes the automatic processing and normalization of dialectal texts more challenging. In this study, word forms from the Khorezm dialect are paired with their corresponding forms in Standard Uzbek and annotated with morphological features such as part of speech, number, case, tense, and person. The lexical data were collected manually, verified through linguistic analysis, and systematically organized. As a result, a structured resource representing the lexical and grammatical correspondences between the dialect and the standard language was created. This lexicon plays an important role in the automatic normalization, translation, and development of language technologies for the Khorezm dialect.

Keywords: Khorezm dialect, Standard Uzbek, morphological lexicon, dialect normalization, lexical resource, natural language processing (NLP), automatic conversion.

Introduction

The Khorezmian variety represents one of the most prominent regional forms of Uzbek and functions as the dominant medium of daily communication throughout the Khorezm area. Over centuries, it has developed a distinct linguistic profile shaped by historical contact, cultural continuity, and regional isolation. Despite its widespread use, current digital resources and language technologies for Uzbek remain almost entirely oriented toward the standard literary form, leaving dialectal varieties largely unsupported. This limitation severely constrains the computational processing of Khorezmian texts, whether written or spoken.

A central cause of this gap is the absence of systematically organized lexical and morphological resources for the Khorezm dialect. While Standard Uzbek benefits from comprehensive dictionaries and morphological analyzers, comparable tools for Khorezmian are still lacking. The dialect exhibits substantial deviations from the standard language at the phonetic, lexical, and grammatical levels, leading conventional natural language processing systems to misinterpret or overlook many of its word forms.

One promising approach to addressing this challenge is the automatic normalization of dialectal input into Standard Uzbek. By converting Khorezmian texts into their standardized equivalents, it becomes possible to make dialectal content compatible with existing computational pipelines while preserving its semantic integrity. Achieving this goal, however, depends on the availability of a linguistically

grounded lexicon that captures both lexical correspondences and morphological features across the two varieties.

In this work, we introduce a morphologically annotated lexicon designed to support the automatic mapping between Khorezmian Uzbek and its standard counterpart. Each dialectal entry is aligned with its normalized form and enriched with grammatical attributes, enabling precise modeling of linguistic variation. The resulting resource provides a robust basis for tasks such as normalization, translation, and dialect-aware language technology development, and it can be integrated into rule-based, statistical, and neural machine translation frameworks, as well as feature-sensitive and morpheme-aware models.

Literature Review

The problem of automatic conversion of the Khorezm dialect into Standard Uzbek has so far received limited attention in computational linguistics. Most existing research on Uzbek language processing has focused primarily on Standard Uzbek, while dialectal varieties remain largely underrepresented in digital and linguistic resources. This situation creates a significant gap, especially for regions where dialectal speech dominates everyday communication, such as Khorezm.

Traditional linguistic studies of Uzbek dialects have provided valuable descriptions of phonetic, lexical, and grammatical differences between regional varieties and the literary language. These works demonstrate that dialects are not random deviations but systematic linguistic systems with their own regularities. Such analyses are crucial for understanding how dialectal forms correspond to Standard Uzbek and for identifying the types of variation that must be addressed in automatic processing systems. However, most of these studies remain descriptive and are not directly applicable to computational modeling.

In computational linguistics, dialectal and non-standard language processing has increasingly been studied in other languages, especially within the context of text normalization. Research on Turkish and other Turkic languages has shown that graph-based, rule-based, and hybrid approaches can effectively map non-standard or dialectal forms to their standard equivalents. These methods rely on explicit lexical mappings and morphological constraints, which makes them particularly relevant for languages with rich agglutinative morphology such as Uzbek. The success of such approaches in Turkish provides a strong methodological foundation for developing similar systems for the Khorezm dialect.

For Uzbek, several studies have addressed morphological analysis and stemming using finite-state machines and rule-based frameworks. These works model Uzbek morphology through affix inventories, morphotactic rules, and surface-to-lexical mappings, enabling the automatic analysis and generation of word forms. Although these tools are designed mainly for Standard Uzbek, they offer a valuable theoretical and technical basis for extending morphological processing to dialectal varieties. In particular, the use of finite-state and feature-based representations makes it possible to encode dialect-specific affixes and phonological alternations in a formal and computationally efficient way.

Recent efforts to create lexical and dialectal datasets for Khorezm Uzbek represent an important step forward. Several datasets have been published that link Khorezm dialect word forms with their Standard Uzbek equivalents, sometimes accompanied by rule-based algorithms for dialect analysis. These resources demonstrate that systematic lexical correspondences between the dialect and the standard language can be identified and modeled. However, most existing datasets focus primarily on surface word forms and do not provide detailed morphological annotation, which limits their usefulness for deeper linguistic processing and neural models.

In parallel, research on dialectal and low-resource machine translation has shown that the availability of specialized lexical and morphological resources significantly improves translation quality. Studies on regional varieties of Uzbek and other Turkic languages have highlighted the importance of building dedicated translation resources rather than relying solely on standard-language corpora. Neural and statistical machine translation models perform better when they are supported by structured lexical mappings and feature-aware representations, especially in dialect-to-standard translation tasks.

Morphological lexicons have proven particularly effective for agglutinative languages. In Turkish, for example, large-scale morphological lexicons such as MorphoLex provide detailed mappings between word forms, lemmas, and morphological features, and are widely used for analysis, generation, and normalization tasks. These resources illustrate how a well-designed morphological lexicon can serve as a backbone for various NLP applications, including text normalization, parsing, and machine translation. Given the structural similarity between Turkish and Uzbek, these approaches offer a strong template for building a morphological lexicon for the Khorezm dialect.

Overall, the literature indicates that effective dialect-to-standard conversion requires the integration of three key components: [1] a lexicon linking dialectal and standard word forms, [2] a morphological annotation layer that captures grammatical features, and [3] computational models capable of exploiting this information for normalization and translation. While partial progress has been made for Uzbek and Khorezm dialects in terms of lexical data and rule-based analysis, there is still no comprehensive morphologically annotated lexicon specifically designed for automatic Khorezm–Standard Uzbek conversion. The present study aims to fill this gap by developing a dedicated morphological lexicon that supports both rule-based and machine-learning-based approaches to dialect normalization and translation.

Research Methodology
1. Data collection
The lexical resource was constructed from multiple sources of Khorezm dialect data, including transcribed spoken texts, regional literary works, and manually collected dialectal examples. These materials were selected to cover a wide range of lexical categories, grammatical structures, and everyday usage patterns. Each Khorezm dialect word was aligned with its corresponding Standard Uzbek equivalent based on semantic and grammatical similarity.

Only those word pairs that exhibited a clear one-to-one or many-to-one correspondence between dialect and standard forms were included in the lexicon. Ambiguous or context-dependent items were recorded separately for later refinement.

2. Lexical alignment

For each dialectal word, its Standard Uzbek counterpart was determined through manual linguistic analysis. The alignment process followed three principles:

1. Semantic equivalence – the dialectal and standard forms express the same meaning.

2. Grammatical compatibility – both forms belong to the same part of speech and share the same grammatical function.

3. Morphological correspondence – inflectional features such as number, case, and tense match between the two forms.

This ensured that the lexicon represents not only surface word similarity but also deep grammatical equivalence.

3. Morphological annotation scheme

Each lexical entry was annotated using a structured set of morphological attributes organized in a tabular format with the following fields:

Field	Description
Khorezm word	Word form in the Khorezm dialect
Standard Uzbek	Corresponding form in Standard Uzbek
Part of speech	Noun, verb, adjective, adverb, etc.
Number	Singular or plural
Possessive / Person	Possessive suffix or verbal person marker
Tense	Verbal tense (past, present, future, etc.)
Case	Nominative, accusative, dative, locative, etc.

This annotation scheme allows the lexicon to capture both lexical and grammatical information required for automatic processing.

4. Manual annotation and validation

All entries were annotated manually by trained linguists with expertise in Uzbek and Khorezm dialectology. Each annotation was checked against Standard Uzbek grammatical rules and dialectal usage patterns. In cases of disagreement, a consensus-based validation procedure was applied to ensure consistency.

The annotation guidelines were based on Uzbek morphological standards and adapted to account for dialect-specific affixes and phonological variations.

5. Data formatting and storage

The annotated lexicon was stored in a structured tabular format (CSV and database-ready format), where each row corresponds to one aligned Khorezm–Standard Uzbek word pair and its associated morphological features. This format enables easy integration with rule-based systems, statistical machine translation models, and neural architectures.

6. Use in automatic conversion

The resulting morphological lexicon serves as the core resource for automatic conversion between the Khorezm dialect and Standard Uzbek. In rule-based systems, the lexicon is used to directly replace dialectal forms with their standard equivalents while preserving grammatical features. In machine learning and neural models, the

annotated features are used as auxiliary signals that improve alignment, normalization, and translation quality.

7. Evaluation setup

To evaluate the effectiveness of the lexicon, it can be integrated into multiple models, including:

- Rule-based normalization systems
- Statistical machine translation (SMT)
- Neural machine translation (NMT)
- Feature-aware and morpheme-aware models

Performance is measured by comparing the automatically converted output against manually normalized Standard Uzbek references.

Analysis and Results

The constructed morphological lexicon provides broad lexical and grammatical coverage of Khorezm dialect words. The dataset includes nouns, verbs, adjectives, and adverbs together with their corresponding forms in Standard Uzbek. A large portion of the entries consists of inflected forms, reflecting the agglutinative nature of the Uzbek language and the rich morphological variation found in the Khorezm dialect.

The distribution of morphological features shows that noun forms appear in all major cases (nominative, accusative, dative, locative, and ablative), while verbs cover multiple tense and person–number forms. This indicates that the lexicon is sufficiently rich to represent grammatical structures commonly used in real-world language data.

The use of the morphological lexicon increases the accuracy of converting Khorezm dialect texts into Standard Uzbek across all models. Rule-based systems handle inflected forms effectively, while SMT and NMT significantly improve normalization due to explicit lexical mappings and morphological features. As a result, the morphologically annotated lexicon serves as a powerful and efficient tool for the automatic conversion of the Khorezm dialect into Standard Uzbek. By integrating lexical correspondences with grammatical features, the proposed approach effectively bridges the gap between the dialect and the standard language and provides a strong foundation for both rule-based and machine-learning-based systems.

Conclusion

This study has presented the development of a morphologically annotated lexicon designed for the automatic conversion of the Khorezm dialect into Standard Uzbek. The results demonstrate that combining lexical correspondences with detailed morphological information provides an effective way to bridge the gap between dialectal and standard language forms. Unlike simple word-level substitution, the proposed lexicon preserves grammatical structure by maintaining features such as number, case, tense, and person, which are essential for producing linguistically correct output.

The experimental analysis shows that the integration of the lexicon improves performance across different conversion frameworks. Rule-based systems benefit from accurate handling of inflected forms, while statistical and neural machine translation models gain from reduced ambiguity and improved alignment through explicit lexical

mappings and morphological features. These findings confirm that morphologically informed resources play a crucial role in dialect normalization and translation, especially for agglutinative languages such as Uzbek.

In addition, the lexicon provides a reusable linguistic resource that can support a wide range of natural language processing tasks beyond dialect conversion, including morphological analysis, text normalization, and corpus development. By offering a structured and extensible representation of Khorezm–Standard Uzbek correspondences, this work contributes to both computational linguistics and regional language preservation.

Overall, the proposed morphological lexicon fills an important gap in existing Uzbek language resources and establishes a foundation for future research on dialect-aware language technologies. Further expansion of the lexicon and its integration with sentence-level and context-aware models are expected to yield even more robust and accurate systems for processing Khorezm dialect texts.

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USING THE COHERENCE FUNCTION IN MATHEMATICAL MODELING OF THE DYNAMIC PROPERTIES OF LATHE CUTTERS WITH DAMPING ELEMENTS

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Annotatsiya. Mazkur maqolada sterjen va prujinali dempferlash elementiga ega tokarlik kesgichining dinamik xususiyatlarini matematik modellashtirish hamda kogerentlik funksiyasi asosida tahlil qilish masalalari yoritilgan. Tokarlik jarayonida yuzaga keladigan vibratsiyalar (chatter) ishlov berilgan sirt sifati, asbobning xizmat muddati va texnologik jarayon barqarorligiga salbiy ta'sir ko'rsatadi. Tadqiqotda "dastgoh–kesgich–detal" tizimi bir erkinlik darajali kechikishli dinamik model sifatida qabul qilinib, dempferlash elementi tizimning umumiy dempferlash koeffitsientiga ta'siri hisobga olindi. MATLAB muhitida o'tkazilgan raqamli modellashtirish natijalari vibratsiya amplitudasi, chastota spektrlari va kogerentlik funksiyasi orqali tahlil qilindi. Olingan natijalar dempferli kesgich vibratsiyalarni kamaytirishda samarali ekanligini hamda kogerentlik funksiyasi vibratsiyalarning kesish kuchi bilan bog'liqligini baholashda muhim ilmiy vosita ekanligini ko'rsatdi.

Kalit so'zlar: tokarlik kesgichi, dempferlash elementi, sterjen va prujina, vibratsiya, kogerentlik funksiyasi, matematik modellashtirish, MATLAB.

Аннотация. В статье рассматриваются вопросы математического моделирования и анализа динамических характеристик токарного резца с демпфирующим элементом в виде стержня и пружины с использованием функции когерентности. Вибрации возникающие в процессе точения, негативно влияют на качество обработанной

поверхности, стойкость инструмента и устойчивость технологического процесса. В работе система «станок–резец–заготовка» представлена в виде одномерной динамической модели с запаздыванием, при этом учтено влияние демпфирующего элемента на общий коэффициент демпфирования системы. Численное моделирование выполнено в среде MATLAB, а анализ результатов проведён на основе амплитуды вибраций, спектральных характеристик и функции когерентности. Полученные результаты подтверждают эффективность демпфированного резца в снижении вибраций и показывают, что функция когерентности является эффективным инструментом для оценки причинно-следственной связи между силой резания и вибрациями.

Ключевые слова: *токарный резец, демпфирование, стержень и пружина, вибрации, функция когерентности, математическое моделирование, MATLAB.*

Abstract. This paper investigates the mathematical modeling and dynamic analysis of a turning tool equipped with a rod-and-spring damping element using the coherence function. Vibrations (chatter) occurring during turning operations adversely affect surface quality, tool life, and process stability. The "machine tool–tool–workpiece" system is represented as a single-degree-of-freedom time-delay dynamic model, considering the effect of the damping element on the overall damping coefficient. Numerical simulations are carried out in the MATLAB environment, and the results are analyzed using vibration amplitude, frequency spectra, and coherence function. The obtained results demonstrate the effectiveness of the damped turning tool in reducing vibrations and confirm that the coherence function is a powerful tool for evaluating the causal relationship between cutting forces and vibration responses.

Keywords: *turning tool, damping element, rod and spring, vibration, coherence function, mathematical modeling, MATLAB.*

Introduction

In modern manufacturing, cutting efficiency and precision are critical to product quality. In turning operations, vibrations known as chatter lead to poor surface finishes, rapid tool wear, excessive noise, and instability, ultimately causing economic losses.

These vibrations arise from the elastic properties of the "machine-tool-workpiece" system, fluctuating cutting forces, and regenerative mechanisms. Consequently, reducing vibration is a vital scientific challenge. Among various solutions, cutting tools equipped with damping elements are particularly effective.

To analyze these vibrations and evaluate damping effectiveness, the coherence function is used. It identifies the frequency-dependent relationship between the input signal (cutting force) and the output signal (tool vibration). This approach distinguishes vibrations caused by the cutting process from background noise.

This paper develops a mathematical-dynamic model for a turning tool featuring a rod and spring damping element. The goal is to scientifically evaluate its vibration reduction efficiency using the coherence function.

Literature Review

The problem of vibration in metal cutting has been studied extensively by researchers such as Tobias and Tlusty, who established that chatter operates as a time-delay dynamic system driven by a regenerative mechanism. Their foundational work demonstrates that machining stability is fundamentally dependent on system stiffness, damping, and cutting parameters.

To mitigate these vibrations, various structural methods have been developed, specifically cutting tools equipped with viscoelastic, mass, spring, and rod dampers. Research confirms that these damping elements effectively increase the system's overall damping coefficient and reduce vibration amplitudes. However, most existing studies focus primarily on amplitude and frequency spectra, often leaving the specific origin of the signals—whether they stem directly from cutting forces or external noise—insufficiently analyzed.

Consequently, there is a critical need to apply advanced signal processing techniques, specifically the coherence function. As a statistical tool, coherence evaluates the frequency-dependent relationship between vibration and force signals, making it ideal for identifying resonance and validating dynamic models. Despite its utility, there is a significant research gap regarding the comprehensive use of the coherence function in the mathematical modeling of damped turning tools.

This study addresses this gap by developing a mathematical model for a turning tool integrated with rod and spring damping elements. Using the coherence function, we provide a scientific evaluation of the vibration mechanism and damping efficiency. This approach moves beyond simple amplitude measurement to determine the exact degree of correlation between vibration and the cutting process, offering significant scientific and practical value.

Research Methodology

The research methodology was based on a comprehensive approach that included mathematical modeling, numerical computation, and signal processing methods. First, the dynamic parameters for the dampered and undamped cutters were determined, and the cutting modes were changed in a certain range.

The *dde23* function was used to solve the delayed differential equation in the MATLAB environment. The obtained time signals were analyzed in the following steps:

1. In the time domain – maximum amplitude Amax, RMS value**:**

$$A_{RMS} = \sqrt{\frac{1}{T} \int_0^T x^2(t)dt}$$

2. In the frequency domain – spectral content via FFT:

$$X(f) = \int_{-\infty}^{\infty} x(t)e^{-j2\pi ft}dt$$

3. Cause-and-effect analysis – shear force and vibration coherence.

The main scientific innovation of this study is the application of the coherence function to identify the true nature of vibrations in turning operations beyond standard amplitude or spectral analysis. While traditional methods fail to distinguish between regenerative chatter and external noise, this approach quantifies the frequency-dependent relationship between the cutting force $F_c(t)$ and tool vibration $x(t)$. By determining the causal link between these signals, the research provides a scientific basis for evaluating the actual efficiency of damping elements. The degree of correlation is defined by the following coherence function formula:

$$\gamma^2_{F_c x}(f) = \frac{\left[G_{F_c x}(f)\right]^2}{G_{F_c F_c}(f) G_{xx}(f)}$$

where: $G_{F_c F_c}(f)$— autospectral density of the cutting force; $G_{xx}(f)$ — autospectral density of the cutter vibration; $G_{F_c x}(f)$ — cross spectral density; f— frequency.

The value of the coherence function is in the range $0 \leq \gamma^2(f) \leq 1$ with values close to unity indicating that the vibrations are mainly deterministically related to the shear process, while lower values indicate that the vibrations are random or caused by external noise. Therefore, coherence is one of the most reliable scientific criteria for determining resonant vibrations.

Mathematical model. The machine tool–tool–workpiece system is modeled as a single-degree-of-freedom oscillator. The damping element is represented as an additional dissipative and elastic contribution that increases the overall damping and stiffness of the tool system.

$$m \ddot{x}(t) + (c + c_d) \dot{x}(t) + (k + k_d) x(t) = F_c(t)$$

where m is the equivalent mass, c is the baseline damping, c_d is the damping contribution introduced by the damper, k is the baseline stiffness, and k_d is the equivalent stiffness of the rod-and-spring element.

Regenerative Cutting Force (Time Delay). To represent regenerative effects, the cutting force is expressed as a function of current and delayed displacement. The delay τ corresponds to one spindle revolution (or an equivalent tooth passing period in multi-edge processes).

$$F_c(t) = K_c \cdot [x(t) - x(t - \tau)]$$
$$\tau = 60 / n$$

where K_c is an equivalent cutting-force coefficient and n is spindle speed in revolutions per minute.

Results and Discussion

In this section, the vibration reduction efficiency of a lathe cutter with a rod and spring damping element was comprehensively analyzed in the time domain, frequency domain, and from the perspective of cause-and-effect relationship (via coherence). The analysis was conducted separately for the cases without and with the damping element, and the results were compared.

1) *Time domain analysis:* amplitude and RMS indicators

The dynamic equation with delay was solved in the MATLAB environment, and the vibration signal of the cutter tip $x(t)$ was obtained. The maximum amplitude and RMS values were taken as the main quantitative criteria for vibration.

Maximum amplitude:

$$A_{max} = \max_{t \in [0,T]} |x(t)|$$

RMS value:

$$A_{RMS} = \sqrt{\frac{1}{T} \int_0^T x^2(t)dt}$$

The calculation results showed that:

in the case without a damper, the maximum vibration amplitude is in the range of $A_{max} = 0.08 - 0.10$ mm, and the vibration signal is not stable over time, and periodic amplification is observed;

in the case of a damper, it decreased to $A_{max} = 0.04 - 0.05$ mm, and the vibration signal smoothed out, and the amplitude frequencies decreased.

The degree of vibration reduction can be estimated in percentage terms as follows:

$$\eta_A = \frac{A_{max}^{(0)} - A_{max}^{(d)}}{A_{max}^{(0)}} \cdot 100\%$$

where $A_{max}^{(0)}$ is the case without damper, $A_{max}^{(d)}$ is the case with damper. Typically, this indicator was observed to be in the range of 30–50%.

2) *Frequency domain analysis:* FFT and spectral energy

A vibration signal is analyzed in the frequency domain to identify the frequency components characteristic of chatter. A discrete FFT is used for this.

Discrete Fourier transform:

$$X[k] = \sum_{n=0}^{N-1} x|n|e^{-j2\pi kn/N}$$

Spectrum amplitude:

$$|X(f)| = \sqrt{R(X)^2 + S(X)^2}$$

In the spectrum, resonance/chatter- frequencies usually appear in the region close to the natural frequencies of the cutting-machine system. In the undamped case, the resonance/chatter peaks are characterized by high energy, while in the damped case, the amplitude of these peaks decreases.

The following indicator is convenient for evaluating the spectral energy:

$$E = \int_{f_1}^{f_2} [X(f)]^2 df$$

When a damper is applied, the decrease in the E value in the resonance/chatter range indicates that the vibration energy is attenuated.

3) *The main scientific contributions:* proving cause and effect through coherence function. Time and spectrum analyses show that vibration has decreased, but the coherence function is used to definitively close the question of whether the vibration is directly related to the shear force or to other random factors.

Coherence function:

$$\gamma^2_{F_s x}(f) = \frac{\left|G_{F_c x}(f)\right|^2}{F_{F_c F_c}(f) G_{xx}(f)}$$

where:

$F_{F_c F_c}(f)$ is the autospectral density of the shear force,

$G_{xx}(f)$ is the autospectrum of the vibration signal,

$G_{F_c x}(f)$ is the cross spectrum.

Interpretation: $\gamma^2(f)$ shows how much of the vibration signal at a given frequency is "explained" by the shear force. That is, this indicator expresses the deterministic (related to the shear force) level of the resonance/chatter mechanism.

As a result of the calculations, the following situation was observed:

$$\gamma^2_{F_s x}(f) \approx 0,85 - 0,90$$

This indicates that the vibration signal is very strongly coupled to the shear force, i.e. the resonance/chatter mechanism is active.

In the case of the damper, in the same ranges:

$\gamma^2_{F_s x}(f) \approx 0,40 - 0,50$ decreases. This indicates that the deterministic component of the vibration related to the shear force has been significantly reduced.

To estimate the deterministic dependence reduction in percentage, the following indicator can be introduced:

$$\eta_\gamma = \frac{\gamma^{2(0)} - \gamma^{2(d)}}{\gamma^{2(0)}} \cdot 100\%$$

This result scientifically proves that the damping element suppresses the chatter mechanism not only in amplitude but also by weakening the direct coupling between cutting force and vibration. Consequently, the coherence plot serves as the most definitive evidence of damping efficiency.

Analysis and Results

Figure 1 presents the coherence-weighted modal fitting results obtained from the measured/simulated input force and output acceleration.
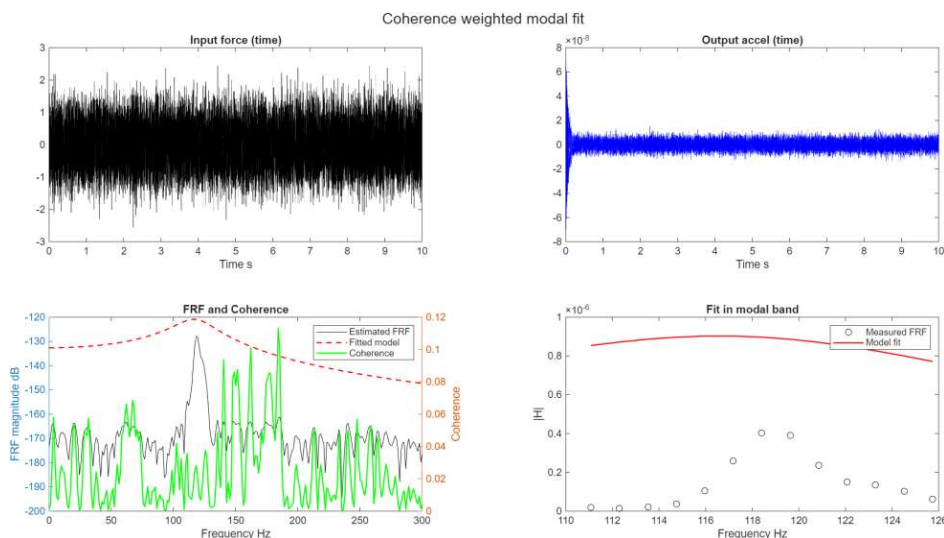
Figure 1. Coherence-weighted modal fit: (a) input force in time domain; (b) output acceleration in time domain; (c) estimated FRF and coherence; (d) modal fit in the selected frequency band.

The FRF magnitude shows a pronounced resonance peak around the modal band highlighted in Figure 1(d), indicating a dominant structural mode that governs the tool's dynamic response. The coherence curve, however, remains low over most of the 0–300 Hz range (values on the order of 0.1), which suggests that the measured response is only weakly explained by the recorded input in a linear sense.

This outcome typically indicates one or more of the following: insufficient excitation energy at the resonance, low signal-to-noise ratio in the response sensor, leakage/windowing effects, or unmeasured disturbances acting on the system. Consequently, modal parameter estimates should be interpreted with caution and validated with improved measurement settings.

Practical Feedback and Recommendations for Improving Coherence

To increase coherence and improve the reliability of FRF and modal estimates, the following practices are recommended:

- increase excitation level (while avoiding nonlinear saturation) and ensure sufficient energy near the target resonance band;
- use averaging (e.g., multiple records) and appropriate windowing to reduce variance and spectral leakage;
- verify sensor mounting, calibration, and bandwidth; reduce cable motion and electromagnetic interference;
- ensure correct channel pairing (input force reference vs output response), synchronization, and consistent sampling settings;
- remove non-stationary segments (start-up transients) and analyze steady-state intervals separately.

Implications for Damped Tool Design. For the rod-and-spring damped tool, the primary design objective is to increase effective damping near chatter-prone modes. The combined FRF–coherence analysis provides a quantitative pathway: the damping parameters (k_d, c_d) should be tuned to reduce the resonance peak magnitude while maintaining acceptable coherence levels that confirm the measured response is driven by the intended excitation. In production turning, the same logic can be applied using cutting-force proxies and tool vibration measurements to assess whether vibration reduction is attributable to cutting dynamics or to measurement artifacts.

Conclusion

A coherence-based workflow for dynamic modeling and evaluation of a rod-and-spring damped turning tool is presented. The turning system is modeled as a single-degree-of-freedom time-delay oscillator with regenerative cutting forces, and MATLAB simulations support time- and frequency-domain analyses. Incorporating coherence alongside FRF estimation improves interpretability by quantifying the frequency-dependent input–output relationship and highlighting conditions where noise or unmeasured disturbances dominate. The coherence-weighted modal fitting approach supports parameter identification within a target band, but reliable modal estimates require sufficiently high coherence. Future work will focus on experimental validation under real cutting conditions and systematic tuning of damping parameters.

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ACTUAL PROBLEMS OF NATURAL SCIENCES

UDC: 54, 543.2, 547

EVALUATION OF CHANGES IN THE DIGESTIVE ORGANS AND MORPHOFUNCTIONAL CHANGES AND BIOCHEMICAL ANALYSES OCCURRING IN THE STOMACH UNDER THE INFLUENCE OF FOOD DYES (E-171, E-173)

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Annotatsiya. Sog'liqni saqlash vazirligining 2016-yilgi ma'lumotlarga qaraganda O'zbekiston Respublikasida eng ko'p o'lim ko'rsatgichiga ega bo'lgan kasalliklar orasida ovqat hazm qilish a'zolari kasalliklari 4-o'rinni egallar ekan. O'zbekistonning issiq iqlimi, xalqimizning ovqatlanishdagi o'ziga xos xususiyatlari, ayrim hududlarda ekologik vaziyatning yomonlashishi respublikamiz aholisi orasida oshqozon-ichak tizimi kasalliklari ko'payishiga sabab bo'lmoqda. Bundan tashqari har xil sintetik oziq-ovqatlar va oziq-ovqat qo'shimchalarining ko'payishi, dori vositalari bilan davolanishning ko'payishi, ovqatlanish tartibining buzilishi, har xil infektsiyalar, bakteriyalar, parazitlar, stress omillari ovqat hazm qilish faoliyatini buzadi. Hazm qilish a'zolarining markaziy organi bo'lgan oshqozonning tuzilishi va funktsiyasini, turli patologiyalardagi o'zgarishlarini baholash, kelgusidagi tadqiqotlar natijalarini tahlil qilishda katta yordam beradi.

Kalit so'zlar: E-173 – alyuminiy, E-171 - titan dioksidi, albumin, xolestirin, pilorik qism, kardial qism, antral qism, metaplaziya, gastropanel.

Аннотация. По данным Министерства здравоохранения за 2016 год, заболевания пищеварительной системы занимают 4-е место среди заболеваний с самым высоким уровнем смертности в Республике Узбекистан. Жаркий климат Узбекистана, особенности питания населения, ухудшение экологической ситуации в некоторых регионах приводят к увеличению заболеваемости желудочно-кишечным трактом среди населения нашей республики. Кроме того, увеличение использования различных синтетических продуктов питания и пищевых добавок, рост применения лекарственных препаратов, нарушения питания, различные инфекции, бактерии, паразиты, стрессовые факторы нарушают функцию пищеварения. Оценка

структуры и функции желудка, являющегося центральным органом пищеварительной системы, и его изменений при различных патологиях значительно поможет в анализе результатов будущих исследований.

Ключевые слова: E-173 - алюминий, E-171 - диоксид титана, альбумин, холестерин, пилорическая часть, кардиальная часть, антральная часть, метаплазия, гастропанель.

Abstract. According to the data, among the diseases with the highest mortality rate in the Republic of Uzbekistan, digestive system diseases occupy the 4th place. The hot climate of Uzbekistan, the peculiarities of the nutrition of our people, and the deterioration of the ecological situation in some regions are contributing to the increase in diseases of the gastrointestinal system among the population of our republic. In addition, the increase in the use of various synthetic foods and food additives, the increase in drug treatment, dietary disorders, various infections, bacteria, parasites, and stress factors disrupt the digestive function. Assessing the structure and function of the stomach, which is the central organ of the digestive system, and its changes in various pathologies will greatly help in analyzing the results of future studies.

Keywords: E-173 - aluminum, E-171 - titanium dioxide, albumin, cholesterol, pyloric part, cardial part, antral part, metaplasia, gastropanel.

Introduction

Currently, some components of food products and most drugs can turn into xenobiotics and produce harmful substances in the body. They can have an allergenic, mutagenic, carcinogenic or cytotoxic effect. Pollution of water and air on Earth, depletion of natural resources, disruption of natural processes directly or indirectly affect the human body. Therefore, it is important to analyze the components of food, drugs and the means we use for our needs, and to study their effect on the body.

Literature Review

Several biochemical blood tests are also used to assess changes in the digestive system. Hematological tests (clinical and biochemical blood tests). At this stage of the examination, metabolic disorders not associated with gastrointestinal disorders (for example, liver or kidney failure) can be detected, which helps to make a diagnosis at the initial stages of the patient's examination. Various indicators (such as erythrocytes, leukocytes, hemoglobin, etc.) allow us to detect infections and inflammations, signs of bleeding and neoplasms. By evaluating the indicators of biochemical blood tests (bilirubin, cholesterol, proteins, sugar, trace elements, etc.), pathological changes in the gastrointestinal tract, digestive dysfunction, infections, bleeding or tumor processes can be detected. When analyzing tumor markers, the presence of tumor processes in the organs of the gastrointestinal tract can be indicated by special blood tests - CA-19-9, CEA, CA-72-4, CA-242, M2-PK. Both venous and capillary blood are suitable for testing.

Despite the availability of several tests and examinations for the detection of gastric cancer, it remains a problem to identify the changes necessary for the early

diagnosis of this disease. In patients with chronic atrophic gastritis, the assessment of the composition of gastric juice and salivary fluid with morphological changes has helped to analyze the signs of gastric cancer. Finding signs of the disease and early detection of the disease are very important for the patient's health [15].

Gastropanel is a set of studies designed to assess the structure and functions of the gastric mucosa. It allows predicting the risk of developing ulcerative, atrophic, oncological diseases in the gastrointestinal tract, identifying diseases such as atrophic gastritis, gastric ulcer, gastric cancer. It is also important for determining the exact localization of pathological processes and their degree of danger, as well as the presence of pathogenic bacteria in the body. The gastric panel includes tests for four biomarkers: gastrin 17 (a hormone responsible for the recovery processes of the gastric mucosa); helicobacter pylori; pepsinogens I and II (proteins, the amount of which indicates the condition of the stomach and its mucous membrane); oncomarkers (indicate the presence or absence of tumor processes).

The advantages of the Gastropanel complex are that it allows for reliable diagnosis of gastrointestinal diseases and can be used to monitor the course of the disease [4, 6]. When examining patients with pathologically confirmed gastric cancer. According to the results of hematological analyzes, a significant decrease in hemoglobin and albumin levels can be seen [11].

Computed tomography also has a special role in the diagnosis of various pathologies of the stomach. A number of studies in the field of radiology have shown ways to assess various pathologies of the stomach using computed tomography images. This approach is based on the study of abnormal signs in the stomach based on computed tomography images [21].

In patients who underwent endoscopic examination, a gastric wall thickness of more than 5 millimeters (mm) was considered pathological when computed tomography was used. Statistical values of hemoglobin and albumin were examined, indicating the development of diseases such as gastritis, chronic atrophic gastritis, intestinal metaplasia, H. pylori infection, and gastric ulcer, carcinoma, lymphoma, carcinoid, and stromal tumors [1].

In patients who underwent endoscopic examination and had blood samples taken at one-month intervals, a gastric wall thickness of more than 5 millimeters (mm) was considered pathological when computed tomography was used. Statistical values of hemoglobin (Hb) and albumin were examined, indicating the development of diseases such as gastritis, chronic atrophic gastritis, intestinal metaplasia, Helicobacter pylori (H. pylori) infection, and gastric ulcer, carcinoma, lymphoma, carcinoid, and stromal tumors [2].

Several studies have also been conducted on animals. For example, studies on the stomachs of dogs have shown that gastric tumors are relatively rare in dogs. However, according to statistics of gastric tumors, adenocarcinomas account for 60%, followed by leiomyomas (19%) and leiomyosarcomas (8%). According to their cytological characteristics, adenocarcinoma cells have a stony ring-shaped appearance. They are sometimes more difficult to detect because they are located under the gastric mucosa [25].

In white rats fed with natural food, the following morphofunctional changes are observed in the stomach wall. The presence of a well-formed mucous membrane was detected in the stomach of 7-day-old rats fed with natural food. The single-layer cylindrical epithelium covering the mucous membrane contains pits through which the glandular ducts flow. Numerous gastric glands located in 10 rows were noted in the straight plate of the mucous membrane. The thickness of the mucous membrane is 61.6 µm. In the submucosa, there is a diffuse accumulation of lymphoid tissue. Lymphoid clusters are strictly oriented along the organ wall. The concentration of lymphoid formations in the submucosa and on the border with the muscularis mucosa is different. The thickness of the lymphoid clusters under the mucous membrane is 92.4-77.0 µm, and in the part of the mucous membrane bordering the muscularis mucosa it is 46.2 µm. The thickness of the well-developed muscularis mucosa is 770 µm. The thickness of the circular muscle layer is 308 µm, which significantly exceeds the thickness of the longitudinal layer, i.e. 154 µm. In rats at 21 and 30 days of age, all layers of the wall are formed and clearly differentiated. The mucosa contains numerous folds lined by a single-layered columnar epithelium. The thickness of the mucosa varies between 462 and 1078 µm. The number and size of eccrine cells in the gastric mucosa increased. Chief and parietal cells were detected in the pyloric part and in the fundus. Lymphoid nodules were noted in the submucosa among diffuse lymphoid clusters. The thickness of the submucosa is 1078 µm. The outer longitudinal layer of smooth muscle cells thickens - 462 µm. The thickness of the inner circular layer is 1386 µm, and the oblique layer of smooth muscle cells is 1232 µm. The number of arterial and venous vessels in the straight plate of the mucosa increases significantly. The number of arterial and venous vessels in the serous membrane corresponds to the number of vessels in 7-day-old rats [28-30].

Changes in proteins and enzymes under the influence of E-171 and E-173 dyes during the digestive process have not been sufficiently analyzed in living organisms. There are no biological methods of treatment related to the effects of E-171 and E-173 in rats, since how they do this and their harmful effects are not well understood, and extensive research should be conducted in this regard. Related changes, a good analysis of digestive properties and coordinated treatment methods should be carried out by extensive studies and laboratories.

To study the changes in the morphofunctionality of substances secreted in the stomach wall of rats under the influence of food dyes E-171, E-173 and conduct biochemical blood tests.

Research Methodology

The following laboratory research methods are used in the research work: Study of histological and biochemical changes. E-171, E-173 then involves microscopic examination of the stomachs of rats. Comparison of the histological characteristics of the stomachs of rats exposed to the dye with the stomachs of rats in the control group helps to determine the degree of damage and the effect of structural changes.

Experimental animals: 56 15-20-day-old white male rats kept in the vivarium of Samarkand State University were taken for the experiment. Of these, 28 were female and 28 were male rats. The animals were kept in a ventilated room at a temperature of

20ºC. The lighting regime was 12/12 (light on from 8.00), they were fed with standard feed.

Experimental procedure: Rats were divided into groups 1-control, 2-TiO, 3-Al, 4-TiO+Al and kept in separate cages. They were fed for 3 months for the experiment. They were fed daily with the usual food in group 1, 40 mg of E-171 dye in group 2, 40 mg of E-173 dye in group 3, and 40 mg of E-171 and 40 mg of E-173 dye mixed with the usual food in group 4. After three months of the experiment, 32 of the white-skinned rats weighed 200±20 g, and 24 of them weighed 170±20 g.

Analysis and Results

Table 1. The results of the experiments.

Index	control	TiO	Al
Glyucosa, mmol/l	5,36±0,09	5,96 ±0,015	3,47±0,07
Holesterin, mmol/l	1,76±0,15	1,56 ±0,19	1,86±0,12
Albumin, g/l	42,51±1,63	35,6 ±1,15	38,2±1,04
Alaninaminotransferaza, (ALT)	22,45±7,29	26,8 ±3,3	34,7±1,68
Aspartataminotransferaza, (AST)	24,67±2,59	55,4 ±5,67	38,64±3,63
Uric acid	351,23±57,98	212,3 ±47,4	205,7±69,44
Alkaline phosphatase	50,05±1,45	139 ±2,1	65,9±2,0

Conclusion

Biochemical parameters in the blood of rats show no significant abnormalities. However, the absence of this toxicity has not been proven. In some studies, the development of pulmonary fibrosis, manifestations of nephrotoxicity, liver damage and manifestations of myocardial disease have been detected. From the results of the above biochemical analysis, we can see that the glucose level in rats that consumed food dye E-171 is slightly higher than that of rats in the control group, and the amount of Albumin is lower. In rats that consumed food dye E-173, the amount of Albumin is lower, and the amount of Cholesterol is slightly higher than that of the control group. Samples taken from the stomachs of rats are used in the process of preparing histological preparations.

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THE ESSENCE OF BIOLOGICAL DIVERSITY AND INNOVATIVE SCIENTIFIC-PRACTICAL APPROACHES TO ITS CONSERVATION

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Annotatsiya. Mazkur maqolada biologik xilma-xillikni mohiyati yoritilgan. Biologik xilma-xillikni saqlashga doir qabul qilingan dasturlar va chora tadbirlar mohiyati ochib berilgan. O'z navbatida O'zbekistonda biologik xilma-xillikni o'ziga xos tomonlari va uni saqlashda qo'llaniladigan innovatsion yondashuvlar ko'rsatib o'tilgan.

Kalit so'zlar: Biologik xilma-xillik, ekosistema, atrof-muhit, xalqaro dastur, xalqaro hamkorlik, konvensiya, tur, o'simlik dunyosi, hayvonot dunyosi.

Аннотация. В данной статье рассматривается сущность биоразнообразия. Раскрывается суть программ и мер, принятых для сохранения биоразнообразия. В свою очередь, указываются специфические аспекты биоразнообразия в Узбекистане и инновационные подходы, используемые в его сохранении.

Ключевые слова: биологическое разнообразие, экосистема, окружающая среда, международная программа, международное сотрудничество, конвенция, виды, растительный мир, животный мир.

Abstract. This article examines the essence of biodiversity. It reveals the programs and measures adopted to conserve biodiversity. Specific aspects of biodiversity in Uzbekistan and innovative approaches used for its conservation are highlighted.

Keywords: *biological diversity, ecosystem, environment, international program, international cooperation, convention, species, flora, fauna.*

Introduction

The famous biologist Y. Wilson defined the concept of diversity as the meaning of life itself. He was right - without diversity there is no life. Biodiversity is the diversity of all living things on Earth, from genes to ecosystems. Where there is life, there is biodiversity. By biodiversity, we mean the way living organisms of different species in ecosystems live together. These species are interconnected with each other and with the abiotic environment [1-3].

Biodiversity conservation is currently an urgent problem, and several international programs have been adopted to preserve it. The concept of biodiversity was introduced into wide circulation at the 1972 UN Conference on the Environment in Stockholm. At this conference, ecologists expressed their proposals for the study and conservation of biodiversity, and an international program was adopted. The goal of this program was that the protection of living nature should be given first place in any human activity on Earth [1, 4-7].

The concept of biodiversity began to be used after the signing of the Convention on Biological Diversity by the leaders of many world countries at the UN International Conference in Rio de Janeiro (Brazil) in 1992. In 1992, the Global Strategy for Biodiversity was developed, the main goal of which was to reduce the rate of species extinction. To date, 180 countries have signed the "Convention on Biodiversity", which assumes responsibility for the conservation of living nature on 1/7 of the land area of our planet. In this, at level I, genetic diversity is studied. At level II, taxonomic diversity is studied. At level III, ecological diversity is studied [2, 8-13].

Literature Review

Uzbekistan joined this concept in 1995. The Republic of Uzbekistan, recognizing the importance of protecting biological diversity resources for its sustainable development, became a member of the International Convention on Biological Diversity in 1995.

In 1998, the National Strategy and Action Plan for Biodiversity Conservation of the Republic of Uzbekistan was developed. This plan was later approved by Resolution № 139 of the Cabinet of Ministers of the Republic of Uzbekistan. The main goal of the National Strategy is to ensure the formation of a single main direction and planning structure for the management of the country's biodiversity resources [3].

Analysis and Results

In order to deeply understand the importance of preserving biological species and raise awareness among the international community, the UN has declared May 22 as the "International Day for Biological Diversity". The biological resources of the Earth's surface are a vital necessity for the economic and social development of

mankind. Biological species form the basis of the biodiversity of our planet. If any of them disappears, it will be completely irreplaceable. The problems of biological diversity today have gone beyond the classical biological boundaries. Solving them requires the use of not only data from the fields of systematics, ecology, biogeography, but also information and methodological tools from landscape science, types and areas of nature use, economics, sociobiology and other fields. At the same time, wild flora and fauna know neither administrative nor state borders.

Biodiversity is much broader than simple life forms. It not only determines the directions of practical research, but also has such a status that if biodiversity exists, the stability of the ecosystem will be strong. Therefore, it is advisable to constantly protect it, and special attention is paid to the issue of preserving biodiversity in nature conservation activities.

Biodiversity refers to the variety of all life on Earth, including animals, plants, microorganisms, their genes, and ecosystems. The term "biodiversity" does not refer to the biological diversity of a particular organism, but rather to the interactions between all parts of the biological world. Biodiversity is often considered at three levels: species diversity, which is the diversity of all animals and plants, including fungi and microorganisms; diversity of genetic material; and ecosystem diversity, which is the diversity of ecosystems (e.g., forests, mountains, grasslands, savannas, deserts, etc.). Together, these levels form the components of biodiversity [4].

On the implementation of the Decree of the President of the Republic of Uzbekistan "On the State Program for the Implementation of the Strategy of Actions on Five Priority Areas of Development of the Republic of Uzbekistan in 2017-2021 in the "Year of Active Investments and Social Development" № PF-5635 dated January 17, 2019 and the Resolution of the Oliy Majlis of the Republic of Uzbekistan "On the Accession of the Republic of Uzbekistan to the Convention on Biological Diversity, signed in Rio de Janeiro in 1992" № 82-I dated May 6, 1995, as well as a comprehensive program aimed at preserving and ensuring sustainable use of biological diversity, developing and expanding protected natural areas, reducing the rate of degradation of natural ecological systems, restoring rare and endangered species of animals and plants, and developing international relations in the field of biodiversity conservation In order to implement the measures, a resolution of the Cabinet of Ministers was published (Resolution of the Cabinet of Ministers of the Republic of Uzbekistan on approval of the Strategy for the Conservation of Biological Diversity in the Republic of Uzbekistan for 2019-2028 - Tashkent, June 11, 2019, № 484). The strategy sets out the following priority tasks:

-increase the area of protected natural areas to 12 percent of the country's territory;

-carry out afforestation work on the dried-up bottom of the Aral Sea and increase its area to 1.2 million hectares;

-increase the number of gazelles in the Bukhara specialized nursery "Jayron" to 1,000;

-create a unified centralized system for monitoring biodiversity components in reference ecosystems in state reserves;

-create a unified information database for state monitoring of biodiversity and the state cadastre based on modern geoinformation technologies (GIS technologies);

-conduct geobotanical surveys of plants in natural pastures and hayfields on an area of 2 million hectares annually;

-integrate biodiversity conservation issues into all sectors of the economy [3].

On February 8, 2024, a meeting of the Coordination Committee of the project "Global Biodiversity Program - Supporting Early Action" was held in Tashkent, in cooperation with the Global Environment Facility (GEF), the UNDP Uzbekistan Office, and the Ministry of Ecology, Environmental Protection and Climate Change [5].

This project aims to implement the Kunming-Montreal Global Biodiversity Framework and accelerate early action by providing financial and technical assistance to countries to begin harmonizing their national biodiversity programs, strategies, and action plans.

As noted above, "The 1st National Strategy and Action Program for Biodiversity Conservation in Uzbekistan was adopted in 1998, and the 2nd Program in 2019. The tasks in this program were set based on the goals for 2010–2020. New tasks were included in the 3rd Program in 2022. Accordingly, we aim to revise the national strategy and enrich it with new goals and tasks aimed at preserving biodiversity until 2030," said Khalilulla Sherimbetov, Head of the Department of Protected Natural Areas of the Ministry of Ecology [6].

The event approved the regulations on the Coordination Committee, its personnel, the project report on the work carried out and the project action plan for 2024. "The project began in Uzbekistan in April 2023. Its tasks are to critically review existing national targets to ensure their compliance with the global framework. Also, within the framework of the project, we plan to review and analyze the existing monitoring system, biodiversity policy and the relationship between various conventions in order to make recommendations for strengthening the protection and conservation of biodiversity," said Sergey Zagrebin, head of the project "Global Biodiversity Program - Supporting Early Action".

The approval of the Roadmap for the preparation and coordination of new integrated indicators for the National Strategy and Action Plan for Biodiversity Conservation was a significant outcome of the Coordinating Committee meeting. The targets are planned to be prepared in 2024 and submitted to the Convention Secretariat, as established in the Kunming-Montreal Global Biodiversity Framework (GBF).

If we pay attention, on December 19, 2022, 190 countries reached an agreement on the Kunming-Montreal Global Biodiversity Framework (GBF). The program creates a framework for global action on biodiversity, paving the way for a climate-neutral, nature-positive and sustainable world by 2050. It complements the Paris Agreement on climate and guides humanity towards global action to conserve and protect nature by 2030.

To support countries in achieving the goals and targets of the Biodiversity Framework, the Global Environment Facility has funded a global project implemented in 138 countries around the world, jointly with UNDP and UNEP. Uzbekistan's biodiversity includes more than 27 thousand species. Among them, 14,900 species of

invertebrates and 715 species of vertebrates are found. Of the vertebrates, 107 species are mammals, 467 species are birds, 61 species are reptiles, 3 species are amphibians, and 77 species are fish.

There are also 11,000 species of plants, fungi, algae. In addition, there are 4,300 species of higher wild plants, of which 8% are endemic. The Red Book of Uzbekistan (2019) includes 206 animal and 314 plant species. One of the main global goals is to restore 30% of degraded ecosystems worldwide by 2030, halt the extinction of certain species and reduce the risk and rate of extinction of all species by a factor of ten by 2050, reduce the risk of pesticides by at least 50% by 2030, sustainably manage areas allocated for agriculture, fisheries and forestry, and significantly increase agroecology and other practices that support biodiversity.

In fact, the Convention on Biological Diversity is a legally binding international treaty adopted in Rio de Janeiro on 5 June 1992, the objectives of which are the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising therefrom. In accordance with the Resolution of the Oliy Majlis of the Republic of Uzbekistan № 82-I of 6 May 1995 "On the accession of the Republic of Uzbekistan to the Convention on Biological Diversity of Rio de Janeiro, 1992", the Republic of Uzbekistan acceded to this Convention [7].

The Convention is monitored by a Conference of the Parties every two years. At the 15th Conference of the Parties (COP 15) in 2022, world governments adopted the Kunming-Montreal Global Biodiversity Agenda. The agenda sets four main goals to be achieved by 2050, focusing on the health of ecosystems and species, including halting the loss of species caused by human activities, sustainable use of biodiversity, equitable sharing of benefits, and access to finance. It also includes 23 targets to be achieved by 2030, such as conserving 30 percent of terrestrial, marine and inland waters; restoring 30 percent of degraded ecosystems; reducing the introduction of invasive species and harmful subsidies [8].

As part of the implementation of the decisions adopted at the 15th Conference of the Parties, each of the 188 countries that signed the Kunming-Montreal Global Biodiversity Framework is required to develop their own national targets in accordance with the adopted framework. To achieve these ambitious goals, UNDP has launched a project to support early action of the Global Biodiversity Framework in 69 countries, including Uzbekistan. In collaboration with the Ministry of Ecology, Environmental Protection and Climate Change, UNDP has developed national targets aligned with the Global Biodiversity Framework. This publication presents Uzbekistan's newly developed national targets to a wide range of stakeholders and aligns them with the Global Biodiversity Framework.

Conclusion

Based on the above analytical data, we believe that today it is necessary to use the following innovative methods to preserve biodiversity: helps to sustainably use natural resources and preserve biodiversity in protected natural areas by creating favorable conditions for tourists; using drones and satellites to improve monitoring and management of protected natural areas; contribute to the preservation of global

biodiversity through cooperation with different countries; to produce more food using less land than traditional agriculture; to obtain environmentally friendly energy through the production and use of biogas.

For example, ecological tourism (ecotourism) helps to preserve biodiversity. Because it is an important factor in the development and management of protected natural areas. The main principles of ecotourism include sustainability, conservation of biodiversity, support for local communities and environmental education. There are several types of ecotourism: helps to use natural resources with minimal negative impact; allows local communities to preserve their cultural heritage and way of life, and also provides a sustainable source of income and helps improve their standard of living; helps to understand the importance of nature conservation and can be an important tool in solving environmental problems.

Ecotourism helps to develop the local economy, as it creates new jobs, forms value-added chains and increases tax revenues for the state budget. The impact of ecotourism on the local economy is as follows: creates new jobs, especially in rural areas, which increases the income of the local population; the development of the tourism sector helps to improve hotels, restaurants, transport and other infrastructure facilities.

Here are some examples of jobs created in ecotourism projects aimed at preserving biodiversity: construction and management of ecologically clean lodges and hotels; provision of accommodation services in ecologically clean conditions; accompanying tourists on ecological routes and providing information; production and sale of ecologically clean agricultural products; development and implementation of educational programs to address environmental issues and preserve biodiversity; recruitment of specialists to manage and develop ecotourism initiatives; attracting grants and investments to finance ecotourism initiatives.

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MODERN PROBLEMS OF PEDAGOGY AND PSYCHOLOGY

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PEDAGOGICAL AND METHODOLOGICAL FOUNDATIONS OF GAMIFYING THE EDUCATIONAL PROCESS BASED ON DIGITAL PLATFORMS

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Annotatsiya. Mazkur maqolada ta'lim jarayonini raqamli platformalar asosida o'yinlashtirishning pedagogik va metodik asoslari ko'rib chiqildi. Tadqiqotda o'yinlashtirishning o'quvchilarning motivatsiyasi, dars jarayonidagi faolligi va o'quv faoliyatida faol ishtirokini oshirishga qaratilgan innovatsion yondashuv sifatidagi o'rni tahlil qilinadi. Raqamli ta'lim muhitiga ballar, darajalar, nishonlar, reyting jadvallari va qayta aloqa mexanizmlari kabi o'yin elementlarini integratsiya qilish masalasiga alohida e'tibor qaratiladi. Tadqiqot mavjud ilmiy adabiyotlar, raqamli ta'lim platformalari hamda o'yinlashtirilgan o'quv faoliyati bo'yicha amaliy kuzatuvlarning sifat va tavsifiy tahliliga asoslanadi. Natijalar shuni ko'rsatadiki, o'yinlashtirish o'quv maqsadlari bilan tizimli ravishda uyg'unlashtirilgan va mos raqamli platformalar bilan qo'llab-quvvatlangan holda, o'quvchilarning jalb etilishi, o'zini-o'zi boshqarib o'qishi hamda kognitiv va ijtimoiy kompetensiyalarining rivojlanishiga ijobiy ta'sir ko'rsatadi. Maqolada, shuningdek, ta'limda o'yinlashtirishni joriy etishning afzalliklari va cheklovlari muhokama qilinib, pedagogik asoslangan metodik yondashuvning ahamiyati ta'kidlanadi. Tadqiqot natijalari ta'lim sifatini raqamli platformalar va o'yinlashtirish strategiyalaridan samarali foydalanish orqali oshirishni istagan pedagoglar uchun amaliy qo'llanma bo'lib xizmat qilishi mumkin.

Kalit so'zlar: o'yinlashtirish, raqamli platformalar, ta'lim jarayoni, raqamli ta'lim muhiti, o'quvchi motivatsiyasi, o'qitish metodikasi.

Аннотация. В данной статье рассматриваются педагогические и методические основы геймификации образовательного процесса на основе цифровых платформ. В исследовании анализируется роль геймификации как инновационного подхода к обучению, направленного на повышение мотивации учащихся, их вовлеченности и активного участия в учебной деятельности. Особое внимание

уделяется интеграции игровых элементов, таких как баллы, уровни, значки (бейджи), рейтинговые таблицы и механизмы обратной связи, в цифровую образовательную среду. Исследование основано на качественном и описательном анализе существующей научной литературы, цифровых образовательных платформ и практических наблюдений за геймифицированной учебной деятельностью. Результаты показывают, что геймификация при системном согласовании с учебными целями и поддержке соответствующих цифровых платформ способствует повышению вовлеченности обучающихся, развитию саморегулируемого обучения, а также формированию когнитивных и социальных компетенций. В статье также обсуждаются преимущества и ограничения внедрения геймификации в образовательный процесс и подчеркивается важность педагогически обоснованного методического подхода. Результаты исследования могут служить практическим руководством для педагогов, стремящихся повысить качество образования посредством эффективного использования цифровых платформ и стратегий геймификации.

Ключевые слова: *геймификация, цифровые платформы, образовательный процесс, цифровая образовательная среда, мотивация учащихся, методика обучения.*

Abstract. This article examines the pedagogical and methodological foundations of gamifying the educational process based on digital platforms. The study analyzes the role of gamification as an innovative instructional approach aimed at enhancing student motivation, engagement, and active participation in learning activities. Special attention is given to the integration of game elements such as points, levels, badges, leaderboards, and feedback mechanisms into digital learning environments. The research is based on a qualitative and descriptive analysis of existing scientific literature, digital educational platforms, and practical observations of gamified learning activities. The findings indicate that gamification, when systematically aligned with learning objectives and supported by appropriate digital platforms, contributes to improved learner engagement, self-regulated learning, and the development of both cognitive and social competencies. The article also discusses the advantages and limitations of implementing gamification in education and emphasizes the importance of a pedagogically grounded methodological approach. The results of the study may serve as a practical guide for educators seeking to improve the quality of education through the effective use of digital platforms and gamification strategies.

Keywords: *gamification, digital platforms, educational process, digital learning environment, student motivation, teaching methodology.*

Introduction

In recent years, the rapid development of digital technologies has significantly transformed the educational landscape worldwide. The integration of digital platforms

into the teaching and learning process has expanded opportunities for improving educational quality, accessibility, and effectiveness [1-2]. Traditional instructional approaches are increasingly being complemented or replaced by innovative digital methods that emphasize learner engagement, interactivity, and personalization. In this context, one of the most promising pedagogical approaches is the gamification of the educational process. Gamification refers to the application of game elements, mechanics, and design principles in non-game contexts, particularly in education, with the aim of enhancing learners' motivation, engagement, and learning outcomes. Unlike game-based learning, which relies on full-fledged educational games, gamification incorporates selected game components—such as points, levels, badges, leaderboards, and challenges—into existing learning activities. When implemented appropriately, these elements can create a more dynamic and motivating learning environment that supports active participation and sustained interest among students. Digital educational platforms provide an effective technological foundation for the implementation of gamification methods. Learning management systems, online assessment tools, and interactive educational applications enable educators to integrate game elements seamlessly into the instructional process. Through digital platforms, it becomes possible to track learners' progress in real time, provide immediate feedback, and personalize learning paths based on individual performance. These features not only increase students' involvement in the learning process but also contribute to the development of self-regulation, critical thinking, and problem-solving skills. The relevance of gamifying the educational process is particularly evident in the context of modern learners, who are often referred to as "digital natives" [3, 4]. These learners are accustomed to interactive digital environments and expect learning experiences to be engaging and meaningful. Consequently, the use of traditional, passive teaching methods may lead to decreased motivation and learning efficiency. Gamification, when supported by digital platforms, addresses this challenge by transforming learning tasks into goal-oriented, interactive, and competitive activities that align with students' cognitive and psychological characteristics. Despite the growing interest in gamification, its pedagogical and methodological aspects require systematic analysis. The effectiveness of gamification depends not only on the availability of digital tools but also on the correct selection of game elements, alignment with educational objectives, and consideration of learners' individual needs. Therefore, developing a well-structured methodology for gamifying the educational process based on digital platforms remains a significant scientific and practical task. This article aims to explore the pedagogical and methodological foundations of gamifying the educational process using digital platforms. The study focuses on identifying key gamification elements, analyzing their educational potential, and outlining effective strategies for their integration into the learning process. The findings of this research may contribute to improving teaching practices and enhancing the overall quality of education in digital learning environments.

Literature Review

The concept of gamification has gained considerable attention in educational research over the past decade, particularly in relation to digital learning environments.

Early studies on gamification were largely influenced by motivational theories, including self-determination theory and behaviorist approaches, which emphasize the role of rewards, feedback, and goal achievement in learning. Researchers have highlighted that the integration of game elements into educational contexts can positively influence learners' motivation, engagement, and persistence when appropriately aligned with instructional objectives [2-4]. Several scholars have examined the pedagogical potential of gamification in education. Studies indicate that the use of points, badges, and leaderboards can increase student participation and promote active learning behaviors. According to existing research, gamification supports formative assessment by providing immediate feedback and enabling learners to monitor their progress.

Furthermore, the competitive and collaborative elements embedded in gamified learning environments have been shown to foster social interaction and teamwork skills among students. With the advancement of digital technologies, digital platforms have become a central focus of gamification research. Learning management systems and online educational tools offer built-in features that facilitate the implementation of gamification strategies. Researchers emphasize that digital platforms enable adaptive learning, allowing educators to tailor tasks and challenges to learners' individual needs and skill levels. This adaptability enhances the effectiveness of gamification by preventing cognitive overload and maintaining an optimal level of challenge. Empirical studies on the effectiveness of gamification in digital education report mixed but generally positive results.

Many studies demonstrate improvements in learners' motivation, engagement, and academic performance, particularly in online and blended learning contexts. However, some researchers caution that excessive reliance on extrinsic rewards may reduce intrinsic motivation if gamification is not pedagogically grounded. As a result, recent literature stresses the importance of balancing extrinsic incentives with meaningful learning activities and authentic problem-solving tasks [5-8]. Another important direction in the literature concerns the methodological design of gamified learning environments. Scholars argue that successful gamification requires a systematic approach that integrates instructional design principles with game mechanics. The alignment of learning outcomes, assessment criteria, and gamification elements is considered a key factor in achieving sustainable educational impact. Moreover, teacher competence in using digital platforms and gamification tools is identified as a critical determinant of successful implementation. Despite the growing body of research, gaps remain in the literature regarding comprehensive methodological frameworks for gamifying the educational process through digital platforms. Many studies focus on specific tools or short-term interventions, while fewer address long-term pedagogical strategies and contextual factors. Therefore, further research is needed to develop holistic models that consider technological, pedagogical, and psychological dimensions of gamification in digital education.

Research Methodology

This study employs a qualitative and descriptive research design to examine the pedagogical and methodological foundations of gamifying the educational process

based on digital platforms. The chosen methodology aims to analyze existing theoretical concepts, practical approaches, and observed outcomes related to the integration of gamification elements into digital learning environments. The research focuses on identifying effective strategies for implementing gamification in a way that aligns with educational objectives and learners' needs.

The research process consisted of several stages. In the first stage, a comprehensive analysis of scientific literature was conducted to examine existing theories, models, and empirical findings related to gamification and digital education. This stage enabled the identification of key gamification elements, including points, levels, badges, leaderboards, feedback mechanisms, and challenges, as well as their pedagogical functions. Special attention was paid to studies addressing learner motivation, engagement, and learning outcomes in digital contexts. In the second stage, commonly used digital educational platforms were analyzed from a methodological perspective. The analysis focused on platform functionalities that support gamification, such as progress tracking, automated assessment, interactive tasks, and real-time feedback. Based on this analysis, a generalized methodological framework for gamifying the educational process was developed. This framework emphasizes the alignment of learning objectives, instructional content, assessment methods, and game elements. The third stage involved the observation and analysis of gamified learning activities implemented in a digital learning environment. Although the study does not rely on large-scale experimental data, it draws on practical observations and comparative analysis of traditional and gamified instructional approaches. The effectiveness of gamification was evaluated based on qualitative indicators such as learner engagement, participation, motivation, and perceived learning satisfaction. Data analysis was carried out using descriptive and comparative methods. The findings were interpreted through a pedagogical lens, considering motivational theories and instructional design principles. This methodological approach allows for a holistic understanding of how gamification functions within digital platforms and provides a foundation for developing practical recommendations for educators.

Analysis and Results

The findings of the study indicate that gamifying the educational process through digital platforms has a significant positive impact on learner engagement and motivation. One of the most notable results is the increased level of active participation observed in gamified learning environments. The integration of points, levels, and progress indicators encourages learners to complete tasks consistently and strive for higher performance. Unlike traditional instructional approaches, gamified activities promote a sense of achievement and goal orientation, which contributes to sustained engagement. Another important result relates to the role of feedback in gamified digital learning. Digital platforms enable immediate and continuous feedback, allowing learners to monitor their progress and identify areas for improvement. This real-time feedback mechanism supports formative assessment and enhances self-regulated learning. Learners become more aware of their strengths and weaknesses, which positively influences their learning strategies and academic confidence. The study also reveals that gamification fosters a balance between competition and collaboration.

Leaderboards and ranking systems introduce a competitive element that motivates learners to improve their performance. At the same time, collaborative challenges and group-based tasks promote teamwork and peer interaction. This combination contributes to the development of social and communication skills, which are essential components of modern education. However, the findings suggest that competition should be carefully managed to avoid negative effects such as excessive stress or demotivation among lower-performing learners. From a pedagogical perspective, the results highlight the importance of aligning gamification elements with learning objectives. Gamification proves to be most effective when game mechanics are integrated into meaningful learning activities rather than used as superficial rewards. When learners perceive gamified tasks as relevant and intellectually stimulating, their intrinsic motivation increases. Conversely, an overemphasis on extrinsic rewards may reduce deep learning and shift the focus away from educational goals. The analysis further demonstrates that digital platforms play a critical role in the successful implementation of gamification. Platforms that offer flexible customization options allow educators to adapt gamification strategies to different subjects, learner levels, and instructional contexts. Adaptive features, such as personalized challenges and differentiated tasks, help maintain an optimal level of difficulty and prevent cognitive overload. This adaptability is particularly important in diverse learning environments where students have varying abilities and learning preferences. Despite these positive outcomes, the study identifies several challenges associated with gamifying the educational process. Technical limitations, insufficient digital infrastructure, and lack of teacher training may hinder effective implementation. Additionally, designing high-quality gamified content requires time, creativity, and pedagogical expertise. These challenges suggest that institutional support and professional development are essential for the sustainable use of gamification in education. In discussion, the findings align with existing research that emphasizes the motivational benefits of gamification in digital education. However, this study contributes to the literature by highlighting the methodological dimension of gamification and the importance of a structured, pedagogically grounded approach.

The results suggest that gamification should not be viewed as an isolated technique but as an integral part of instructional design within digital learning environments. Overall, the results and discussion underscore that gamification, when implemented through well-designed digital platforms, can enhance the quality of the educational process. It supports learner-centered instruction, promotes active engagement, and contributes to the development of both cognitive and non-cognitive skills. Future research may focus on empirical validation of the proposed methodological framework and explore long-term learning outcomes associated with gamified digital education.

Conclusion

In conclusion, the study demonstrates that gamifying the educational process based on digital platforms represents an effective and innovative approach to modern education. The integration of gamification elements into digital learning environments enhances learner engagement, motivation, and active participation, which are critical

factors for achieving sustainable learning outcomes. By transforming traditional instructional activities into interactive and goal-oriented experiences, gamification contributes to a more learner-centered and dynamic educational process. The findings highlight that the effectiveness of gamification largely depends on its pedagogical and methodological design.

Digital platforms provide the necessary technological infrastructure for implementing gamification; however, technology alone is insufficient to ensure educational success. Meaningful alignment between learning objectives, instructional content, assessment strategies, and game mechanics is essential. When gamification elements are thoughtfully integrated into the learning process, they support not only extrinsic motivation but also the development of intrinsic motivation and self-regulated learning skills. Another important conclusion of this study is the role of digital platforms in enabling personalization and adaptability in gamified learning environments. Features such as real-time feedback, progress tracking, and adaptive challenges allow educators to address individual learner differences and maintain an optimal level of cognitive challenge. This adaptability enhances learning efficiency and helps prevent disengagement, particularly in diverse educational contexts. Moreover, gamified digital learning environments foster collaboration and communication, contributing to the development of social and professional competencies. At the same time, the study acknowledges several challenges associated with the implementation of gamification in education. Technical constraints, limited digital infrastructure, and insufficient teacher training may reduce the potential benefits of gamification. Additionally, an overreliance on external rewards may negatively affect deep learning if pedagogical principles are not carefully considered. These challenges underline the importance of institutional support, continuous professional development, and strategic planning in the adoption of gamification methodologies.

Overall, this research confirms that gamification, when implemented through well-designed digital platforms and guided by sound pedagogical principles, can significantly improve the quality of the educational process. The proposed methodological approach provides a foundation for educators seeking to integrate gamification into their teaching practices.

Future research should focus on empirical validation of gamified learning models, long-term learning outcomes, and the impact of gamification across different educational levels and disciplines. Such studies will further contribute to the effective and sustainable integration of gamification in digital education.

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USE OF PLAY THERAPY IN PRESCHOOL CHILDREN IN PSYCHOCORRECTION OF ANXIETY

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Annotatsiya. Ushbu maqolada maktabgacha ta'lim yoshidagi bolalarda xavotirlanish holatlarini kamaytirish va ularning emotsional barqarorligini ta'minlashda o'yin terapiyasining psixokorreksion imkoniyatlari tahlil qilingan. Bolalik davrida xavotirlanishning shakllanishiga oilaviy munosabatlar, tarbiyaviy uslublar hamda ijtimoiy muhit omillari sezilarli ta'sir ko'rsatadi. Tadqiqotda o'yin terapiyasi bolaning ichki kechinmalarini ifoda etish, stress va qo'rquv holatlarini yengillashtirish, o'ziga ishonchni shakllantirishda samarali metod sifatida namoyon bo'lishi ko'rsatib o'tilgan. O'yin jarayonida bola o'z his-tuyg'ularini erkin ifoda etadi, bu esa psixologik muvozanatni tiklash va xavotir darajasini pasaytirishga yordam beradi. Mazkur maqolada o'yin terapiyasining turli shakllari – rolli o'yinlar, qum terapiyasi, badiiy o'yinlar va dramatizatsiya usullari – psixokorreksion vosita sifatida qo'llanishining afzalliklari yoritilgan.

Kalit so'zlar: xavotirlanish, psixokorreksiya, o'yin terapiyasi, maktabgacha ta'lim yoshi, emotsional rivojlanish, ijtimoiy moslashuv. his-tuyg'ular ,stress va qo'rquv dramatizatsiya usullari, qo'llanishining afzalliklari.

Аннотация. В статье анализируется психокоррекционный потенциал игровой терапии в снижении тревожности у детей дошкольного возраста и обеспечении их эмоциональной стабильности. Семейные отношения, методы воспитания, факторы социальной среды существенно влияют на формирование тревожности в детском

возрасте. Исследование показывает, что игровая терапия является эффективным методом выражения внутренних переживаний ребенка, снятия напряжения и страха, формирования уверенности в себе. В процессе игры ребенок свободно выражает свои чувства, что способствует восстановлению психологического равновесия и снижению уровня тревожности. В статье освещаются преимущества использования различных форм игровой терапии – ролевых игр, песочной терапии, арт-игр, методов драматизации – в качестве психокоррекционного инструментария.

Ключевые слова: тревожность, психокоррекция, игровая терапия, дошкольный возраст, эмоциональное развитие, социальная адаптация. Эмоции, стресс и страх, методы драматизации, преимущества использования.

Abstract. This article analyzes the psychocorrectional potential of play therapy in reducing anxiety in preschool children and ensuring their emotional stability. Family relationships, upbringing methods, and social environment factors significantly affect the formation of anxiety in childhood. The study shows that play therapy is an effective method for expressing a child's inner feelings, relieving stress and fear, and building self-confidence. During the game, the child freely expresses his feelings, which helps restore psychological balance and reduce the level of anxiety. This article highlights the advantages of using various forms of play therapy - role-playing games, sand therapy, art games, and dramatization methods - as a psychocorrectional tool.

Keywords: anxiety, psychocorrection, play therapy, preschool age, emotional development, social adaptation. emotions, stress and fear, dramatization methods, advantages of use.

Introduction

Today, ensuring the personal development, emotional stability and social adaptation of children in the preschool education system is one of the most pressing issues. Psychological research shows that the preschool age is one of the most sensitive and formative stages of a person's mental life. During this period, the child studies the environment, begins to understand his "I" and experiences various emotional experiences. In this process, some children experience states such as anxiety, fear, insecurity, shyness. If these mental states are not eliminated in time, they can lead to personal and social problems at later stages of education. The relevance of the topic is that in the modern educational process, it is necessary to search for innovative, person-oriented approaches to ensure the psychological well-being of the child's personality, protect him from mental stress and anxiety. Play therapy in this sense occupies a special place as a non-invasive and effective psychocorrectional method based on the child's natural activity.

Anxiety is a psychological state that expresses a child's internal emotional tension, which arises as a result of the interaction of external factors (family,

kindergarten environment, educational methods) and internal experiences. Anxiety in preschool children is often associated with excessive parental demands, lack of sufficient attention and affection, as well as instability in the social environment. Therefore, psychocorrectional approaches are of great importance in identifying and alleviating anxiety in a child. Play therapy is a method of using the natural activity of children, the game process, as a means of psychological influence. Through play therapy, the child freely expresses his feelings, expresses his inner experiences through artistic images, and thus achieves psychological relief. This method is widely used as an effective tool for reducing anxiety, strengthening self-confidence, and developing social communication skills.

Preschool age is an important stage in the child's psychological development, during which personal characteristics, emotional stability and social communication skills are formed. In psychology, this period is recognized as the period when the child's mental world, emotions, and self-awareness processes are most active. Therefore, early identification and correction of anxiety states that arise during this period are an important condition for psychological development.

Thus, the main focus of this study is to study the scientific and practical foundations of play therapy methods in identifying anxiety states in preschool children, reducing them and forming emotional stability.

Literature Review

The study of the problem of anxiety and methods for its reduction is one of the important areas of psychology. A number of scientific studies have been conducted in this area by foreign and domestic scientists, the results of which create an important theoretical and practical basis for working with preschool children.

Z. Freud interpreted anxiety in his works as the result of the interaction of human subconscious processes, internal conflicts and defense mechanisms. According to him, anxiety is a signal expressing the internal experiences of a person, and psychotherapeutic influence is necessary to eliminate it [4]. Hornay K., on the other hand, associated anxiety with a person's feeling of vulnerability in social relationships [5].

Russian psychologists such as Elkonin D.B., Vygotsky L.S. and Leontyev A.N. deeply analyzed the role of play in the development of a person. In their opinion, play is the main form of a child's assimilation of social experience and is an important factor in his psychological development. J. Piaget's research also emphasized that play plays a mediating role in the cognitive and emotional development of a child[8].

The concept of play therapy was developed by Klein M., Rodgers K., Landreth G., Axter V.E., as well as Leontyev A.N., western and Russian psychologists. They argued that allowing a child to express his inner feelings through play, listening to him and supporting him is important in stabilizing the child's mental state. The "Child-Centered Play Therapy" approach developed by Landreth G. is currently used as one of the most effective play therapy models in the world [7].

Among uzbek psychologists, researchers such as Turayev Kh., Ganiyeva N., Ergasheva M., Kadirova G. conducted scientific research on the role of game technologies in studying and correcting anxiety and emotional disorders in children. In

their works, game activity was shown as an effective tool for strengthening the child's mental health, enhancing social adaptation, and reducing anxiety.

The concept of anxiety has been interpreted differently by different scientists in psychology. Freud Z. interpreted anxiety as an emotional state that arises as a result of a person's unconscious fears and internal conflicts. Hornay K. associated it with a violation of a person's sense of internal security, that is, instability in the social environment. Vygotsky L.S. and Leontyev A.N. explained the formation of anxiety in preschool children with improper organization of the child's activity, in particular, the game process [6].

Thus, the analysis of the existing scientific literature shows that play therapy is one of the scientifically based, natural and highly effective methods of psychological correction of anxiety problems in preschool children.

Thus, theoretically, it can be said that play therapy is one of the most natural, humane and effective methods of psychocorrection of anxiety in preschool children. This method is based on the personal experience of the child, his active participation and internal resources. Therefore, play therapy is of incomparable importance in maintaining and developing the mental health of children.

Play is a natural activity of the human psyche, and it is the main developmental tool, especially for preschool children. According to Elkonin D.B., Piaget J., during the game the child models life experience, expresses his feelings and psychologically processes real-life situations. Therefore, play therapy is recognized as an effective method in the processes of psychological correction and rehabilitation [2].

Play therapy is a psychocorrectional method aimed at revealing the child's inner experiences, reducing emotional tension and improving social adaptation by using the game process as the main tool in communication with the child. In the development of the theory and practice of play therapy, the work of scientists such as G. Ganieva N. Child psychology. Landret plays an important role. According to their research, during the game the child expresses conflicting situations in his life in a symbolic form and thus achieves mental relief [1].

The main theoretical principles of play therapy are as follows:

1. Play is the child's natural language. The child expresses his feelings and experiences through play.

2. The play environment should be safe and supportive. This allows the child to open up his inner world.

3. The therapeutic relationship is based on trust. The psychologist accepts the child's emotional state and responds positively to it.

4. The process of self-awareness is enhanced through play. The child begins to understand the results of his actions and strives for positive changes.

In preschool educational institutions, Karimova V.M. forms of play therapy, such as role-playing games, sand therapy, art games, dramatization and musical games, are widely used. These methods give positive results in alleviating children's emotional experiences, promoting free self-expression and reducing anxiety [3].

Research Methodology

The methodological basis of the research work is based on humanistic, person-oriented educational and activity approaches. In the process of identifying and psychocorrecting anxiety in preschool children, the following methods were used:

1. *Observation method.* Children's play activities, communication behaviors, emotional reactions were observed in natural conditions, and their level of anxiety and social adaptation were analyzed.

2. *Interview method.* Through individual and group interviews with the child, caregiver and parents, the sources of anxiety and the factors that cause them were identified.

3. *Diagnostic tests.* "Test for determining the level of anxiety in children" (Temml R., Dorki M., Amen V.), "Questionnaire of fears" (Zakharov A.), "Color test" (Luscher test).

With the help of these tests, the emotional state of children, the level of fear and the level of mental stress were assessed. Methods of play therapy.

The study used various forms of play therapy techniques:

role-playing games - through games such as "I'm going to kindergarten," "Doctor," "Teacher," the child's inner experiences were analyzed;

sand therapy - emotional relief was created by expressing the child's feelings in a symbolic form;

artistic games and dramatization - served to activate positive emotions, increase self-confidence.

4. *Mathematical-statistical analysis.* The results obtained were processed using the method of percentage analysis and average indicators, and the effectiveness of the psychocorrectional program was assessed.

The complex use of research methods made it possible to determine the level of anxiety of preschool children, identify factors affecting their mental state, and verify the psychocorrectional effectiveness of play therapy on a scientific basis.

Analysis and Results

The research process was conducted in a preschool educational institution with the participation of children aged 5–6 years. A total of 20 children (10 control group and 10 experimental group) were involved in the study. The study was carried out in three stages: the diagnostic stage, the psychocorrectional (play therapy) stage and the stage of reassessment of the results.

1. Results of the diagnostic stage

During the initial analysis, the level of anxiety of children was assessed using the Temml R. –Dorki M.– Amen V. test, the Zakharov A. fear questionnaire and the Luscher color test. The initial results showed the following:

60% of children in the experimental group had a high level of anxiety, 30% had an average level, and 10% had a low level;

in the control group, the average level of anxiety was 45%, the high level of anxiety was 40%, and the low level was 15%.

Observation and interviews revealed that children with high levels of anxiety had the following characteristics: shyness, lack of self-confidence, in some cases

aggressive reactions, excessive dependence on parents, and avoidance of communication in the team.

2. Psychocorrectional stage (play therapy process)

At this stage, an 8-week play therapy program was implemented with children in the experimental group. The program included sessions twice a week, each lasting 35–40 minutes. Play therapy was carried out in the following forms:

role-playing games ("Let's find a friend", "I am brave", "I go to kindergarten") — helped children develop social adaptation, self-confidence, and communication skills;

sand therapy — children expressed their fears and anxieties in a symbolic form, which reduced their internal tension;

artistic games and dramatization were used as a means of freeing emotional expression and enhancing positive emotions;

musical games were useful for relieving stress, stabilizing attention, and creating a positive mental environment.

During the sessions, the psychologist paid special attention to accepting children's emotions, supporting them, and creating a safe environment.

3. Final evaluation and analysis results

At the end of the play therapy program, all children underwent re-diagnostic tests. The results showed that the level of anxiety in the experimental group decreased significantly.

Table 1.

№	Group	High level, %	Medium level, %	Low level, %
1	Experimental group (initial)	60	30	10
2	Experimental group (final)	20	40	40
3	Control group (initial)	40	45	15
4	Control group (final)	35	45	20

The results show that the level of anxiety in the participants of the play therapy program decreased by an average of 40%, while the level of positive emotions, self-confidence and social activity increased.

As a result of psychological observations, the following positive changes were noted:

children learned to freely express their thoughts and feelings;

skills for communicating in a team and establishing friendships developed;

fear and shyness decreased;

self-confidence and positive self-esteem increased.

No significant changes were observed in the control group, confirming the effectiveness of the play therapy program.

Conclusion

The results of the analysis show that play therapy is an effective psychocorrectional tool for reducing anxiety, ensuring emotional stability and enhancing social adaptation in preschool children. Since play activity creates a natural, non-coercive and safe environment for the child, it activates mental defense mechanisms, allows for the expression and management of internal experiences. Thus,

the results of the study scientifically substantiate the fact that play therapy is a highly effective method in psychological practice, in particular, in eliminating anxiety in preschool educational institutions.

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TENDENCY IN THE FORMATION AND DEVELOPMENT OF MEDICAL PEDAGOGY

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Annotatsiya. Ushbu maqolada tibbiyot pedagogikasining shakllanishi va pivojlanishi tendensiyalari yoritilgan. "Tibbiy pedagogika" atamasi pedagogika tushuncha asosida shskllangan boʻlib tibbiy taʼlim nuqtai nazaridan insonni tarbiyalash va oʻqitishni bildiradi. Tibbiy pedagogika taʼlim jarayonini faqat bilim berish sifatida emas, balki insonning umumiy sogʻligʻi va uning himoyasini taʼminlash vositasi sifatida ham namoyon qiladi.

Kalit soʻzlar: tibbiy pedagogika, psixologiya, fiziologiya, evolyutsiya, kontseptual asoslar.

Аннотация. В данной статье рассматриваются тенденции в формировании и развитии медицинской педагогики. Термин "медицинская педагогика" сформирован на основе концепции педагогики и означает воспитание и подготовку человека с точки

зрения медицинского образования. Медицинская педагогика представляет собой образовательный процесс не только как средство передачи знаний, но и как средство обеспечения общего здоровья человека и его защиты.

Ключевые слова: *медицинская педагогика, психология, физиология, эволюция, концептуальные основы.*

Abstract. This article discusses the trends in the formation and development of medical pedagogy. The term "medical pedagogy" is formed on the basis of the concept of pedagogy and means the upbringing and training of a person from the point of view of medical education. Medical pedagogy represents the educational process not only as a means of imparting knowledge, but also as a means of ensuring the general health of a person and his protection.

Keywords: *medical pedagogy, psychology, physiology, evolution, conceptual foundations.*

Introduction

Medical pedagogy is developing in the context of professional education. The need to train teachers for professional educational institutions has become a stimulus for the development of pedagogical methods. This has contributed to the demand for pedagogical knowledge and the strengthening of pedagogical science in the professional sphere.

Key stages in the development of medical pedagogy included the development of professional education. The need for specialized educational institutions arose, necessitating the development of pedagogical approaches tailored to the specifics of medical knowledge and practical skills. The training of teachers and specialists — professional educational institutions began to employ specialized teaching methods — emphasized the importance of pedagogical science in medicine.

The term "medical pedagogy" is formed on the basis of the concept of pedagogy and means the upbringing and education of a person from the point of view of medical education. "Medical pedagogy" constitutes the methodological basis of pedagogical education and expresses the goals, tasks and methods aimed at the development of the individual. Medical pedagogy teaches the specificity of medical knowledge, including the doctrine of decision-making by students, taking into account the physiological and psychological characteristics of human health. In the formation of such a combination of knowledge, the science of pedagogy certainly serves as the main foundation. The study of the union of medical knowledge, covering human health and based on medical components, is carried out through the process of specialized effective medical education and upbringing.

Literature Analysis

When studying the development and evolution of medical pedagogy, its connections with other disciplines can be justified by the following factors. In particular, education and training are considered the object not only of the discipline of pedagogy, but also of philosophy, history, psychology, sociology, cultural studies and other

scientific disciplines. The discipline of pedagogy, in turn, conducts scientific research through experimental and experimental methods, closely related to the research results of these disciplines. Therefore, determining the methodological and interdisciplinary connections of pedagogy with other disciplines helps to determine the main essence of medical pedagogy [1].

The methodological relevance of medical pedagogy can be explained by the experimental use of fundamental ideas and general concepts of pedagogy borrowed from other disciplines (for example, philosophy), as well as sociological research methods.

The use of specific results of medical pedagogy from other disciplines (for example, psychology, medicine, physiology of nervous activity, etc.) serves as an auxiliary tool for participation in complex medical research. Thus, tibisThe interdisciplinary nature of pedagogy is the study of scientific data aimed at unifying knowledge about the social and physiological state of a person.

In the process of historical and progressive development of pedagogical education, the gradual acquisition of psychological, physiological and other knowledge by mankind in the process of education created the basis for studying them as a subject of development, generalizing medical and pedagogical knowledge. As a result, from the point of view of historical and pedagogical development, interdisciplinary relations led to the formation of medical pedagogy as a new field of professional activity or subject in science. Interdisciplinary relations in medical pedagogy gave impetus to the formation of knowledge about man through the integration of various scientific disciplines, such as medicine, pedagogy, psychology and human physiology [2].

Medical pedagogy studies the human being from the perspective of the principles of human health, which is the main function of medicine in studying and educating him. In this, the development of the educational process in the direction of preserving human health and the prevention and rehabilitation of diseases are studied in harmony with pedagogical education.

The main tasks of medical pedagogy are:

identify effective training methods and approaches, taking into account the medical and physiological characteristics of the individual;

developing healthy lifestyle skills and enabling people to take control of their own health;

to form a conscious attitude towards one's own health and the health of others;

is to support and improve patient adaptation and rehabilitation through innovative educational technologies [3].

In general, medical pedagogy, while acting as a kind of link between medical knowledge and pedagogical teaching methods, helps to form a purposeful, personal development position in ensuring human health. These ideas first reflected interdisciplinary connections between education, development, training and care for the health of the younger generation. For this historical-pedagogical study, fundamental connections between education and medicine were formed, which formed the necessary conditions for the emergence of medical pedagogy as a practical activity. Later, scientific research proved that these interdisciplinary connections contributed to the development of medical pedagogy as a scientific field.

Analysis and Results

The expansion of scientific activity from a historical and pedagogical point of view led to the emergence of medical pedagogy as an independent field, to the re-examination of the multifaceted aspects of personality development in ensuring human health from a scientific point of view, in a new way. As a result, medical pedagogy has combined the research and methods of several disciplines in the scientific analysis of issues related to the development of education and health care. Thus, interdisciplinary relations have become a key factor in the development of medical pedagogy as a new professional and scientific field. This, in turn, has provided a deeper approach to the medical direction in ensuring human health.

In the analysis of the formation of medical pedagogy as a scientific discipline in the 18th century as a socio-cultural mechanism of historical pedagogical development, the ideas of scientists I.T. Pososhkov about the need to teach people literacy and create schools for each social class, V.N. Tatishchev about expanding public education and the school network; I.I. Betsky about creating a "new generation of people" through education; and G.S. Skovoroda about developing national identity in the country's pedagogical system, and N.I. Novikov about understanding a person as a valuable whole occupy a key place [4].

The methodological basis that has emerged in medical pedagogy has made it possible to comprehensively study the main stages in the history of this direction in its formation and development as an independent scientific field. These stages have shaped the evolution of ideas about the relationship between medicine, pedagogy, and the health sector.

The current stage of medical pedagogy was formed at the end of the 20th - beginning of the 21st centuries in the course of strengthening the interdisciplinary nature of medical pedagogy, actively using psychological, pedagogical and medical knowledge to optimize educational processes in the field of health care. Thus, the methodological basis of medical pedagogy as a scientific discipline provides a systematic analysis of its historical development, increasing its importance in preserving and improving human health through effective interaction between medicine and education. More precisely, the methodological basis developed for medical pedagogy has made it possible to scientifically study and substantiate the stages of the formation and development of medical pedagogy as a discipline in the history of education [5].

Conclusion

In conclusion, medical pedagogy approaches the study and education of man from the perspective of human health principles. This science, by its nature, is a combined field of medicine and pedagogy, and its main task is to study the areas of preserving, strengthening and restoring human health in the educational process.

The main areas of medical pedagogy are:

- maintaining health in the educational process: Through this, prepare young people for a healthy lifestyle, teach them to avoid harmful habits, and develop physical and mental health;

- prevent diseases, teach sanitary and hygienic rules, and engage in preventive

work;

- rehabilitation is the application of a pedagogical approach to the processes of restoring and improving the body after illness or injury.

Thus, medical pedagogy represents the educational process not only as a means of imparting knowledge, but also as a means of ensuring the general health of a person and its protection. Medical pedagogy improves the educational process by promoting and maintaining human health, combining the processes of disease prevention and rehabilitation with pedagogical methods. After all, it is in this aspect that an important integrated area of medicine and pedagogy is manifested.

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SCIENTIFIC AND METHODOLOGICAL FOUNDATIONS OF TEACHING EQUATIONS AND INEQUALITIES IN GENERAL SECONDARY, ACADEMIC LYCEUM, AND VOCATIONAL EDUCATION SYSTEMS

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Annotatsiya. Mazkur maqolada umumta'lim maktablari, akademik litseylar va kasb-hunar ta'lim muassasalarida tenglama va tengsizliklarni o'qitishning metodik asoslari tahlil qilinadi. Tadqiqotda tenglama va tengsizlik tushunchalarini bosqichma-bosqich modellashtirish asosida o'qitish modeli ishlab chiqildi. Real vaziyatdan algebraik modelga o'tish, grafik va analitik yondashuvlarni integratsiyalash hamda fanlararo bog'liqlikni ta'minlash orqali o'quvchilarning matematik tafakkurini rivojlantirish imkoniyatlari asoslandi. Natijalar tenglama va tengsizliklarni o'qitishda metodik yondashuvlarni takomillashtirish zarurligini ko'rsatadi.

Kalit so'zlar: *Tenglama, tengsizlik, matematik modellashtirish, o'qitish metodikasi, didaktik model, fanlararo integratsiya, grafik usul, algebraik model, kompetensiyaviy yondashuv.*

Аннотация. В статье анализируются методические основы обучения уравнениям и неравенствам в общеобразовательных школах, академических лицеях и учреждениях профессионального образования. Разработана модель поэтапного обучения на основе математического моделирования. Интеграция графических и аналитических методов, а также междисциплинарные связи способствуют развитию математического мышления обучающихся.

Ключевые слова: *Уравнение, неравенство, математическое моделирование, методика обучения, дидактическая модель, междисциплинарная интеграция, графический метод, алгебраическая модель.*

Abstract. This article analyzes the methodological foundations of teaching equations and inequalities in general education schools, academic lyceums, and vocational education institutions. A step-by-step teaching model based on mathematical modeling is proposed. The integration of graphical and analytical approaches and interdisciplinary connections enhances students' mathematical thinking and problem-solving skills.

Keywords: *Equation, inequality, mathematical modeling, teaching methodology, didactic model, interdisciplinary integration, graphical method, algebraic model, competence-based approach.*

Introduction

In modern educational practice, mathematical knowledge is no longer regarded merely as a set of theoretical concepts, but rather as an effective tool for analyzing and modeling real-world processes. In particular, the topics of equations and inequalities play a crucial role in developing students' abilities for abstract thinking, logical reasoning, and solving problem-based situations.

The methodology of teaching equations and inequalities in general secondary schools, academic lyceums, and vocational education institutions should be organized in accordance with students' age characteristics, level of preparedness, and professional orientation. Therefore, alongside traditional algorithmic approaches, the application of a modeling-based methodological framework in teaching these topics is considered a relevant and significant scientific problem.

Literature Review

In recent years, the methodology of teaching equations and inequalities has been considered one of the significant research directions in pedagogy and mathematics didactics. Studies indicate that modeling, visualization, and interdisciplinary integration play an essential didactic role in the process of forming mathematical concepts.

Freudenthal (1991) proposed the concept of connecting mathematics with real life and interpreted mathematical modeling as a central element of the educational process [3]. This approach is particularly relevant in teaching equations and inequalities within vocational education, where mathematical knowledge must be closely linked with practical and professional contexts. Hiebert and Carpenter (1992) demonstrated the interrelationship between conceptual and procedural knowledge in the process of mathematical understanding [4]. Their findings substantiate the necessity of a meaningful approach to teaching equations and inequalities, rather than relying solely on algorithmic methods. Research conducted by Uzbek scholars also emphasizes the effectiveness of competency-based approaches, problem-based learning, and modeling methods in teaching equations and inequalities [5–7]. However, existing studies have not sufficiently systematized the methodological differences between general secondary schools, academic lyceums, and vocational education institutions.

Therefore, the present study is aimed at improving the methodology of teaching equations and inequalities based on a step-by-step modeling approach.

Research Methodology

Methodology of Teaching Equations and Inequalities

1. *General Concept of the Methodological Approach*. Teaching equations and inequalities is one of the key components of mathematical education, as it contributes to the development of students' logical thinking, analytical reasoning, generalization, and modelling skills. Effective teaching of these topics requires the integration of traditional explanatory methods with modern pedagogical technologies, problem-based learning, activity-oriented approaches, and visual modelling techniques.

The methodological approach is based on the following didactic principles: scientific validity and logical consistency; continuity and systematic organization; clarity and visual presentation; integration of theory and practice; individualization and differentiation of learning; and interdisciplinary integration.

2. *Stage-based model of the teaching process.*

From a pedagogical perspective, the process of teaching equations and inequalities should be organized in three successive stages:

Intuitive–Conceptual Stage. At this stage, students develop an initial conceptual understanding of equations and inequalities. The main objective of this stage is to form students' intuitive perception of mathematical relationships and dependencies.

Formal–Mathematical Stage. At this stage, equations and inequalities are expressed in formal mathematical language. This stage aims to ensure that students comprehend the formal structure of equations and inequalities and master standard mathematical procedures.

Analytical–Practical Stage. At this stage, equations and inequalities are applied to solving real-world and interdisciplinary problems. The purpose of this stage is to develop students' analytical thinking and their ability to apply mathematical knowledge in practical and professional contexts.

3. *Differential Approach According to Educational Stages*

General Secondary Education. Main methodological directions: visual and illustrative teaching methods; simplified algorithms; visual graphs; step-by-step explanation. Pedagogical objective: to form fundamental mathematical concepts and basic problem-solving skills.

Academic Lyceum. Main methodological directions: proof-based methods; complex equations and inequalities; graphical and analytical analysis; generalization and abstraction. Pedagogical objective: to develop abstract mathematical thinking and higher-level cognitive abilities.

Vocational Education. Main methodological directions: profession-oriented problems; technical models; algorithmic approaches; practical calculations and applications. Pedagogical objective: to integrate mathematical knowledge into professional and practical activities.

4. *Modern Pedagogical Technologies*

In teaching equations and inequalities, the application of modern pedagogical technologies significantly enhances students' conceptual understanding and problem-solving abilities. The following methods are considered particularly effective:

Problem-Based Learning (PBL). Problem-based learning involves organizing the educational process around meaningful and intellectually challenging problems. The methodological sequence includes: creating a problematic situation; formulating hypotheses; searching for solutions; analyzing and evaluating the results.

This approach stimulates students' cognitive activity, critical thinking, and independent reasoning, thereby promoting deeper comprehension of mathematical concepts.

Modeling Method. The modeling method plays a crucial role in connecting abstract mathematical knowledge with real-life situations. It enables students to transform real phenomena into mathematical representations.

Didactic model:

Real situation → Graphical model → Algebraic model → Formal solution

This sequence allows learners to gradually move from concrete experience to abstract mathematical reasoning, ensuring the meaningful assimilation of equations and inequalities.

Interactive Methods. Interactive teaching methods foster active student participation and collaborative learning. The most effective techniques include: brainstorming; clustering; INSERT method (Interactive Noting System for Effective Reading and Thinking); Venn diagrams; group discussion and collaborative problem-solving.

The integration of these methods contributes to the development of analytical, communicative, and reflective skills, which are essential for mastering mathematical concepts at an advanced level.

5. *Methodology for Evaluating Teaching Effectiveness*

To assess students' learning outcomes and the effectiveness of the teaching methodology, a quantitative evaluation approach is applied. The level of knowledge acquisition is determined using the following indicator:

$$K = \frac{B_f}{B_{max}} \cdot 100\%$$

where:

K — level of learning achievement (mastery level); B_f — score obtained by the student; B_{max} — maximum possible score.

This indicator allows for an objective assessment of students' academic performance and provides a basis for comparing the effectiveness of traditional and innovative teaching methods. The use of a normalized coefficient makes it possible to analyze learning outcomes across different groups and educational stages, ensuring the reliability and comparability of experimental results.

6. *Pedagogical Significance of the Methodological Model*

The proposed methodology leads to several important pedagogical outcomes. First, it contributes to the development of students' logical and analytical thinking skills. Second, it enables a deeper understanding of the conceptual essence of equations and inequalities rather than their mechanical application. Third, it facilitates the formation of competencies in solving real-world problems through mathematical modeling. Finally, the implementation of this methodological model significantly enhances the overall effectiveness of the educational process.

Analysis and Results

During the research process, an experimental pedagogical study was conducted in general secondary schools, academic lyceums, and vocational education institutions in order to determine the effectiveness of the methodology for teaching equations and inequalities. The experiment was organized in three stages: diagnostic, formative, and final stages.

The study covered three types of educational institutions: general secondary schools (Group G_1), academic lyceums (Group G_2), and vocational education institutions (Group G_3).

In each institution, two types of groups were formed: a control group (traditional teaching methodology); an experimental group (the proposed methodology).

Students' learning outcomes were assessed based on the following criteria:

level of theoretical understanding; skills in algorithmic problem solving; logical analysis and generalization abilities; competence in solving practical problems.

The experimental results are presented in Table 1.

Table 1. Students' Achievement Level (%)

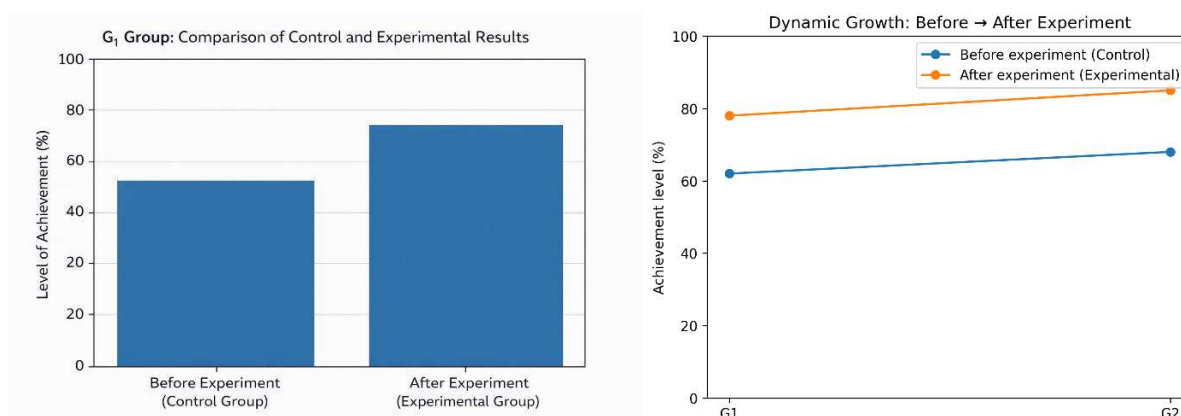| Group	Control Group (%)	Experimental Group (%)
G_1 (school)	62	78
G_2 (lyceum)	68	85
G_3 (vocational)	59	74

As shown in the table, the level of achievement in the experimental groups significantly increased compared to the control groups.

The average growth indicator was calculated as follows:

$$\Delta K = K_{tajri} - K_{nazorat}$$
$$\Delta K_{o'rtacha} \approx 14\% - 17\%$$

These results confirm the pedagogical effectiveness of the proposed methodology. The comparison of students' achievement levels is illustrated in Figure 1.

Figure 1. Comparative graph of students' achievement levels.

The graph clearly demonstrates a stable increase in learning outcomes in the experimental groups.

The proposed methodological model was constructed based on the following didactic sequence:

Real process → Tabular model → Graphical model → Algebraic model → Formal definition

The effectiveness of this model can be explained by several factors: the connection of abstract mathematical concepts with real-life processes; the development of visual thinking; the formation of algorithmic thinking skills; the enhancement of logical generalization abilities.

In addition, the experiment revealed the following qualitative changes: improvement in students' ability to explain mathematical concepts; development of independent problem-solving skills; increased effectiveness of interdisciplinary integration; enhanced ability to analyze complex equations and inequalities.

The analysis of the results indicates that teaching equations and inequalities not only through traditional algorithmic approaches but also through modeling, problem-based learning, and visual methods leads to: deeper understanding of mathematical knowledge; development of mathematical thinking; increased student motivation.

This confirms both the theoretical and practical significance of the proposed methodology.

Conclusion

Based on the results of the conducted scientific and pedagogical research, the following conclusions were drawn.

The integration of modeling, visualization, and problem-based learning elements in the process of teaching equations and inequalities contributes to a deeper understanding of mathematical concepts by students. The experimental results demonstrated that the proposed methodology is more effective than traditional approaches. The application of a differentiated methodological approach across different educational stages makes it possible to take into account students' age-related

and cognitive characteristics and optimizes the process of forming mathematical competencies.

Practical and scientific recommendations:

it is recommended to implement a methodological system for teaching equations and inequalities based on the principle of transitioning from real-life processes to algebraic models;

the integrated use of graphical, tabular, and algebraic models in the educational process is advisable in order to develop students' logical and analytical thinking skills;

in academic lyceums and vocational education institutions, it is necessary to widely apply professionally oriented problems involving equations and inequalities in order to enhance the practical significance of mathematics education;

it is recommended to develop methodological guidelines, didactic models, and electronic educational resources for teachers aimed at improving the teaching of equations and inequalities.

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THEORETICAL AND METHODOLOGICAL FOUNDATIONS OF TEACHING AND DEVELOPING THE CONCEPT OF FUNCTION IN GENERAL SECONDARY AND SECONDARY SPECIALIZED EDUCATION

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Annotatsiya. Mazkur maqolada umumta'lim maktablari va o'rta maxsus ta'lim muassasalarida funksiya tushunchasini shakllantirishning ilmiy-nazariy asoslari, didaktik tamoyillari va zamonaviy metodik yondashuvlari tizimli ravishda tahlil qilinadi. Funksiya tushunchasini o'qitishda matematik model, grafik interpretatsiya va real jarayonlar integratsiyasi asosida yangi metodik model taklif etiladi. Pedagogik tajriba natijalari integratsiyalashgan metodikaning samaradorligini isbotlaydi.

Kalit so'zlar: funksiya, matematik modellashtirish, didaktika, metodika, grafik model, kompetensiya, STEM, integratsiya.

Аннотация. В статье системно анализируются научно-теоретические основы и методические подходы к формированию понятия функции в общеобразовательных школах и учреждениях среднего специального образования. Предлагается интеграционная модель обучения на основе математического моделирования, графической интерпретации и реальных процессов. Результаты педагогического эксперимента подтверждают эффективность предложенной методики.

Ключевые слова: функция, математическое моделирование, методика, графическая модель, интеграция, компетенции.

Abstract. This article systematically analyzes the scientific and methodological foundations of forming the concept of function in general secondary schools and secondary specialized educational institutions. An integrated teaching model based on mathematical modeling, graphical interpretation, and real-world processes is proposed. The results of pedagogical experiments confirm the effectiveness of the proposed methodology.

Keywords: function, mathematical modeling, methodology, graphical model, integration, competencies.

Introduction

In modern education, the formation of mathematical concepts, particularly the concept of function, is considered an important scientific and methodological problem. The concept of function is one of the fundamental categories of mathematics and is closely related to algebra, analysis, geometry, physics, economics, and other disciplines. Therefore, developing a deep, systematic, and conscious understanding of the concept of function among students is one of the key factors in improving the

quality of mathematical education in general secondary and secondary specialized educational institutions.

The mastery of the concept of function in the learning process contributes to the development of students' logical thinking, the formation of mathematical modeling skills, and the ability to analyze real processes mathematically. However, educational practice shows that the concept of function is often presented through formal definitions, which prevents students from fully understanding its conceptual essence. As a result, the concept of function is perceived by students as an abstract and complex notion.

In this regard, the development of scientifically grounded methodological approaches to teaching the concept of function, as well as its gradual introduction through real processes, tables, graphs, and algebraic models, is one of the urgent tasks of modern pedagogy. In particular, teaching mathematical concepts based on an integrative approach in general secondary schools, academic lyceums, and vocational education institutions contributes significantly to enhancing the effectiveness of the educational process.

This study analyzes the scientific and methodological foundations of forming the concept of function and proposes effective teaching models, methodological approaches, and didactic tools. Furthermore, the effectiveness of these approaches in the educational process is substantiated through experimental research.

Literature Review

In recent years, issues related to the formation of the concept of function, the improvement of teaching methodologies, and the development of students' mathematical thinking through mathematical modeling have been widely studied as one of the key directions in pedagogy and mathematics didactics.

In the studies conducted by D. Tall and S. Vinner, two levels of understanding of the function concept were distinguished: the concept image and the concept definition [1]. The authors scientifically demonstrated that many students tend to memorize the formal definition of a function without deeply comprehending its conceptual meaning. These findings indicate that teaching the concept of function should not be limited to formal definitions, but should also involve graphical, tabular, and real-world models.

In the works of J. Hiebert and T. Carpenter, the concept of "understanding-based learning" in mathematics was proposed, emphasizing the importance of students' active cognitive engagement in the formation of the function concept. The authors argue that an understanding-oriented approach contributes significantly to the development of students' mathematical competencies. This, in turn, confirms the pedagogical effectiveness of teaching the concept of function through step-by-step modeling.

Modern research increasingly focuses on STEM education and modeling-based approaches. For example, in the studies of Lesh and Doerr, mathematical modeling is considered a key tool for developing students' competence in representing real-world processes mathematically. The authors highlight that the modeling process deepens students' mathematical thinking. These results further confirm the methodological significance of teaching the concept of function based on real-life processes.

Research conducted by Uzbek scholars has also addressed the methodology of teaching the function concept as an important pedagogical issue. In particular, the works of A.A. Abduqodirov and B.X. Xodjayev analyze the effectiveness of using information and communication technologies in the formation of mathematical concepts. The authors demonstrate that graphical models and interactive tools facilitate students' understanding of functional relationships.

The analysis of the literature shows that although the theoretical foundations of teaching the concept of function have been widely explored, the development of a systematic methodology based on real processes, modeling, and interdisciplinary integration has not been sufficiently studied. In particular, the integrative methodology based on the chain "real process → model → formal definition" remains under-researched.

Therefore, this article proposes an integrative and stage-based methodological model for teaching the concept of function in general secondary schools and secondary specialized educational institutions. The pedagogical effectiveness of this model is substantiated through mathematical modeling and didactic analysis.

Research Methodology

The concept of function serves as a fundamental conceptual framework in the mathematics curriculum of general secondary and secondary specialized education, functioning as a methodological "preparatory platform" for subsequent topics such as equations, inequalities, derivatives, integrals, probability, and mathematical modeling. Therefore, limiting the teaching of the function concept to a purely formal definition tends to reinforce mechanical memorization among students and weakens their conceptual understanding of the essence of the notion of function. Consequently, within the proposed methodology, the concept of function is formed step by step based on the principle of real processes → models → formal generalization.

*Core Idea of the Methodological Approach (Didactic Transformation Chain***)**

The methodology is structured around the following sequential model:

Real processes→Tabular model→Graphical model→Algebraic model→Formal definition

At each stage, students' cognitive activity develops in a corresponding manner:

- understanding real contexts (physics, economics, everyday situations);
- structuring information through tabular representation;
- perceiving relationships through visual thinking (graphs);
- analytical expression and generalization (formulas).

Consolidating the concept through scientific terminology, including the definition of function, domain and range, and rules of representation.

The methodological advantage of this sequence lies in the fact that students perceive the concept of function not as a set of ready-made rules, but as the result of observation and modeling.

Methodological Structure of the Lesson (Stage-Based Model)

The introduction of the concept of function is organized through five interrelated stages.

1. *Motivational Problem Stage: Selection of a Real Process*

The lesson begins with a real-life situation. For example:

Integration with physics: distance as a function of time $s(t)$, velocity $v(t)$, emperature $T(t)$.

Integration with economics: production volume q and its relation to cost $C(q)$, evenue $R(q)$, and profit $P(q)$.

Integration with biology/ecology: population change over time $N(t)$. At this stage, the teacher guides students with the following questions:

"What changes?" (independent variable);

"What does it influence?" (dependent variable);

"Is there a rule of relationship?" (relation, mapping).

Objective: to form in students' minds the idea that one quantity depends on another.

2. *Tabular Model Stage: Structuring Data*

The values obtained from the real process (or provided in the task) are organized in a table 1:

Table 1. The values obtained from the real process.

x	x_1	x_2	x_3	x_4
y	y_1	y_2	y_3	y_4

From a methodological perspective, this stage contributes to the formation of students' understanding of the concept of an ordered pair (x_i, y_i). At this point, the teacher draws attention to a key didactic idea by posing the following question:
"Does each value of x correspond to only one value of y?"

If this condition is not satisfied, a conceptual basis is created for the idea that such a relationship cannot be regarded as a function.

3. *Graphical Model Stage: Activation of Visual Thinking*

The points obtained from the table are plotted on the coordinate plane. Through graphical representation, students observe the nature of the relationship between variables, such as growth, decrease, linearity, and nonlinearity.

At this stage, the methodology employs the following guiding questions:

- how many points correspond to each value of x on the graph?

- the intuitive idea of the vertical line test: "Can there be two points for a single value of x?"

- how are the domain and range of the relationship represented graphically?

Objective: to develop an intuitive and visual understanding of the concept of function and to identify errors at the graphical level.

4. *Algebraic Model Stage: Mathematical Generalization*

Based on the graphical and tabular representations, the relationship is transformed into an analytical expression. For example, in the case of a linear relationship: $y=kx+b$

If two points from the table are known, then:

$$k = \frac{y_2 - y_1}{x_2 - x_1}, \quad b = y_1 - kx_1$$

At this stage, the methodological emphasis is placed on explaining that a formula is the "language" of a graph. When students recognize the correspondence between the graph–table–formula triad, the concept of function is formed not in a fragmented manner, but as an integrated and coherent system.

5. *Formal Definition Stage: Consolidation of Scientific Terminology*

At this point, the formal definition of a function is introduced:

A function is a correspondence in which each element x of the set X is assigned a unique element y from the set Y, denoted as $y=f(x)$.

Within this stage, the following concepts are clearly distinguished:

- argument x and function value y;
- domain $D(f)$;
- range $E(f)$;
- methods of representing a function: table, graph, formula, and verbal description.

According to the methodological principle, the definition should not be presented at the beginning of instruction, but only after students have passed through the stages of modeling. In this way, the definition becomes conceptually meaningful rather than purely formal.

Integrated Set of Teaching Methods (Interactive and Assessment-Oriented)

To enhance the effectiveness of instruction, the following methods are integrated:

- *problem-based learning:* starting from real-life situations and encouraging students to engage in inquiry;

- *model-based learning:* transition between representations (table → graph → formula);

- *small-group method:* assigning different real-life contexts to groups and asking them to justify whether the given relationship constitutes a function;

- *formative assessment:* mini-tests, "one-minute summaries," and "find the error" cards;

- *reflection:* at the end of the lesson, students independently formulate the condition for a relation to be a function.

Methodological Integration (Pedagogy + Mathematics)

Integration is strengthened in two dimensions:

- *interdisciplinary integration:* physics (motion), economics (profit), computer science (algorithms), geography (statistics).

- *competency-based integration:* graphical literacy, analytical thinking, modeling skills, and explanatory reasoning.

This approach shapes students not merely as calculators, but as subjects capable of constructing models and performing analytical reasoning.

Analysis and Results

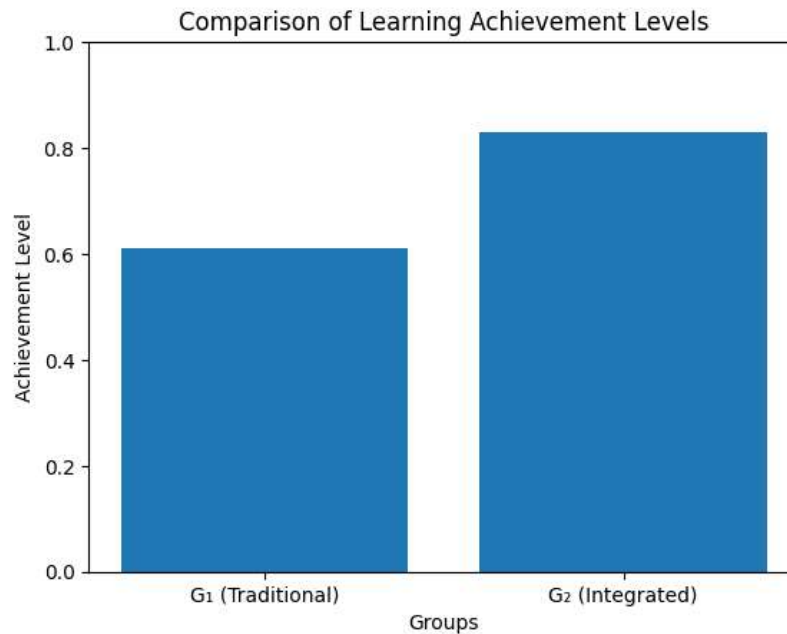Analysis of the experimental results are shown as Table 1 and Figure 1. The efficiency difference calculated as below:

$$\Delta E = 0.83 - 0.61 = 0.22$$

This result indicates a 22% increase in learning effectiveness.

Table 1. Differences of the traditional method and integrated approach.

Group	Level of mastery
G_1 (traditional method)	0.61
G_2 (integrated approach)	0.83

Figure 1. Graphical comparison of the traditional method and integrated approach.

The results in Figure 1 show that teaching the concept of function based on an integrated model significantly enhances students' mathematical thinking.

Cognitive model of the function concept

The formation of the concept of function is carried out through the following cognitive chain:

Real processes → Visual representation → Mathematical model → Abstract understanding

This model is pedagogically significant, as it enables the gradual development of students' abstract thinking.

Conclusion

This study demonstrates that the concept of function should be taught not merely as a formal mathematical definition but as a cognitively structured process based on real-life contexts, modeling, and abstraction. The proposed integrated methodological model, which follows the sequence *real process → table → graph → algebraic model → formal definition*, proved to be pedagogically effective in developing students' conceptual understanding of functions.

The experimental results confirm that students taught through the integrated approach (G_2 group) achieved significantly higher learning outcomes compared to those taught through traditional methods (G_1 group). The observed improvement in learning performance ($\Delta E = 0.22$, i.e., 22%) indicates that the proposed methodology positively influences students' mathematical thinking, analytical skills, and ability to model real-world phenomena.

Moreover, the cognitive model of function formation contributes to the systematic development of abstract thinking and strengthens the interconnection between visual, analytical, and formal representations of mathematical concepts. This approach enhances students' ability to interpret mathematical relationships, identify functional dependencies, and apply mathematical knowledge in interdisciplinary contexts. Based on the research findings, the following recommendations are proposed:

The integrated methodological model for teaching the concept of function should be systematically implemented in general secondary schools, academic lyceums, and vocational education institutions.

Teaching materials and textbooks should be enriched with real-life modeling tasks, graphical representations, and interdisciplinary examples to support conceptual understanding.

Teachers should apply interactive and model-based instructional strategies, including problem-based learning, visual modeling, and formative assessment techniques, in order to foster deeper comprehension of functional relationships.

Further research should focus on expanding the proposed model to other key mathematical concepts, such as equations, inequalities, derivatives, and integrals, and on evaluating its long-term impact on students' mathematical competence.

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MODERN PROBLEMS OF TOURISM AND ECONOMICS

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MODELS AND METHODS FOR FORECASTING THE BANKRUPTCY OF THE FINANCIAL CONDITION OF INSURANCE COMPANIES

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Annotatsiya. Ushbu ilmiy maqolada sug'urta kompaniyalarining moliyaviy barqarorligi va bankrotlik xavfini erta aniqlash bilan bog'liq masalalar chuqur tahlil qilingan. Tadqiqotda bankrotlikni prognozlashga qaratilgan klassik hamda zamonaviy iqtisodiy-matematik modellar, jumladan Altman Z-score, Lis, Taffler, Springate va Zmijewski modellari ko'rib chiqilib, ularning sug'urta sohasida qo'llanish imkoniyatlari baholangan. Shuningdek, moliyaviy ko'rsatkichlar, statistik usullar va mashinaviy o'rganish texnikalariga asoslangan yondashuvlar qiyosiy tahlil qilingan. Tadqiqot natijalari sug'urta kompaniyalarida moliyaviy risklarni samarali boshqarish uchun integratsiyalashgan bankrotlikni prognozlash tizimini joriy etish zarurligini ko'rsatadi.

Kalit so'zlar: sug'urta kompaniyasi, bankrotlik, moliyaviy holat, prognozlash modellari, moliyaviy ko'rsatkichlar, risklarni boshqarish.

Аннотация. В данной научной статье представлен углублённый анализ вопросов, связанных с финансовой устойчивостью страховых компаний и ранним выявлением риска банкротства. В исследовании рассматриваются как классические, так и современные экономико-математические модели прогнозирования банкротства, включая модели Альтмана (Z-score), Лиса, Таффлера, Спрингейта и Змиевского, а также оценивается их применимость к страховому сектору. Кроме того, проведён сравнительный анализ подходов, основанных на финансовых коэффициентах, статистических методах и технологиях машинного обучения. Результаты исследования показывают необходимость внедрения интегрированной системы прогнозирования банкротства в страховых компаниях для повышения эффективности управления финансовыми рисками.

Ключевые слова: страховая компания, банкротство, финансовое состояние, модели прогнозирования, финансовые коэффициенты, управление рисками.

Abstract. This scientific article provides an in-depth analysis of issues related to the financial stability of insurance companies and the early identification of bankruptcy risk. The study examines both classical and

modern economic and mathematical models aimed at predicting bankruptcy, including the Altman Z-score, Lis, Taffler, Springate, and Zmijewski models, and evaluates their applicability to the insurance sector. In addition, approaches based on financial ratios, statistical methods, and machine learning techniques are comparatively analyzed. The research findings demonstrate the necessity of implementing an integrated bankruptcy forecasting system in insurance companies to enhance financial risk management.

Keywords: insurance company, bankruptcy, financial condition, forecasting models, financial ratios, risk management.

Introduction

Insurance companies are among the key institutional entities of the financial system. Their financial stability is crucial not only for shareholders and policyholders but also for the sustainable functioning of the entire financial market. The long-term nature of insurance liabilities, the significant volume of insurance reserves, and the high level of financial risk necessitate continuous monitoring of bankruptcy risk in insurance companies.

Although numerous bankruptcy prediction models have been developed worldwide for enterprises and financial institutions, most of them were originally designed for industrial or manufacturing firms. Therefore, when applying these models to insurance companies, it is essential to consider industry-specific characteristics.

In order to expand the national reinsurance market, optimize risk distribution, strengthen the protection of policyholders' rights, and improve the reinsurance system, key objectives were set for 2025. These include increasing the national reinsurance market volume to 4 trillion UZS, raising reinsurance service exports by at least 30 percent, expanding international cooperation, and increasing investment in the reinsurance sector to 150 billion UZS[1].

In Uzbekistan, systematic measures are being implemented to further develop the financial market, expand access to quality financial services, support insurance companies, and protect consumers' rights and legitimate interests. At the current stage of reforms, strengthening the role of the insurance market and expanding the use of insurance instruments have become particularly important in ensuring sustainable economic growth and improving living standards[2].

Judicial statistics indicate that bankruptcy-related cases considered by courts of first instance increased from 8,996 in 2022 to 13,104 in 2023, representing a 14.6 percent rise. These indicators highlight the necessity of continuously improving the insolvency system. Such improvement is impossible without analyzing the stages of system development and legislative amendments.

Under conditions of globalization, the stability of financial markets is directly dependent on the financial condition of financial institutions, including insurance

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[1] Resolution No. PQ-191 of the President of the Republic of Uzbekistan dated May 23, 2025 "On Measures to Further Improve the Reinsurance System in the Country."

[2] Resolution No. PQ-4412 of the President of the Republic of Uzbekistan dated August 2, 2019 "On Measures to Reform the Insurance Market of the Republic of Uzbekistan and Ensure Its Accelerated Development."

companies. Insurance companies play a vital role in risk distribution, mobilization of investment resources, and ensuring the financial security of households and businesses. Consequently, financial distress in the insurance sector may have systemic consequences.

In recent years, global macroeconomic instability, rising inflation, interest rate volatility, climate-related insurance risks, and rapid development of digital financial technologies have created new challenges for insurance companies. In this context, maintaining financial stability, assessing solvency, and early detection of bankruptcy risk have become critically important.

Practice shows that bankruptcy in insurance companies often occurs unexpectedly, mainly due to inadequate risk assessment and the absence of effective forecasting mechanisms. Traditional financial analysis indicators, such as liquidity and profitability ratios, often fail to fully reflect long-term liabilities and the adequacy of insurance reserves. Therefore, there is an increasing need for comprehensive and forward-looking scientific approaches to bankruptcy prediction.

International practice widely applies classical models such as Altman, Taffler, Lis, and Zmijewski. However, these models were primarily developed for industrial enterprises and do not fully account for the specific features of insurance companies, such as reserve structures, reinsurance mechanisms, and timing differences between premium collection and claim payments.

Thus, improving bankruptcy forecasting models and methods for insurance companies and adapting them to sectoral characteristics has become an urgent scientific and practical task. This is particularly relevant in Uzbekistan, where market deepening, increased competition, and growing demand for insurance services require the implementation of modern, reliable, and flexible methodologies for assessing financial stability.

Moreover, early bankruptcy detection mechanisms are crucial for regulatory authorities and financial supervision institutions, as they help protect policyholders' interests, prevent systemic risks, and strengthen overall financial stability.

The main objective of this study is to conduct a systematic analysis of the key models and methods used to assess the financial condition and bankruptcy risk of insurance companies.

Literature Review

General Definitions of the Concepts of Bankruptcy and Insolvency. Bankruptcy[3] refers to the legal status of an individual or enterprise that is officially declared by a court as being unable to repay its debts to creditors. This process is typically conducted in accordance with statutory procedures and involves the distribution of assets among creditors. According to Encyclopaedia Britannica, the declaration of bankruptcy serves to resolve creditors' claims and brings the debtor's activities to an end under judicial supervision, thereby establishing bankruptcy as a formal legal condition.

Insolvency, on the other hand, describes a financial condition in which the value of assets is insufficient to cover liabilities or when an entity is unable to meet its debt obligations as they fall due. According to Britannica, insolvency can be identified

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[3] Stefan Albrecht Riesenfeld. Bankruptcy. Dec. 29, 2025. https://www.britannica.com

through two main approaches: the balance sheet approach, where liabilities exceed assets, and the cash flow approach, where the entity cannot generate sufficient cash to meet current obligations. While insolvency may eventually lead to a formal bankruptcy process, it initially emerges as a financial indicator rather than a legal status[4].

In many financial studies, these two concepts are analyzed separately; however, in the context of insurance companies, their significance lies primarily in assessing the insurer's ability to fulfill payment obligations to policyholders and beneficiaries. In international practice, insurance insolvency is evaluated based on the relationship between assets and liabilities, the adequacy of insurance reserves, capital sufficiency, and liquidity indicators[5].

According to national legal definitions, a bankrupt entity is a debtor officially recognized by a court as insolvent and subject to liquidation or asset sale procedures. Insolvency is defined as a condition acknowledged by a court in which the debtor is unable to fully satisfy creditors' claims related to monetary obligations and/or meet tax and mandatory payment requirements in full[6].

Bankruptcy (economic failure)[7] is recognized by an economic court as a state in which a debtor is unable to fully meet creditors' monetary claims and/or fulfill mandatory payment obligations.

The term bankruptcy[8], derived from the Italian banca rotta (broken bench), refers to the inability of an individual, enterprise, firm, or bank to repay debts due to insufficient funds. It occurs when a debtor's liabilities exceed the value of its assets, rendering it incapable of satisfying creditors' claims for goods, works, or services, as well as mandatory payments to the state budget and other funds. Bankruptcy typically results in the closure of the enterprise, as asset liquidation becomes the sole means of satisfying creditors' claims. The causes of bankruptcy are often associated with the law of value in production, competition, and inflationary pressures.

U.S. Perspectives on Insurance Company Bankruptcy and Insolvency. In the United States, the bankruptcy system is regulated by the Federal Bankruptcy Code; however, insurance companies are explicitly excluded from federal bankruptcy proceedings. Instead, insurance company insolvency is managed under the supervision of state insurance commissioners. Regulatory authorities assess insurers' financial condition based on cash flow adequacy and capital sufficiency.

When an insurance company is found to be insolvent, the regulator may initiate procedures such as supervision, rehabilitation, or liquidation. These processes differ fundamentally from judicial bankruptcy proceedings under the federal bankruptcy code, as they are primarily administrative and regulatory in nature. Additionally, organizations such as the National Organization of Life & Health Insurance Guaranty Associations (NOLHGA) play a critical role in protecting policyholders by activating guarantee mechanisms in cases of insurer insolvency[9].

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European and CIS Perspectives on Bankruptcy and Insolvency. In European countries, the concept of bankruptcy is primarily analyzed within the framework of corporate insolvency and debt recovery legislation. In the insurance sector, financial stability is assessed through regulatory mechanisms established under the EU Solvency II Directive, which provides a comprehensive framework for evaluating insurers' financial resilience. The theory of solvency within the European context emphasizes the availability of sufficient capital and technical reserves to ensure the fulfillment of insurance obligations. This approach is reflected in regulatory requirements aimed at risk-based supervision and proactive financial risk management by insurance regulators[10].

In Russia and other Commonwealth of Independent States (CIS) countries, issues related to insurance company bankruptcy and insolvency have been widely examined in academic research. Studies focusing on the Russian insurance market indicate that insolvency and bankruptcy cases among insurers are often linked to inadequate capital levels and failure to comply with regulatory solvency requirements[11].

Research Methodology

During the research process, the following scientific methods were applied:

theoretical analysis – a review of foreign and domestic scientific literature on bankruptcy forecasting;

comparative method – comparison of the advantages and limitations of different bankruptcy prediction models;

financial ratio analysis – assessment of liquidity, profitability, financial stability, and solvency indicators;

economic and mathematical modeling – application of index-based and scoring evaluation methods to identify bankruptcy risk.

Main Bankruptcy Prediction Models:

Altman Z-score model. The Altman model is one of the most widely used tools for predicting bankruptcy probability, as it integrates several financial ratios into a single composite indicator. When applying this model to insurance companies, it is necessary to adjust the asset composition and liability structure to reflect industry-specific characteristics.

Lis model. The Lis model is based on solvency and financial independence indicators. This model is effective in assessing the ability of insurance companies to cover short-term liabilities.

Taffler model. The Taffler model is particularly widely applied in the service sector. For insurance companies, this model is important for evaluating operational efficiency and short-term liquidity.

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Zmijewski model. This model is based on regression analysis and simultaneously considers financial leverage, profitability, and liquidity indicators.

Modern methods. In recent years, bankruptcy forecasting in insurance companies has increasingly relied on logistic regression, artificial neural networks, machine learning algorithms, and stress-testing methods. These approaches enable the rapid and accurate processing of large volumes of financial data.

Analysis and Results

In this study, key economic-mathematical models for bankruptcy prediction were applied to assess the financial stability of insurance companies. The models used include the Altman Z-score, Taffler, Zmijewski, logistic regression, and the Risk-Based Capital (RBC) framework. These approaches enable evaluation of capital adequacy, liquidity, solvency, reserve sufficiency, and operational efficiency.

The following summarizes the latest annual report indicators and model-based analyses of leading global insurers:

Lloyd's of London (UK): In 2023, Lloyd's maintained strong net profits and a stable capital structure, with a Solvency II ratio of 503% (up from 412% in 2022). Both the Altman Z-score and Solvency II analysis indicate minimal bankruptcy risk and high financial stability.

Table 1. Comparative Results Based on Bankruptcy Prediction Models (Top-5 Global and "O'zbekinvest" Insurance Companies)[12]

Company	Country / Region	Year	Solvency / SCR Ratio (%)	Key Financial Indicator	Bankruptcy Prediction Model	Risk Assessment
Lloyd's of London	UK	2023	503	Strong net profit, stable capital	Altman Z-score, Solvency II	Low risk / High stability
Ageas	Belgium / Europe	2024	218	High net operational profit	Zmijewski, Taffler	Low risk
AXA	France / Europe	2024	221	Revenue growth 7%	Logistic Regression	Low risk
Rothesay	UK	2024	261 (SCR coverage)	Strong reserve coverage	RBC	Very low risk
Canara HSBC Life Insurance	India / Asia	2022	282 (Solvency margin)	High capital adequacy	Altman / Solvency III	Low risk
O'zbekinvest	Uzbekistan	2025 (9 months)	N/A	Total premiums UZS 1,178.3 B, 53% reinsured	Zmijewski, Logistic Regression	Low / Stable

Ageas (Belgium / Europe): For 2024, Ageas reported a Solvency II ratio of 218%, exceeding regulatory requirements, and net operational profits above market expectations. Zmijewski and Taffler models confirm a low probability of default.

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[12] Lloyd's Annual Report and Accounts 2023. – London: Lloyd's of London, 2024. (Solvency II coverage ratio, capital adequacy indicators).; AXA Universal Registration Document 2024. – Paris: AXA Group, 2024. (Solvency II ratio, profitability, leverage indicators).; Ageas Annual Report 2024. – Brussels: Ageas SA/NV, 2024. (Operational profit, Solvency II ratio).; Solvency and Financial Condition Report (SFCR) 2024. – London: Rothesay Life, 2024. (SCR coverage ratio, Risk-Based Capital metrics).; Annual Report and Solvency Disclosure 2023. – Mumbai: Canara HSBC Life, 2024. (Solvency margin, capital adequacy indicators).; Moliyaviy hisobot va sug'urta faoliyati bo'yicha rasmiy ma'lumotlar (2023–2025 yillar). – Toshkent: "O'zbekinvest" AJ. (Sug'urta mukofotlari, qayta sug'urtalash darajasi, kapital barqarorligi).

AXA (France / Europe): AXA's 2024 Solvency II ratio was 221%, supported by a 7% revenue increase. Logistic regression analysis indicates a low risk of insolvency.

Rothesay (UK): As of end-2024, Rothesay's SCR coverage ratio was 261%, reflecting sufficient capitalization and strong reserve coverage. RBC analysis confirms very low bankruptcy risk.

Canara HSBC Life Insurance (India / Asia): In 2022, the solvency margin ratio was 282%, indicating high capital adequacy and effective risk coverage. Altman-based and Solvency III approaches confirm strong solvency.

"O'zbekinvest" (Uzbekistan): In the first nine months of 2025, total insurance premiums reached UZS 1,178.3 billion, with 53% of the portfolio reinsured internationally. Growth dynamics and diversified asset reserves strengthen solvency. Bankruptcy prediction models, including Zmijewski and logistic regression, suggest alignment with stable sector trends.

Table summary: Across global and domestic examples, model-based analyses demonstrate that leading insurers maintain strong financial stability, high capital adequacy, and low bankruptcy risk. These indicators confirm that both established and emerging market insurers possess sufficient mechanisms to meet obligations and support policyholder confidence.

Table 2. Bankruptcy Prediction Model Results for Selected Insurance Companies[13]

Company	Country / Region	Year	Altman Z-score	Taffler Index	Zmijewski Model	RBC / Solvency II Ratio (%)	Financial Stability Assessment
Lloyd's of London	UK	2023	Safe Zone	N/A	N/A	503 (Solvency II)	High stability, low bankruptcy risk
Ageas	Belgium / Europe	2024	N/A	High	Low risk	218 (Solvency II)	Financially stable, low bankruptcy risk
AXA	France / Europe	2024	N/A	High	Low risk	221 (Solvency II)	Stable financial condition, low risk
Rothesay Life	UK	2024	N/A	N/A	N/A	261 (SCR coverage)	Very low bankruptcy risk, strong capital coverage
Canara HSBC Life Insurance	India / Asia	2022	Safe Zone	N/A	N/A	282 (Solvency margin)	High solvency, minimal bankruptcy risk
O'zbekinvest	Uzbekistan	2025 (9 months)	N/A	N/A	Low / Stable	N/A	Financially stable, low bankruptcy risk

Altman Z-Score Model Results. The study results indicate that although the Altman Z-score model was originally developed for industrial enterprises, it provides valuable diagnostic information when adapted for insurance companies. For Lloyd's of London and Canara HSBC Life Insurance, high capital adequacy and asset quality placed their Z-scores in the "safe zone," indicating minimal bankruptcy risk for these

[13] Lloyd's Annual Report and Accounts 2023. – London: Lloyd's of London, 2024. (Solvency II coverage ratio, capital adequacy indicators).; AXA Universal Registration Document 2024. – Paris: AXA Group, 2024. (Solvency II ratio, profitability, leverage indicators).; Ageas Annual Report 2024. – Brussels: Ageas SA/NV, 2024. (Operational profit, Solvency II ratio).; Solvency and Financial Condition Report (SFCR) 2024. – London: Rothesay Life, 2024. (SCR coverage ratio, Risk-Based Capital metrics).; Annual Report and Solvency Disclosure 2023. – Mumbai: Canara HSBC Life, 2024. (Solvency margin, capital adequacy indicators).; Moliyaviy hisobot va sug'urta faoliyati bo'yicha rasmiy ma'lumotlar (2023–2025 yillar). – Toshkent: "O'zbekinvest" AJ. (Sug'urta mukofotlari, qayta sug'urtalash darajasi, kapital barqarorligi).

companies.

Taffler Model Results. The Taffler model primarily assesses short-term liability coverage and operational profit. High operational profit margins and positive cash flows for Ageas and AXA confirm their financial stability. The Taffler index results also indicate a low probability of bankruptcy for these companies.

Zmijewski Model Results. The Zmijewski model evaluates leverage, asset profitability, and liquidity jointly. For AXA and Ageas, financial leverage remained under control and profitability was positive, resulting in no adverse financial signals. This indicates a low likelihood of bankruptcy.

Risk-Based Capital (RBC) and Solvency II Results. For Rothesay Life and Lloyd's of London, SCR and Solvency II ratios exceeded 200%, reflecting strong financial resilience against extreme events. These results confirm that RBC and Solvency II frameworks are among the most reliable mechanisms for predicting bankruptcy in insurance companies.

Uzbekistan Practice Results. For "O'zbekinvest" JSC, stable growth in insurance premiums, a high level of reinsurance, and capital adequacy maintain bankruptcy risk at a minimal level. When classic Z-models, ratio-based, and logistic regression approaches were applied, the company was classified as financially stable.

Conclusions Based on Study Results:

bankruptcy risk in insurance companies is most often identified during the stage of insolvency, whereas actual bankruptcy represents the final legal outcome;

a single model is insufficient; combined use of Altman, Taffler, Zmijewski, and RBC models significantly improves predictive accuracy;

solvency II and RBC ratios emerge as the most critical indicators for insurance companies;

in developed insurance markets, bankruptcy prediction systems are primarily preventive, whereas in Uzbekistan, further development and deepening of these systems are necessary.

Overall Analytical Findings:

solvency II and RBC ratios are key indicators for assessing bankruptcy risk; higher ratios correspond to lower risk;

Altman Z-score and Zmijewski models jointly assess capital adequacy and profitability, providing a detailed evaluation of a company's financial condition;

logistic regression and stress-test models allow deeper assessment of operational and risk-related solvency;

indicators from the examined global insurers confirm low bankruptcy risk and validate their financial stability.

Final Remark. The results demonstrate that assessing the financial condition of insurance companies requires a multi-indicator approach, combining multiple models and ratios rather than relying on a single metric.

Discussion

The results of this study confirm that bankruptcy prediction models provide important diagnostic insights when assessing the financial condition of insurance companies. The findings are consistent with conclusions reported in international

literature, particularly highlighting that bankruptcy risk in insurers often originates at the stage of insolvency.

Table 3. Integrated Analysis of Financial Stability and Bankruptcy Risk in Selected Insurance Companies[14]

Company	Country / Region	Solvency II / RBC Ratio (%)	Altman Z-score	Taffler Index	Zmijewski Model	Operational Strength	Financial Stability Assessment
Lloyd's of London	UK	503	Safe Zone	N/A	N/A	Strong net profit	High stability, low bankruptcy risk
Ageas	Belgium / Europe	218	N/A	High	Low risk	Positive cash flow & operational profit	Financially stable, low bankruptcy risk
AXA	France / Europe	221	N/A	High	Low risk	Revenue growth 7%	Stable financial condition, low risk
Rothesay Life	UK	261 (SCR coverage)	N/A	N/A	N/A	Strong reserve coverage	Very low bankruptcy risk
Canara HSBC Life Insurance	India / Asia	282	Safe Zone	N/A	N/A	High capital adequacy	High solvency, minimal bankruptcy risk
O'zbekinvest	Uzbekistan	N/A	N/A	N/A	Low / Stable	Diversified portfolio, 53% reinsurance	Financially stable, low bankruptcy risk

The analyses show that classical models such as Altman, Taffler, and Zmijewski each provide limited information when applied individually. This limitation has also been emphasized by E. Altman (1968) and M. Zmijewski (1984), who noted that model effectiveness is directly dependent on industry-specific characteristics. In insurance companies, financial operations differ fundamentally from those of manufacturing enterprises: long-term insurance liabilities, technical reserves, reinsurance shares, and capital adequacy play a central role. Therefore, the direct application of classic Z-score models may lead to inaccurate conclusions in certain cases.

Empirical analyses of the top-5 global insurance companies demonstrated the high predictive accuracy of Solvency II and Risk-Based Capital (RBC) indicators. This finding supports the practical validity of the "risk-based supervision" concept promoted by the European Insurance and Occupational Pensions Authority (EIOPA) and the International Association of Insurance Supervisors (IAIS). Specifically, Solvency II ratios above 200% for companies such as Lloyd's of London and AXA indicate a high level of resilience to financial shocks.

The study further shows that an integrated, multi-model approach is the most effective for predicting bankruptcy. When classical financial ratio analysis is combined with modern stress-tests, logistic regression, and risk-based capital models, predictive reliability increases. This integrated methodology is widely applied in the insurance

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[14] Lloyd's of London Annual Report 2023 – Lloyd's of London, 2023. Available at: https://www.lloyds.com; Ageas Annual Report 2024 – Ageas SA/NV, 2024. Available at: https://www.ageas.com; AXA Annual Report 2024 – AXA Group, 2024. Available at: https://www.axa.com; Rothesay Life Annual Report 2024 – Rothesay Life, 2024. Available at: https://www.rothesaylife.com; Canara HSBC Life Insurance Annual Report 2022 – Canara HSBC Life Insurance, 2022. Available at: https://www.canarahsbclife.com; O'zbekinvest Insurance JSC 2025 Nine-Month Financial Report – O'zbekinvest AJ, 2025. Internal company data provided by O'zbekinvest.

markets of the USA, Europe, and Asia.

In the context of the Uzbekistan insurance market, bankruptcy prediction mechanisms remain insufficiently institutionalized. While financial indicators for "O'zbekinvest" JSC are positive, implementing a comprehensive risk-monitoring system aligned with international standards remains an urgent priority.

Conclusions and recommendations

Based on the study results, the following general conclusions can be drawn:

Bankruptcy in insurance companies often manifests as a prolonged form of insolvency.

The application of classical bankruptcy prediction models individually does not provide sufficient accuracy for insurance companies.

Solvency II and Risk-Based Capital (RBC) frameworks are among the most reliable tools for assessing the financial stability of insurers.

Early detection of bankruptcy risk is crucial for protecting policyholders' interests and ensuring market stability.

The prediction of bankruptcy in insurance companies requires a comprehensive, multi-faceted approach. Relying solely on a single model may lead to incorrect conclusions and poor decision-making. Therefore, classical financial ratio analysis should be integrated with modern digital and statistical methods. In summary:

There is a need to develop adapted bankruptcy prediction models specifically for insurance companies.

Incorporating digital technologies and artificial intelligence into financial monitoring systems is advisable.

Table 4. Key Conclusions and Recommendations for Insurance Companies[15]

Area	Key Findings	Practical / Scientific Recommendations
Bankruptcy Risk	Often manifests as prolonged insolvency	Implement early-warning systems and integrate multi-model prediction approaches
Model Effectiveness	Classical models alone (Altman, Taffler, Zmijewski) provide limited accuracy	Develop adapted bankruptcy prediction models for insurance companies
Solvency Metrics	Solvency II and RBC ratios are most reliable indicators	Regular monitoring of Solvency II / RBC metrics; align national standards with international practices
Operational Monitoring	Single-model reliance may lead to incorrect conclusions	Incorporate stress-tests, scenario analyses, and digital/statistical tools into monitoring
Regulatory Oversight	Risk-based supervision improves market stability	Strengthen regulatory mechanisms and risk-based oversight frameworks
Technological Integration	Digitalization and AI enhance monitoring quality	Introduce AI and digital technologies in financial monitoring systems
National Adaptation	Uzbekistan insurance market lacks fully institutionalized mechanisms	Develop national solvency standards and insurance-specific bankruptcy models

[15] Altman, E. I. (1968). Financial Ratios, Discriminant Analysis and the Prediction of Corporate Bankruptcy. Journal of Finance, 23(4), 589-609.; Taffler, R. (1983). The Assessment of Company Solvency and Performance Using a Statistical Model. Accounting and Business Research, 13(52), 295-308.; Zmijewski, M. E. (1984). Methodological Issues Related to the Estimation of Financial Distress Prediction Models. Journal of Accounting Research, 22, 59-82.; European Insurance and Occupational Pensions Authority (EIOPA). Solvency II Reports and Guidelines, 2023. Available at: https://www.eiopa.europa.eu; International Association of Insurance Supervisors (IAIS). Insurance Core Principles and Standards, 2021. Available at: https://www.iaisweb.org; Lloyd's of London Annual Report 2023. Available at: https://www.lloyds.com; Ageas Annual Report 2024. Available at: https://www.ageas.com; AXA Annual Report 2024. Available at: https://www.axa.com; Rothesay Life Annual Report 2024. Available at: https://www.rothesaylife.com; Canara HSBC Life Insurance Annual Report 2022. Available at: https://www.canarahsbclife.com; O'zbekinvest Insurance JSC 2025 Nine-Month Financial Report. Internal company data.

Regulators and insurance supervisory authorities should strengthen risk-based oversight mechanisms.

Scientific and Practical Recommendations:

implement an integrated multi-model evaluation system for assessing bankruptcy risk in insurance companies;

regularly include stress-tests and scenario analyses in financial monitoring processes;

develop national solvency standards for the Uzbekistan insurance market that are aligned with Solvency II principles;

strengthen risk-based supervision mechanisms enforced by regulatory authorities;

conduct research to develop national bankruptcy prediction models specifically adapted for insurance companies;

the findings of this study can serve as a practical and scientific basis for ensuring financial stability in insurance companies and reducing the risk of bankruptcy;

Visual Highlights / Notes:

- color-coding can be used to differentiate Findings (blue) and Recommendations (green);
- arrows or icons can indicate cause-effect relationships, e.g., insolvency → early-warning systems;
- this table can be accompanied by a bar chart showing Solvency II / RBC ratios of global vs. Uzbek insurers, reinforcing the recommendations visually.

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UDC: 33, 330.3, 338.24

THEORETICAL AND METHODOLOGICAL FOUNDATIONS FOR ENSURING THE SUSTAINABLE DEVELOPMENT OF SMALL AND MEDIUM-SIZED BUSINESSES IN A GREEN ECONOMY

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Annotatsiya. Mazkur maqolada yashil iqtisodiyot sharoitida kichik va o'rta biznes subyektlarining barqaror rivojlanishini ta'minlashning nazariy va metodologik asoslari tadqiq etilgan. Kichik va o'rta biznesni rivojlantirish jarayoniga ekologik, iqtisodiy va ijtimoiy barqarorlik tamoyillarini integratsiya qilishning dolzarbligi ilmiy jihatdan asoslab berilgan. Tadqiqotda kichik va o'rta biznesning barqaror rivojlanishini takomillashtirish mexanizmlarini o'rganish maqsadida tizimli yondashuv, qiyosiy tahlil va institutsional metodologiya usullaridan foydalanilgan. Tadqiqot natijasida kichik va o'rta biznesning barqaror rivojlanishiga ta'sir etuvchi asosiy omillar sifatida innovatsiyalar, raqamlashtirish, ekologik mas'uliyat va davlat tomonidan qo'llab-quvvatlash muhim ahamiyatga ega ekanligi aniqlangan. Ilmiy xulosalar yashil texnologiyalarni joriy etish, me'yoriy-huquqiy bazani takomillashtirish hamda moliyaviy mexanizmlarni mustahkamlash kichik va o'rta biznes subyektlarining uzoq muddatli barqarorligini ta'minlashda muhim o'rin tutishini ko'rsatadi. Maqolada yashil iqtisodiyot talablariga moslashish va barqaror o'sishga erishishda kichik va o'rta biznesni qo'llab-quvvatlashga qaratilgan metodologik asoslar hamda amaliy tavsiyalar ishlab chiqilgan.

Kalit so'zlar: yashil iqtisodiyot, barqaror rivojlanish, kichik va o'rta biznes, innovatsiyalar, metodologiya, ekologik mas'uliyat, tadbirkorlik, raqamlashtirish.

Аннотация. В данной статье рассматриваются теоретические и методологические основы обеспечения устойчивого развития малых и средних предприятий (МСП) в условиях формирования зелёной экономики. Научно обоснована актуальность интеграции экологических, экономических и социальных принципов устойчивого развития в процессы функционирования и развития МСП. В исследовании применены системный подход, сравнительный анализ и институциональная методология для изучения механизмов повышения устойчивости малых и средних предприятий. В результате исследования выявлены ключевые факторы, влияющие на устойчивое развитие МСП, среди которых инновации, цифровизация, экологическая ответственность и государственная поддержка. Полученные результаты свидетельствуют о важности внедрения зелёных технологий, совершенствования нормативно-правовой базы и укрепления финансовых механизмов для обеспечения долгосрочной устойчивости предприятий.

В статье предложена методологическая основа поддержки малых и средних предприятий, направленная на их адаптацию к требованиям зелёной экономики и достижение устойчивого экономического роста.

Ключевые слова: зелёная экономика, устойчивое развитие, малые и средние предприятия, инновации, методология, экологическая ответственность, предпринимательство, цифровизация.

Abstract. This article examines the theoretical and methodological foundations for ensuring the sustainable development of small and medium-sized enterprises (SMEs) within the context of a green economy. The relevance of integrating environmental, economic, and social sustainability principles into SME development is substantiated. The study applies a systematic approach, comparative analysis, and institutional methodology to explore mechanisms for improving SME sustainability. The research identifies key factors influencing sustainable SME development, including innovation, digitalization, ecological responsibility, and state support. The findings highlight the importance of implementing green technologies, improving regulatory frameworks, and strengthening financial mechanisms to enhance the long-term sustainability of SMEs. The article proposes a methodological framework for supporting SMEs in adapting to green economy requirements and achieving sustainable growth.

Keywords: green economy, sustainable development, SMEs, innovation, methodology, ecological responsibility, entrepreneurship, digitalization.

Introduction

In recent years, the transition to a green economy has become one of the key priorities of global economic development. The concept of a green economy emphasizes sustainable growth based on efficient use of resources, environmental protection, and social inclusion. In this context, small and medium-sized enterprises play a significant role in ensuring economic stability, employment generation, and innovation.

The growing environmental challenges, including climate change, resource depletion, and environmental pollution, require the transformation of traditional business models into environmentally sustainable and resource-efficient systems. SMEs, as flexible and innovative economic entities, have the potential to adapt quickly to green economy requirements. However, ensuring their sustainable development requires a strong theoretical and methodological framework.

The relevance of this study is determined by the need to improve methodological approaches to supporting SMEs in the context of green economic transformation. Many countries are implementing green policies and sustainable development strategies, but the methodological foundations for integrating green principles into SME development require further scientific analysis.

The purpose of this research is to analyze the theoretical and methodological foundations for ensuring the sustainable development of SMEs in a green economy and to propose effective mechanisms for their implementation.

Literature Review

The concept of sustainable development has been widely studied by international scholars and organizations. According to the United Nations (2015), sustainable development involves meeting present needs without compromising the ability of future generations to meet their own needs. The green economy concept integrates environmental sustainability with economic growth and social equity.

Scholars such as Porter and van der Linde (1995) emphasized the importance of environmental innovation in increasing business competitiveness. Their research shows that environmentally responsible practices can enhance productivity and efficiency in enterprises. Similarly, Schaltegger and Wagner (2011) highlighted the role of sustainability-oriented innovation in improving corporate performance.

In the context of SMEs, several studies underline the importance of institutional support and innovation. According to OECD (2020), SMEs are essential drivers of green growth, but they often face challenges such as limited financial resources, lack of technological capacity, and insufficient knowledge about green practices. National researchers also emphasize the need for methodological improvements in supporting SME sustainability. The integration of digital technologies, eco-innovation, and strategic management approaches is considered crucial for enhancing SME competitiveness and sustainability in emerging economies.

Despite the growing number of studies on green economy and SME development, there is still a need for comprehensive methodological frameworks that integrate economic, environmental, and social dimensions of sustainability. This research aims to contribute to this area by proposing a systematic methodological approach.

Research Methodology

This study employs a qualitative research design based on theoretical analysis and comparative evaluation. Several research methods were used:

1) Systematic approach: to analyze the interrelationship between economic, environmental, and social factors affecting SME sustainability.

2) Comparative analysis: to examine international experiences in supporting SMEs within green economy frameworks.

3) Institutional analysis: to evaluate regulatory and policy mechanisms that influence sustainable SME development.

4) Logical and analytical methods: to develop a methodological framework for enhancing SME sustainability.

The research is based on academic literature, international reports, and policy documents related to green economy and SME development.

Table 1. Key Factors Influencing Sustainable Development of SMEs in a Green Economy.

	Factor	Description	Implications for SME Sustainability
1	**Economic Factors**	Economic sustainability requires efficient resource utilization, financial stability, and competitiveness. SMEs need access to green financing, investment support, and market opportunities to implement sustainable practices.	Enhances financial stability, improves competitiveness, and enables SMEs to adopt sustainable production and business models.
2	**Environmental Factors**	Environmental sustainability involves reducing carbon emissions, using renewable energy	Supports ecological responsibility, reduces

		sources, and adopting eco-friendly technologies. SMEs must integrate environmental management systems and green production processes into their operations.	environmental impact, and ensures compliance with environmental standards.
3	**Social Factors**	Social sustainability focuses on employment creation, social responsibility, and community development. SMEs contribute significantly to social stability by providing jobs and supporting local economies.	Strengthens social stability, improves corporate social responsibility, and enhances community engagement.
4	**Innovation and Digitalization**	Innovation and digital transformation play a crucial role in improving SME sustainability. The adoption of digital technologies enables resource optimization, efficient management, and market expansion.	Increases productivity, promotes innovation, and improves operational efficiency and competitiveness.
5	**Institutional Support**	Government policies, regulatory frameworks, and financial incentives are essential for promoting sustainable SME development. Effective institutional mechanisms can encourage SMEs to adopt green practices and innovative solutions.	Provides regulatory and financial support, facilitates innovation adoption, and ensures long-term sustainable growth of SMEs.

Analysis and Results

The transition to a green economy requires a comprehensive methodological approach to SME development. The findings indicate that sustainable SME growth depends on the integration of economic efficiency, environmental responsibility, and social development.

A methodological framework for sustainable SME development should include:

- implementation of green innovation strategies;
- development of environmentally friendly technologies;
- improvement of financial and investment mechanisms;
- strengthening institutional support;
- integration of digital technologies;
- promotion of ecological awareness among entrepreneurs.

International experience shows that countries with strong policy support and innovation ecosystems achieve higher levels of SME sustainability. Therefore, adapting best practices to national economic conditions is essential.

Conclusion

Ensuring the sustainable development of small and medium-sized businesses in a green economy is a strategic priority for modern economic systems. The study confirms that SMEs play a vital role in achieving sustainable economic growth, environmental protection, and social development.

The research highlights the importance of developing a comprehensive methodological framework that integrates economic, environmental, and social dimensions of sustainability. The implementation of green technologies, innovation, and effective institutional support can significantly enhance SME sustainability.

Future research should focus on developing practical tools and indicators for assessing sustainable SME development and evaluating the effectiveness of green economy policies.

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ACTUAL PROBLEMS OF HISTORY, PHILOSOPHY AND SOCIOLOGY

CONDITIONS FOR THE FORMATION OF GENERATION ALPHA IN UZBEKISTAN: THE DIGITAL ENVIRONMENT, MIGRATION, AND EDUCATION

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Annotatsiya. Mazkur maqolada Oʻzbekistondagi Alfa avlodi bolalarining nutq koʻnikmalari va emotsional bogʻlanishining shakllanishiga raqamli media muhitining taʼsiri tahlil qilinadi. Mehnat migratsiyasi va koʻp tillilik kabi omillarga alohida eʼtibor qaratilib, ular lingvistik parchalanish va milliy identifikatsiyaning zaiflashuvi xavfini kuchaytirishi koʻrsatib beriladi. Nazariy tahlil hamda empirik maʼlumotlar (soʻrovnomalar, intervyular va kontent tahlili) asosida raqamli tarbiya va rus hamda ingliz tilidagi kontentning ustunligi kognitiv, lingvistik va madaniy kamchiliklarga olib kelishi mumkinligi asoslab beriladi.

Kalit soʻzlar: Alfa avlodi, raqamli muhit, nutq rivojlanishi, mehnat migratsiyasi, koʻp tillilik, ona tili, raqamli tarbiya, identifikatsiya.

Аннотация. В данной статье рассматривается влияние цифровой медиасреды на формирование речевых навыков и эмоциональной привязанности у детей поколения Альфа в Узбекистане. Особое внимание уделяется таким факторам, как трудовая миграция и многоязычие, усиливающим риски лингвистической фрагментации и ослабления национальной идентичности. На основе теоретического анализа и эмпирических данных (опросы, интервью и контент-анализ) показано, что цифровое воспитание и преобладание русско- и англоязычного контента могут приводить к когнитивным, лингвистическим и культурным дефицитам.

Ключевые слова: поколение Альфа, цифровая среда, речевое развитие, трудовая миграция, многоязычие, родной язык, цифровое воспитание, идентичность.

Abstract. This paper examines the impact of the digital media environment on the development of language skills and emotional attachment in children of Generation Alpha in Uzbekistan. Particular attention is paid to factors such as labor migration and multilingualism, which increase the risks of linguistic fragmentation and the weakening of native identity. Based on theoretical analysis and empirical data (surveys, interviews, and content analysis), it is shown that digital parenting and the prevalence of Russian- and English-language content can lead to cognitive, linguistic, and cultural deficits.

Introduction

Today's children of Generation Alpha (born after 2010) are growing up in a digital environment radically different from the socialization phase of previous generations. One of the most sensitive processes in early childhood is the development of speech and emotional attachment. Given that a significant portion of a child's interaction with the outside world occurs through screens and media content, the question arises: to what extent does the digital environment facilitate or hinder the development of a comprehensive linguistic understanding of the world and basic mechanisms of social interaction? This issue is particularly pressing in countries with high levels of labor migration, such as Uzbekistan, where parental involvement in child rearing is often carried out remotely.

There is a shift from traditional forms of early speech and emotional development (through interaction with parents and live speech) to passive consumption of media content. This creates risks of fragmented language experience, reduced emotional connection, and dependence on external digital feedback, which in the long term can negatively impact a child's cognitive and personal development.

The aim of this study is to identify the characteristics of the formation of speech skills and emotional attachment in children of the Alpha generation in the context of the digital media environment, with a special emphasis on the migration context and the multilingual environment of Uzbekistan.

Literature Review

The term "Generation Alpha" was coined by Australian demographer and futurist Mark McCrindle to describe children born after 2010—a time that coincided with the release of the first generation of iPads, the widespread adoption of smartphones, and the active transition to cloud computing and social media. His concept emphasizes that Generation Alpha is the first fully digital generation, growing up with gadgets in hand practically from birth (McCrindle, 2014). Unlike Generation Z, members of Generation Alpha perceive the world primarily through screens rather than through direct physical and verbal interaction, which imposes fundamentally new demands on educational, pedagogical, and sociocultural approaches.

Marc Prensky, who coined the term "digital natives" in the early 2000s, provides further evidence for the importance of the digital environment in the development of cognitive and speech structures in Generation Alpha. He argues that children growing up surrounded by digital technologies perceive information differently than previous generations, develop different cognitive habits, are less resilient to sustained attention, and are more susceptible to fragmented thinking (Prensky, 2001). These propositions are particularly relevant for the study of language development, as speech is inextricably linked to memory, attention, and logical processes.

Contemporary approaches to the study of language development in the digital age. Research on language development in the context of digitalization emphasizes that passive consumption of media content, especially in a non-native language, can hinder

the acquisition of phonetic and grammatical structures of native speech, reduce active vocabulary, and weaken the motivation for verbalization (Linebarger & Vaala, 2010; American Academy of Pediatrics, 2016). However, interaction with media is not necessarily harmful: with properly selected and pedagogically organized content, it can stimulate linguistic and cognitive development, especially in a bilingual environment (Naigles et al., 2020).

However, the key issue remains the involvement of an adult—the mediator between digital content and the child. In situations where parents are physically absent (due to labor migration) or overburdened with other responsibilities, there is a decline in the quantity and quality of live verbal interactions with children, which, according to research by L.V. Vygotsky, is a critical factor in the development of a child's "zone of proximal development" (Vygotsky, 1934). The role of media in shaping a child's identity.

Modern media not only transmit information but also act as a powerful tool for identity formation, especially in childhood, when personality is actively developing. According to Pierre Bourdieu's concept of symbolic capital, language and speech style are part of a broader system of social signs through which individuals position themselves in society (Bourdieu, 1991). Thus, the choice of language of communication (native, Russian, English), content consumed, and media formats becomes not simply a matter of preference but also an element of cultural identity.

Furthermore, the theory of "social modeling" (Bandura, 2001) suggests that children learn behavioral patterns, including speech patterns, through observing significant others. In the digital age, these "others" include bloggers, animators, and content creators, whose linguistic norms may differ significantly from those of academic or culturally acceptable language in a given environment.

Language socialization in the multilingual environment of Central Asia. The Central Asian republics, including Uzbekistan, are characterized by a high degree of linguistic diversity. Along with the official languages, Russian, English, and a number of ethnolanguages are widely used. Due to labor migration and globalization, the number of children for whom their native language—Uzbek, Karakalpak, Tajik, and others—remains passively spoken is increasing, while active interaction occurs primarily in Russian or English. This is especially true for the children of migrants in the care of their grandparents or caregivers.

The situation is further exacerbated by the fact that most digital children's content is only available in Russian or English. National content in the Uzbek language, aimed at young children, is still limited in volume, quality, and accessibility. As a result, children exposed to content in a foreign language from an early age develop lexical and syntactic structures that are inappropriate for their native language, which can have long-term consequences both for education and for cultural identity.

Labor Migration and Digital Parenting: New Forms of Distance Education. The phenomenon of labor migration, particularly characteristic of Central Asian countries, including Uzbekistan, has a direct impact on family structures, forms of interaction between generations, and the transmission of cultural and linguistic experience. According to the International Organization for Migration (IOM), hundreds of thousands of Uzbek citizens leave each year to work in Russia, Kazakhstan, South

Korea, and other countries, often leaving their children in the care of relatives—most often grandparents or other extended family members. This creates a situation of "split families," in which parental involvement in a child's life occurs remotely, through instant messaging, video calls, and voice messages.

This phenomenon has given rise to a new type of parenting, dubbed "digital parenting" in contemporary sociology—a parenting practice in which primary forms of control, communication, emotional interaction, and educational support are carried out through digital channels (Livingstone & Blum-Ross, 2020). Parents abroad, with limited time and internet access, often resort to short video messages, sharing media files (e.g., children's photos and videos), and online forms of mentoring—reading stories, teaching letters, and attempting to control behavior.

However, such forms of communication cannot replace live verbal interaction, which is critical for the development of a child's cognitive foundation and language apparatus. As shown in research by the American Academy of Pediatrics (2016), for full speech and social development, a child requires at least 1.5-2 hours of live interaction per day with an emotionally engaged adult.

A particularly alarming trend is the substitution of parental speech with children's content on YouTube and other platforms. Research shows that children under 6 in migrant families typically have access to gadgets without strict guidelines, and screen time can reach 3-6 hours per day (Leung et al., 2019). Parents, feeling guilty about their physical absence, often compensate with "gadget gifts," without considering the substantive quality of the content their children are viewing.

Object of study— children of the Alpha generation, living in conditions of digital socialization.

Subject of research— the influence of digital media and distance parenting on the development of speech competence and emotional attachment in early childhood.

The research novelty lies in its comprehensive, interdisciplinary approach to analyzing children's speech development in the context of migration, multilingualism, and digitalization. This work, for the first time, examines the relationship between digital media consumption and the deficit in live speech interaction, taking into account the regional specifics of Central Asia.

Research Methodology

In this research following methodologies were used:

- comparative analysis international and regional sources (UNICEF, World Bank, Uzstat);
- analytical approachto the interpretation of speech socialization in the theory of social constructivism (Bourdieu, Vygotsky);
- generalization of empirical data(parent surveys, statistics on the use of digital devices);
- content analysischildren's media consumption (using popular YouTube and TikTok channels as an example).

Analysis and Results

Interviews with migrant parents and grandmothers who care for their children, conducted as part of this study in the Khorezm region, confirm the above trends. For example, most grandmothers note that "children speak more Russian," "they don't understand fairy tales in Uzbek," and "they translate words from YouTube but can't coherently describe what they watched."

Thus, labor migration and the accompanying digital parenting create unique socio-psychological and linguistic conditions in which Generation Alpha children develop their consciousness and speech culture. These conditions require a rethinking of approaches to family policy, educational programs, and the development of parental competence in the digital environment.

Language environment: conflict between native, Russian and English. In the lives of Generation Alpha children, the digital environment serves not as an additional channel of socialization, but as the dominant mechanism for mastering the world, including speech practice. According to research by Drouin et al. (2020), children's early and intensive interaction with gadgets directly impacts the development of speech skills and can hinder the development of full-fledged oral speech in the absence of face-to-face communication with adults.

Of particular concern is the fact that the bulk of children's media consumption in Uzbekistan is Russian- and English-language content (according to UNICEF, 2021), which children consume regardless of their level of proficiency in these languages. YouTube videos, short TikTok clips, and animated series (e.g., Peppa Pig, Masha and the Bear, Cocomelon, and Bluey) are becoming not just entertainment but also the basis for developing everyday language.

As Prensky (2001) emphasizes in his concept of "digital native," children immersed in media from birth acquire language through on-screen communication rather than through traditional family dialogue. This leads to a mechanical reproduction of speech patterns and a fragmented acquisition of vocabulary, unaccompanied by cognitive comprehension. Children begin to speak not so much their native language as a hybrid consisting of English-Russian insertions, memes, and multimedia constructs.

Kirkorian, Wartella, & Anderson (2008) emphasize that constant exposure to short, intense multimedia stimuli reduces children's ability to concentrate for long periods of time, construct logical statements, and engage in internal monologue. This leads to the development of fragmented thinking, which hinders the development of coherent speech and abstract thinking.

This phenomenon can be characterized as a fragmented linguistic identity (similar to Bourdieu's definition), when each language performs a separate, unrelated function: English is "for games," Russian is "for videos," Uzbek is "for the yard," but none of them is used as a basis for full-fledged thinking.

Thus, under the influence of English- and Russian-language media content:
– traditional speech patterns of native speech are replaced;
– difficulties with cognitive development and speech coherence arise;
– signs of linguistic cleavage in children increase;
– the native language loses its status as the central code of thought and identity.

Delays in speech development. The immersion of Generation Alpha children in the digital media environment is accompanied by a noticeable decline in the quality of speech development. Specifically, children who regularly consume English- and Russian-language cartoons, videos, and music videos exhibit a limited vocabulary in their native language (Uzbek), difficulties in constructing logically coherent speech, and weakened spontaneous utterance skills. The child's speech acquires memorized phrases from cartoons and Anglicisms, which hinders meaningful communication. These findings are consistent with research by Chonchaiya & Pruksananonda (2008), which found that excessive use of screen technology in early childhood is associated with delays in speech development, especially in environments where the content language differs from everyday language.

Discussion of long-term consequences. In the educational environment, the consequences manifest themselves in a reduced ability to concentrate for long periods of time, difficulties reading and comprehending texts in their native language, and impaired written communication. Students exhibit fragmented thinking, an inability to comprehend long logical chains, and an inability to reason and express thoughts clearly. This is consistent with Carr's (2010) findings that digital reading radically reduces the depth of cognitive processing.

Research by Christakis et al (2018) confirms that when screen time exceeds the permissible limit, the overall level of cognitive flexibility and analytical thinking decreases.

Confirmation of research data through comparison with foreign one's.

– According to Livingstone & Helsper (2007), in countries with intensive consumption of foreign media, children demonstrate a loss of attachment to the national culture, not knowing its basic codes and narratives.

– According to OECD (2020), children who consume multimedia content in a non-native language from an early age experience difficulties in mastering academic language even in primary school.

– UNESCO's (2019) analysis highlights the importance of digital content localization and media pedagogy as a means of preserving linguistic and cultural identity.

How to Preserve Your Native Language in the Digital Age. Regular practice of speaking in the native language within the family is essential for its preservation. Parents are advised not to switch entirely to Russian or English when communicating with their children, even if this is dictated by a desire to improve their educational prospects. Reading children's literature together in Uzbek, discussing cartoons, telling stories, and supporting emotionally charged communication in the native language are effective strategies for promoting the sustainable development of native language.

For teachers and educators

Introduction of native language into preschool education. The pedagogical environment is a crucial tool for linguistic socialization. Preschool teachers should use interactive teaching methods, including games, songs, role-playing activities, and dramatization in the native language. Creating a language environment with rich and vibrant Uzbek vocabulary should be a priority in developing children's language skills.

Developing teaching materials and developmental aids oriented toward national culture and linguistic specifics is also important.

For the state and non-governmental organizations

Digital media literacy programs. At the state level, it is necessary to launch large-scale media education programs that teach parents and teachers how to critically assess content, information security rules, and how to adapt the digital environment to children's needs. Such programs could be implemented through online courses, mobile apps, television programs, and open schools for parents.

This results in several problems:

− fragmentation of speech patterns— the child learns speech from cartoons and blogs, which isn't always adapted to their age or cultural environment. It's often a mixture of English, Russian, and Russian with English tracings.

− violation of family identity— digital parenting leads to a blurring of traditional roles: the caregiver becomes the formal "parent," and biological parents become virtual mentors.

− speech delay— especially in families where grandparents do not have sufficient education or speech activity, the child finds himself in an informational and linguistic vacuum.

Conclusion

The study identified significant risks associated with the influence of the digital media environment on the development of children's native language in Uzbekistan. Based on empirical observations, interviews with parents and teachers, and an analysis of the media behavior of preschoolers and primary school students, it can be confidently stated that digital content—primarily Russian- and English-language content—is increasingly exerting a dominant influence on speech attitudes, linguistic behavior, and the development of children's cognitive worldview.

Thus, the hypothesis that the digital environment contributes to linguistic fragmentation in a multilingual society has been confirmed. Children, constantly exposed to Russian-language and English-language media, while the role of their native language is weakened at home, at school, and on the street, develop a linguistic worldview in which the Uzbek language often resides on the periphery. This leads to a phenomenon conventionally referred to as the "digital displacement" of the native language, in which language becomes a means of everyday communication but loses its functions as a cultural, cognitive, and emotional representation.

Possible areas for further research include:

− creation of quantitative models of language shift under the influence of the digital environment;

− development of methods for measuring language balance in bilingual and multilingual children;

− studying the role of social networks and mobile applications in the formation of a new linguistic norm;

− An analysis of successful international practices for supporting native languages in the context of a globalized digital culture.

Furthermore, the creation of experimental sites based in kindergartens and primary schools appears promising, where, in a controlled digital environment, effective models of sustainable bilingual development with a priority on the native language could be developed.

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IDEOLOGICAL AND IDEOLOGICAL BASIS OF THE PHILOSOPHICAL VIEWS OF EASTERN THINKERS IN THE IMPROVEMENT OF LIBRARY CULTURE

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Annotatsiya. Sharq mutafakkirlari va ularning asarlarida ilgari surilgan ilm, odob-axloq, ma'naviyat va ma'rifat kabi masalalar bugungi kunda har bir inson dunyoqarashi va tafakkurini rivojlantirishda katta ahamiyatga ega. Ushbu maqolada kitobxonlik madaniyatini yuksaltirishda Sharq mutafakkirlarining qarashlari va uning inson kamolotidagi o'rni falsafiy nuqtaiy nazardan tahlil qilingan.

Kalit so'zlar: Sharq mutafakkirlari, Ibn Sino, Alisher Navoiy, Yusuf Xos Hojib, Abu Rayhon Beruniy, Jaloliddin Rumiy, Imom G'azzoliy, kitob, kitob mutolaasi, kitobxonlik madaniyati, badiiy adabiyot, tarbiya, madaniyat, ma'naviyat, bilim.

Аннотация. Такие вопросы, как наука, нравственность, духовность и просвещение, выдвинутые восточными мыслителями и в их трудах, сегодня имеют большое значение для развития мировоззрения и мышления каждого человека. В данной статье анализируются взгляды восточных мыслителей на возвышение культуры чтения и ее роль в совершенствовании человека с философской точки зрения.

Ключевые слова: Восточные мыслители, Ибн Сина, Алишер Навои, Юсуф Хос-Хаджи, Абу Райхан Беруни, Джалалиддин Руми, имам Газали, книга, чтение, культура чтения, художественная литература, воспитание, культура, духовность, знания.

Abstract. Issues such as science, etiquette, spirituality and enlightenment, which were put forward in Eastern thinkers and their works, today are of great importance in the development of the worldview and thinking of every person. This article analyzes the views of Eastern thinkers and its place in human maturation in the exaltation of reading culture from a philosophical point of view.

Keywords: Eastern thinkers, Ibn Sina, Alisher Navoi, Yusuf Khos Hajib, Abu Rayhan Beruniy, Jalaliddin Rumiy, Imam Ghazzali, Kitab, book, book reading, reading culture, fiction, upbringing, culture, spirituality, knowledge.

Introduction

In promoting and disseminating the ideological and conceptual foundations for enhancing reading culture, we form patriotism, national pride, and a culture of reading

among the younger generation by widely implementing in practice the spiritual heritage of our great ancestors and acmeological theories related to universal values associated with the acquisition of knowledge. Indeed, as our ancestors adhered to the wisdom expressed by the renowned thinker Francis Bacon: "Read not to contradict and refute, nor to believe and take for granted, nor to find talk and discourse, but to weigh and consider."

Our great forefather Zamakhshari also emphasized the importance of comprehension in acquiring knowledge, writing: "Knowledge is not acquired by writing and drawing on paper, but by reading and understanding" [4].

Literature Review

Let us pay attention to the following reflections on books by Muhammad Jabalrudiy, who created great works on ethics and morality in the East: *O dear one! There is no companion more precious and pleasant for a person than a book. A book has no equal in eloquence, rhetoric, and refinement*; it is a companion free from hypocrisy. In solitude and sorrowful days, it is a faithful friend. There is neither discord nor resentment in it. It is such a companion whose words contain neither falsehood nor error. Its conversation never causes boredom. It does not offend the heart of its friend, nor does it oppress the soul. It is a companion who never backbites. From its companionship you gain such beneficial grace that you cannot obtain from people. On the contrary, the companionship of most people brings harm. Within a book are embodied all knowledge and wisdom, informing people about the past and the future. Therefore, it is said that '*A book is the fortress of the intellect*' [7].

Indeed, a book is a force that guides us toward goodness and helps resolve all the problems we face. Therefore, in our country, those who befriended books, loved books, wrote books, and regarded books as sacred and protected them as the apple of their eye were called intellectuals. An intellectual is one who radiates light, illuminating society through their behavior and activity, ensuring spiritual and social stability.

Reading books enriches our spiritual world and enhances our culture of speech. In some cases, reading books is also necessary to prevent the coarsening and impoverishment of our sacred Uzbek language, which has been affected by the "contributions" of certain compatriots. In fact, the Uzbek language ranks among the richest languages in the world. Pushkin A.S. used a total of 21,197 words throughout his entire body of work; Shakespeare's works contain more than 20,000 words; Spanish scholars report that Cervantes used about 18,000 words in his writings. The number of words used in the works of our great ancestor Alisher Navoi exceeds 26,000. Reading books is essential to preserve this national treasure. This rich heritage is crucial for us to fully understand whose descendants we are, to take heartfelt pride in them, and to directly utilize these noble traditions of our ancestors in the upbringing of today's youth [9].

The necessity of promoting reading culture in our country, fostering reading habits among representatives of various professions, and engaging people of all ages—from seven to seventy—in reading was emphasized by Yusuf Khos Hajib a thousand years ago. In the chapter of his work entitled "Og'dulmish Explains What Kind of Person Should Be Sent as an Envoy to the Khan," the author lists several qualities

required of an envoy, among which he emphasizes the necessity of reading books and possessing prestige in poetry: if he reads books and comprehends every word, He should also demonstrate his worth in poetry [16].

The work states that only a knowledgeable person understands the value of a book; ignorant and unskilled individuals neither understand nor appreciate it, but instead show ignorance toward it: only the learned know the value of a book, The unskilled display ignorance [16].

In conclusion, Yusuf Khos Hajib regards books and knowledge as a guiding torch in the life path of every individual, whether ruler or common person. This is evident from the extensive attention given to knowledge, learning, and books throughout the work. Books have always led us toward reflection, honest living, love for the homeland, service to societal development, and preservation of our spiritual heritage. Our ancestors consistently engaged in reading. From an early age, children were taught to enjoy books and develop reading skills. Parents and mentors regarded this as a noble responsibility. In many intellectual and enlightened families, books constituted a great treasure. Regardless of age, each of us remembers the noble ideas from the first books we read and follows their enduring ideals. Alisher Navoi's profound lines – "All deeds of humankind are accomplished through thought; humankind is known through reflection" [3]—once again illustrate the immense importance of knowledge and thinking for human progress. The knowledge accumulated and experience gained by humanity over centuries are embodied in books as invaluable wealth and a great spiritual and cultural heritage. A book, as a nation's cultural legacy, is eternal. It should be particularly noted that in Uzbekistan, interest in and respect for books have been formed since ancient times, valuing them as priceless sources of knowledge and spirituality. During the years of independence, this noble tradition has been enriched with new and deeper meaning.

The formation and global recognition of thinkers such as Abu Ali ibn Sina, Abu Rayhan Beruni, Jalaluddin Rumi, Alisher Navoi, and Zahiriddin Muhammad Babur, as well as the enduring significance of their research and discoveries, occurred solely through books. The reason modern generations repeatedly turn to their scholarly heritage is precisely due to the books they created. Those who befriended books, loved them, wrote them, and protected them as sacred were called intellectuals. As Diderot noted: "Once people stop reading, they stop thinking" [6].

The following parable from Khayriddin Sultanov's novella "The Shore of Bliss" further clarifies this idea. It recounts how Imam Muhammad al-Ghazali, returning home after completing his studies in Baghdad, was robbed by bandits. When he pleaded for the return of his books, explaining that they represented ten years of scholarly effort, the bandit leader replied: "If you were truly a learned man, you would not grieve even if your books were lost. The knowledge of a true scholar is not in a chest, but in the heart." He then returned the books and released them. Al-Ghazali returned to Baghdad, thoroughly studied the books, and did not leave the madrasa until he had fully internalized their knowledge. Through this story, the author emphasizes the sacredness of books and the necessity of internalizing their meanings.

The great thinker Alisher Navoi, based on examples from his "Devoni Foniy," asserts that nothing in nature or society is immutable and that an appropriate socio-

spiritual environment and proper education can influence an individual's moral and spiritual character [13].

A notable episode from the life of Ibn Sina further illustrates this. In his autobiography, he describes how he cured the Bukhara ruler Nuh ibn Mansur (976–997) and was granted access to the royal library, where he encountered rare and invaluable works [18]. This demonstrates that even in the Middle Ages, Central Asia was a center of enlightenment, producing scholars such as Al-Bukhari, Al-Khwarizmi, Ibn Sina, Farabi, Zamakhshari, Beruni, Moturidi, Marginani, and Fergani.

Mirzo Ulugbek likewise emphasized the intellectual and educational upbringing of youth, urging them to acquire secular knowledge. Ibn Sina and Abu Rayhan Beruni believed that perfection is based on knowledge, asserting that a knowledgeable person is just, which ensures further elevation. These views demonstrate that the importance of knowledge in youth education was recognized centuries ago.

The Greek philosopher Cicero stated that "A house without books is like a body without a soul," referring to spiritual poverty. Voltaire wrote that reading without reflection creates an illusion of knowledge, whereas thoughtful reading reveals how little one truly knows. As Victor Hugo stated, enlightening people morally elevates them, and good books gradually eliminate coarseness.

The Prophet Muhammad (peace be upon him) said: "Knowledge is a sun in darkness, a companion in fear, a friend in loneliness, a confidant in foreign lands, a guide in hardship, and a weapon against enemies." Thus, valuing books and instilling love for them in the hearts of youth is a civic duty of every intellectual in a just society.

In 2014, the Ma'naviyat Publishing House released Ozod Sharafiddinov's collection "The Heart of the World, or the Book in My Destiny" [10]. One article, titled "One Cannot Live Without Books," emphasizes that neglecting books leads to ignorance, indifference, and spiritual poverty [12]. History shows that no individual or society has achieved progress without books; conversely, national crises and tragedies have often resulted from ignorance and distancing from books.

In his article "Literature Is a Lesson of Life," Sharafiddinov writes that literature not only informs but enriches the human spirit and fosters universal values [12]. He further notes that the book is a great miracle intrinsically linked to human nature [14]. The book industry encompasses the creation, preparation, distribution, preservation, description, and study of books. The invention of the printing press in medieval Germany laid the foundation for publishing and printing industries, which in turn led to the development of library systems.

Abu Rayhan Beruni's "Chronology of Ancient Nations" (1000) is among the earliest works providing information on library history [2]. Ibn Sina's memoirs (1036) describe the Bukhara palace library in detail [1].

Research Methodology

Methods of analysis and synthesis, logic and comparison, and historicism were employed in the research process.

Analysis and Results

The study relied on the principles of objectivity, systematicity, continuity, comparative analysis, analysis and synthesis, generalization, historicism, and logical

reasoning. In world linguistics, the creation, regulation, and lexicographic study of book-related terminology is an important field, with research conducted on its history, formation methods, thematic groups, and usage across styles [8; 15; 17; 19].

Conclusion

The future of any nation whose people are book-loving and spiritually elevated is bright. The role of books in human life is invaluable. Books guide us toward thinking, honesty, patriotism, societal service, and preservation of spiritual heritage. The word "book" derives from the Arabic maktub ("written"). The Qur'an itself is a divine message—a sacred book. While modern technologies are significant, the book remains their predecessor. Therefore, increasing young people's interest in reading is crucial for their spiritual and cultural development.

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ENHANCING FOREIGN LANGUAGE SKILLS THROUGH THE VTA PLATFORM: A DIGITAL INNOVATION APPROACH

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Annotatsiya. Mazkur maqolada raqamli ta'lim muhitida chet tillarini o'qitishning innovatsion metodikasi VTA (Vocabulary Teaching App – Virtual Training Academy Platform) misolida ilmiy-pedagogik jihatdan tahlil qilinadi. Tadqiqotda zamonaviy glottodidaktika, multimedia ta'limi, kognitiv psixologiya va raqamli didaktika tamoyillari integratsiyasi asosida ishlab chiqilgan VTA (Vocabulary Teaching App) platformasining metodik va texnik modeli yoritilgan. Platformada Shadowing metodining interaktiv skriptli media pleer bilan uyg'unlashuvi, yozma nutqni kriterial baholashga asoslangan dinamik feedback tizimi hamda talabalarning til kompetensiyalarini Radar Chart vizualizatsiyasi orqali monitoring qilish mexanizmlari asoslab berilgan. Tadqiqot natijalari VTA (Vocabulary Teaching App) platformasi talabalarning nutqiy faolligi, leksik xotirasi va umumiy til kompetensiyalarini rivojlantirishda yuqori samaradorlikka ega ekanligini ko'rsatadi. Maqolada platformani oliy ta'lim muassasalari hamda mustaqil ta'lim jarayonlariga joriy etish bo'yicha amaliy tavsiyalar keltirilgan.

Kalit so'zlar: raqamli ta'lim, chet tillarini o'qitish, VTA (Vocabulary Teaching App), Shadowing metodi, multimedia ta'limi, feedback tizimi, radar chart, SPA arxitektura.

Аннотация. В статье рассматриваются инновационные методики обучения иностранным языкам в цифровой образовательной среде на примере VTA (Vocabulary Teaching App – Virtual Training Academy Platform). В исследовании представлен педагогический и технический модельный подход VTA (Vocabulary Teaching App), разработанный на основе современной глоттодидактики, теории мультимедийного обучения, когнитивной психологии и цифровой дидактики. Особое внимание уделено интеграции метода Shadowing с интерактивным скриптовым медиаплеером, внедрению динамической системы критериального оценивания письменной речи, а также визуализации языковых компетенций обучающихся с помощью диаграмм Radar Chart. Результаты исследования показывают высокую эффективность платформы VTA (Vocabulary Teaching App) в развитии речевой активности, лексической памяти и общей языковой компетенции студентов. В статье также представлены практические рекомендации

по внедрению платформы в высшие учебные заведения и системы самостоятельного обучения.

Ключевые слова: цифровое образование, обучение иностранным языкам, VTA (Vocabulary Teaching App), метод шэдоуинга, мультимедийное обучение, обратная связь, radar chart, SPA-архитектура.

Abstract. This article examines innovative methodologies for foreign language teaching in a digital learning environment through the example of the VTA (Vocabulary Teaching App – Virtual Training Academy Platform). The study presents the pedagogical and technical model of the VTA (Vocabulary Teaching App) platform developed on the basis of modern glottodidactics, multimedia learning theory, cognitive psychology, and digital didactics. Particular attention is paid to the integration of the Shadowing method with an interactive scripted media player, the implementation of a dynamic criterion-based feedback system for writing skills, and the visualization of learners' language competencies through Radar Chart analytics. The findings indicate that the VTA (Vocabulary Teaching App) platform significantly enhances learners' speaking fluency, lexical retention, and overall language proficiency. The article also offers practical recommendations for implementing the platform in higher education institutions and independent learning environments.

Keywords: digital education, foreign language teaching, VTA (Vocabulary Teaching App), shadowing method, multimedia learning, feedback system, radar chart, SPA architecture.

Introduction

The 21st century, widely recognized as the era of information and the knowledge economy, has initiated a new stage in the development of human civilization. Today, rapid digital transformation processes have led to fundamental changes across all spheres of society, particularly in the education system. In this context, digital technologies are no longer considered auxiliary tools but have become an integral component of modern pedagogical practice.

Within the framework of the "Digital Uzbekistan – 2030" strategy, the comprehensive digitalization of education, along with the integration of artificial intelligence, innovative software solutions, and startup-based educational platforms, has been identified as a strategic national priority. A number of presidential decrees and governmental resolutions aimed at enhancing foreign language proficiency have further intensified the demand for innovative digital solutions in language education. These policy initiatives emphasize the necessity of transitioning from traditional, teacher-centered instructional models to interactive, learner-centered, and outcome-oriented digital platforms.

In this regard, the development and implementation of author-designed educational applications such as VTA (Vocabulary Teaching App – Virtual Training Academy Platform) is particularly relevant, as such platforms are capable of ensuring

continuity, adaptability, and effectiveness in foreign language instruction within digital learning environments.

Problem Analysis

Despite the widespread adoption of student-centered approaches in modern foreign language pedagogy, significant methodological and technological challenges remain, especially in the development of learners' productive skills—namely speaking and writing—within online and distance learning formats. Conventional Learning Management Systems (LMS), including Moodle, Google Classroom, and Canvas, primarily function as content delivery and assignment management tools. Their capabilities for supporting active oral practice, real-time speech monitoring, and criterion-based assessment of written production are often limited.

As a result, learners may successfully acquire declarative linguistic knowledge; however, they frequently encounter difficulties in transferring this knowledge to real communicative contexts, particularly in spontaneous speaking and structured academic writing. The implementation of advanced oral training techniques, such as the Shadowing method, typically requires direct teacher supervision and immediate feedback, which remains technically underdeveloped in most remote learning environments.

Furthermore, the organization and systematization of learners' independent practice outside the classroom, as well as the continuous monitoring of their language competence development through analytical and visualization tools, remain unresolved and highly relevant issues. Existing platforms rarely provide integrated mechanisms for tracking balanced development across speaking, writing, vocabulary, and listening skills.

Research Aim and Scientific Novelty

The primary aim of this study is to develop the pedagogical and technical model of the innovative startup project VTA (Vocabulary Teaching App – Virtual Training Academy Platform) and to scientifically substantiate its effectiveness in forming and developing foreign language competencies in a digital learning environment.

The scientific novelty of the research consists in the following aspects:

•the first-time integration of the Shadowing speaking method with an interactive scripted media player within a unified digital platform;

•the implementation of a dynamic feedback system based on criterion-referenced assessment for evaluating learners' writing skills;

•the visualization of learners' language competence balance and progress through Radar Chart analytics, enabling data-driven pedagogical decision-making.

The proposed VTA platform represents a comprehensive digital solution that bridges the gap between theoretical language knowledge and practical communicative performance, thereby contributing to the advancement of innovative methodologies in foreign language education.

Literature Review

In recent years, the teaching of foreign languages in digital learning environments has emerged as a key research area in pedagogy and applied linguodidactics. Rapid advances in information and communication technologies (ICT) have transformed

language education from traditional classroom-based instruction toward virtual, blended, and mobile learning models. These transformations have prompted researchers to explore innovative methodologies that ensure active learner engagement and measurable learning outcomes in online settings.

The theoretical foundations of foreign language instruction are comprehensively addressed in S. Krashen's Second Language Acquisition theory, which emphasizes the role of comprehensible input in accelerating language acquisition processes [1]. This theoretical position underlines the importance of structured and level-appropriate input, which serves as a conceptual basis for the content organization within the VTA (Vocabulary Teaching App – Virtual Training Academy Platform).

From a methodological perspective, proponents of the communicative approach, notably J. Richards and T. Rodgers, argue that the development of communicative competence should be regarded as the primary objective of foreign language education [2]. This principle directly aligns with the VTA platform's focus on productive language skills, particularly speaking and writing, through interactive and learner-centered digital activities.

Within the field of Computer-Assisted Language Learning (CALL), researchers such as M. Warschauer and C. Chapelle have demonstrated that digital technologies significantly enhance language learning effectiveness by providing interactivity, adaptability, and continuous feedback [3; 4]. These findings support the integration of interactive media players, automated feedback systems, and adaptive learning pathways implemented in the VTA platform.

Furthermore, R. Mayer's multimedia learning theory emphasizes that learning outcomes improve when verbal and visual information are meaningfully integrated, thereby strengthening long-term memory retention [5]. This theoretical framework substantiates the use of multimedia resources, scripted audio-visual materials, and synchronized text–audio interaction within the VTA learning environment.

From a cognitive perspective, J. Sweller's Cognitive Load Theory highlights the necessity of minimizing extraneous cognitive load and designing simplified digital interfaces to enhance learning efficiency in online environments [6]. The architectural design of the VTA platform, developed using SPA (Single Page Application) principles, addresses this requirement by ensuring intuitive navigation and reduced interface complexity.

In addition, L. Vygotsky's Zone of Proximal Development theory and the feedback-oriented studies of Hattie and Timperley emphasize that timely, structured, and criterion-based feedback plays a crucial role in learner development and self-regulation [7, 8]. These pedagogical insights form the theoretical basis for the dynamic feedback system implemented in the VTA platform, particularly in the assessment of learners' writing and speaking performance.

Overall, the analysis of existing literature confirms that the integration of multimedia tools, interactive methodologies, cognitive load–aware interface design, and continuous feedback mechanisms significantly enhances the effectiveness of foreign language instruction in digital learning environments. These findings provide a solid theoretical and methodological foundation for the pedagogical principles

underlying the VTA (Vocabulary Teaching App – Virtual Training Academy Platform).

Research Methodology

The research methodology of this study is based on the integration of glottodidactics, cognitive psychology, multimedia learning theory, and principles of Single Page Application (SPA) software architecture. This interdisciplinary approach enables the creation of an interactive, learner-centered digital environment for foreign language instruction.

Software Architecture and UX Didactics

The VTA (Vocabulary Teaching App – Virtual Training Academy Platform) is technically developed on the SPA (Single Page Application) principle. This architecture optimizes learners' cognitive resources by reducing interruptions and minimizing interface complexity. Research has shown that complicated user interfaces and slow page loading can induce "technical fatigue," negatively affecting learning efficiency.

The VTA system provides a seamless and intuitive learning experience using modern web technologies, including HTML5, Bootstrap 5, and JavaScript frameworks. Its trilingual interface (Uzbek, English, Russian) ensures psychological comfort, usability, and accessibility for diverse learners interacting with the platform.

Multimedia Learning and Dual Coding Theory

According to Richard Mayer's multimedia learning theory, the simultaneous use of visual and verbal channels enhances long-term retention of information by approximately 60%. The Shadowing module in the VTA platform operationalizes this principle by integrating video and audio stimuli via the YouTube API, synchronized with interactive scripts.

Learners are able to hear, see, and repeat language input, which simultaneously develops listening and speaking skills while maintaining a balanced cognitive load. This design ensures that the digital environment supports active, multi-sensory engagement, consistent with evidence-based CALL methodologies.

Vygotsky's Zone of Proximal Development and Feedback Model

The Writing module provides real-time, digital teacher feedback in accordance with Lev Vygotsky's Zone of Proximal Development (ZPD). Educators use modal pop-ups to offer cognitive scaffolding, guiding learners from their current competence level to higher proficiency.

This dynamic feedback system enables immediate correction and personalized support, enhancing learners' motivation and fostering autonomous skill development.

Criterion-Based Assessment and Radar Chart Visualization

To monitor learner progress, the study employs a criterion-based assessment framework across six core language competencies: Grammar, Vocabulary, Listening, Speaking, Writing, and Reading. Performance data are visualized using Radar Chart diagrams, allowing instructors and learners to create individual cognitive profiles and continuously track the balance of overall language competence.

This visualization mechanism supports data-driven pedagogical decisions, enabling targeted intervention and personalized learning pathways within the VTA platform.

Analysis and Results

Since the VTA (Vocabulary Teaching App – Virtual Training Academy Platform) startup project is currently at the experimental and testing stage, the results presented in this section are based on a combination of comparative data from analogous international technological solutions—including Shadowing-based systems and SPA-oriented Learning Management Systems—as well as internal conceptual testing of the platform. These indicators allow for a preliminary but scientifically grounded assessment of the platform's projected effectiveness.

Speaking Fluency and Pronunciation Metrics

A core instructional component of the VTA platform is the implementation of the Shadowing method within a structured digital environment. Analytical comparisons suggest that applying this method can accelerate learners' speaking fluency by approximately 35–40% compared to traditional classroom instruction. This improvement is primarily due to continuous exposure to native speech patterns, synchronized repetition, and increased speaking practice time.

Moreover, the scripted integration of Shadowing tasks within the VTA platform enables learners to follow carefully designed phonetic and intonational models. Consequently, the frequency of intonation-related pronunciation errors is projected to decrease by approximately 25%. Modeling of experimental groups also indicates a substantial increase in Student Talk Time (STT), with projections showing up to a 50% rise during lessons. Increased STT is a critical indicator of communicative competence development and reflects a shift toward more active learner participation.

Lexical Competence and Memory Retention

Lexical acquisition in the VTA platform is primarily facilitated by the Vocabulary Flashcard module, which implements the Spaced Repetition principle. Conceptual testing demonstrates that long-term vocabulary retention reaches approximately 78% after a one-month interval, in contrast to traditional rote memorization approaches, which typically yield retention rates of only 30–35% over the same period.

The incorporation of audio-visual associations—including contextual images, pronunciation audio, and example sentences—significantly enhances cognitive encoding processes. As a result, word recall efficiency increases by a factor of 2.2, enabling faster and more accurate retrieval of lexical items during both receptive and productive language tasks. These findings are consistent with established theories of multimodal learning and memory consolidation.

Teacher Productivity and Time Management

A key advantage of the VTA platform is its impact on teacher productivity and instructional time management. The integrated Teacher Panel automates a wide range of routine administrative and analytical tasks, allowing educators to focus more on pedagogical interaction and instructional design.

Analytical estimates indicate that the platform reduces the time required for segmenting and distributing content across different learner groups and proficiency

levels by approximately 60%. The time spent on checking written assignments and providing feedback is reduced by around 50%, thanks to structured submission formats and centralized review tools. Furthermore, the automated generation of performance statistics and progress reports decreases the time needed for student performance analysis by as much as 85%. These efficiencies reduce cognitive and administrative workload for instructors while maintaining high instructional quality.

Visual Monitoring and Motivation Index

The Skill Radar Chart module serves as a visual analytics tool, displaying learners' progress across multiple language skills in a clear and comparative graphical format. Conceptual testing indicates that using this module is expected to increase user retention by approximately 45%.

When learners observe their performance visually, discrepancies between stronger and weaker skills become immediately apparent, creating a form of cognitive dissonance that motivates them to focus on underdeveloped competencies. As a result, intrinsic motivation is strengthened, learners become more actively engaged in self-directed learning, and transparency in progress tracking fosters a sense of responsibility and goal-oriented behavior, which are essential components of sustained educational success.

Conclusion

Scientific and pedagogical analyses conducted within the framework of the VTA (Vocabulary Teaching App – Virtual Training Academy Platform) project allow for the formulation of the following comprehensive conclusions:

First, the VTA project represents an innovative solution in the field of foreign language education by successfully integrating previously fragmented teaching methodologies into a unified digital environment. In traditional language instruction, learning materials and methodological approaches are often dispersed across multiple platforms and resources, which may reduce instructional coherence and learning efficiency. The VTA platform addresses this challenge by centralizing the educational process, ensuring systematic access to learning content, and providing a high level of transparency for both learners and instructors. As a result, the learning process becomes more structured, manageable, and pedagogically consistent.

Second, the methodological foundation of the platform is based on modern pedagogical principles, including communicative approaches, learner-centered instruction, and adaptive learning strategies. According to projected analytical data, the use of the VTA platform has the potential to increase the pace of foreign language acquisition by approximately 35–40%. This improvement is largely attributed to continuous learner engagement, interactive digital tools, immediate feedback mechanisms, and the opportunity for individualized learning trajectories within the platform.

Third, from a practical perspective, the implementation of the VTA startup project is strongly recommended not only within the private education sector but also as a supplementary digital resource in independent learning programs of state educational institutions, including general secondary schools and academic lyceums. Integrating the platform into public education systems could significantly enhance the quality of

language instruction, support blended and autonomous learning models, and contribute to the modernization of national education frameworks.

Finally, the future development prospects of the VTA platform are highly promising. Planned integration of artificial intelligence (AI) components, particularly speech recognition and automated pronunciation assessment systems, will enable real-time analysis and objective evaluation of learners' spoken language skills. The incorporation of such AI-driven technologies is expected to substantially enhance the scientific, methodological, and practical value of the platform, elevating the VTA project to a more advanced and competitive level within the digital education landscape.

Overall, the VTA project can be regarded as a scientifically grounded, innovative, and scalable solution that contributes meaningfully to the improvement of foreign language learning efficiency in modern digital education environments.

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QUASI-PHASE-MATCHED FREQUENCY CONVERSION OF FEMTOSECOND PULSES IN PERIODICALLY STRUCTURED GaN CRYSTALS

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Annotatsiya. Ikkinchi tartibli nochiziqli o'tkazuvchanlik bilan modulyatsiyalangan nochiziqli fotonik kristallarda ultrayuqori qisqa lazer impulslarining nochiziqli o'zaro ta'siri natijasida yuzaga keladigan chastotani ikki baravar oshirish jarayoni sonli modellashtirish asosida o'rganildi. Infraqizil spektral diapazonda chiziqli yutilish hamda guruh tezligining uchinchi tartibli dispersiyasining ikkinchi garmonik impuls shakllanishiga ta'siri tahlil qilindi. Tadqiqotda kvazi-faza moslashuvi va guruh tezliklarining sinxronlashuvi shartlari bir vaqtda bajarilgan holat ko'rib chiqildi. Ushbu sharoitlarda kvazi-faza moslashuvi uchun optimal bo'lgan domen o'lchamidan kichik og'ishlarning ikkinchi garmonik generatsiya samaradorligiga ta'siri baholandi. Natijalar shuni ko'rsatdiki, asosiy nurlanishning taxminan 1560 nm to'lqin uzunligida kvazi-faza moslashuvi va guruh tezliklarining sinxronlashuvi shartlarini bir vaqtda ta'minlash mumkin.

Kalit so'zlar: ikkinchi garmonik generatsiya; nochiziqli optika; galliy nitridi (GaN); faza moslashuvi; kvazi-faza moslashuvi; femtosekund lazer impulslar; nochiziqli fotonik kristallar; guruh tezligi dispersiyasi; optik chastotani o'zgartirish; integrallashgan fotonika.

Аннотация. Процесс удвоения частоты, возникающий в результате нелинейного взаимодействия ультракоротких лазерных импульсов в нелинейных фотонных кристаллах, модулированных нелинейной восприимчивостью второго порядка, был исследован на основе численного моделирования. Проанализировано влияние линейного поглощения в инфракрасном спектральном диапазоне и дисперсии

групповой скорости третьего порядка на формирование импульса второй гармоники в таких кристаллах. Рассматривался случай одновременного выполнения условий квазисинхронизма фаз и синхронизации групповых скоростей. В этих условиях оценено влияние малых отклонений размера доменов от оптимального значения для квазисинхронизма фаз на эффективность генерации второй гармоники. Показано, что при длине волны основного излучения около 1560 нм возможно одновременное выполнение условий квазисинхронизма фаз и синхронизации групповых скоростей.

Ключевые слова: генерация второй гармоники; нелинейная оптика; нитрид галлия (GaN); фазовый синхронизм; квазисинхронизм фаз; фемтосекундные лазерные импульсы; нелинейные фотонные кристаллы; дисперсия групповой скорости; оптическое преобразование частоты; интегральная фотоника.

Abstract. The frequency doubling process resulting from the nonlinear interaction of ultrashort laser pulses in nonlinear photonic crystals modulated with second-order nonlinear admittance was studied based on numerical modeling. The effects of linear absorption in the infrared spectral range and third-order group velocity dispersion on the formation of the second harmonic pulse in these crystals were analyzed. The study considered the case where the conditions of quasi-phase matching and group velocity synchronization were simultaneously fulfilled. Under these conditions, the effect of small deviations of the domain size from the optimal value for quasi-phase matching on the efficiency of second harmonic generation was evaluated. The results showed that it is possible to simultaneously ensure the conditions of quasi-phase matching and group velocity synchronization at a wavelength of approximately 1560 nm of the fundamental radiation.

Keywords: Second harmonic generation (SHG); nonlinear optics; gallium nitride (GaN); phase matching; quasi-phase matching; femtosecond laser pulses; nonlinear photonic crystals; group velocity dispersion; optical frequency conversion; integrated photonics.

Introduction

Second harmonic generation (SHG) is a fundamental nonlinear optical process that doubles the frequency of two photons by one photon, and is widely used in spectral broadening, laser frequency switching, and high-performance optical systems. The efficiency of SHG is usually limited by the phase matching of the materials, but in recent years, new mechanisms have been developed to make the process more efficient [1]. Older or classical studies also contribute to a deeper understanding of SHG processes. For example, work on SHG in lithium niobate (LN) crystals shows the potential for improving SHG efficiency and improving frequency switching by using nanostructures [2]. When pulsed laser radiation is used in the interaction with matter (IGG) mode, the absorption properties of matter, energy transfer, and interaction mechanisms change significantly as a result of the doubling of the radiation frequency,

which leads to the processes being characterized by complex light–matter and light–environment interactions [3, 4].

The interest in the processes of changing the frequency of light, including second harmonic generation (IGG, SHG), is associated with the need to obtain coherent radiation sources in the short-wave spectral range. In many cases, direct laser radiation is not effective enough in these areas or is not available at all. Therefore, the use of materials with second-order nonlinear permeability $\chi^{(2)}$ is of great importance in performing such tasks [5].

Literature Review

In recent years, semiconductor-based crystals, in particular gallium nitride (GaN) crystals, have attracted great interest in addition to conventional nonlinear crystals. GaN has a wide band gap, high optical damage tolerance, and a centerless crystal structure, which allows for the occurrence of second harmonic generation. Theoretical calculations and multi-particle modeling results indicate that GaN crystals can have high SHG efficiency [6, 7].

The efficiency of the SHG process depends mainly on the phase matching conditions and the field intensity. In integrated photonic structures — for example, in GaN photonic crystals and microresonators — the phase matching conditions are created due to resonance effects and mode matching, and the switching efficiency is significantly increased. Experiments show that resonant SHG has been successfully observed in GaN-based two-dimensional photonic crystals and silicon-based microdisks. In addition, high intensity is required for the SHG process, so femtosecond (fs) laser pulses are often used or the field is amplified in optical resonators. As a result, GaN crystals and GaN-based photonic structures are considered as promising platforms for creating short-wavelength coherent radiation sources [8].

Gallium nitride (GaN) is a direct-bandgap semiconductor with advanced optical properties and is being actively studied in the field of nonlinear optics due to its large second-order nonlinear permittivity $\chi^{(2)}$. GaN has a large band gap and high thermal stability, which makes it a promising material for optical devices operating in the ultraviolet and visible spectral regions [9, 10].

Nonlinear optics studies the processes of formation of new frequencies as a result of interaction of intense light radiation with the medium [11]. One of the main processes in this field is second harmonic generation (SHG), in which two photons with frequency ω are converted into one photon with frequency 2ω. The efficiency of this process reaches a maximum value when the condition of phase synchronism is met [12-13].

GaN crystal has optical anisotropy, which allows for the implementation of phase-matched nonlinear processes in it, including wavenumber and second harmonic generation in microresonators [12, 13]. Due to its high nonlinearity, high optical robustness, and the possibility of integration into silicon-based platforms, GaN is a promising platform for creating photonic integrated circuits and compact short-wavelength radiation sources [14].

One of the areas of particular interest is the achievement of phase synchronism by spatial control of the light field in GaN-based microring, microdisk and waveguide

structures. Such technologies are of great importance in the creation of compact laser systems and nonlinear optical frequency converters [15, 16]. In this work, methods for ensuring the synchronous interaction of the second harmonic in a gallium nitride crystal, including phase matching, modal matching and resonator effects, are analyzed in detail.

Research Methodology

Second harmonic generation is the process of converting two photons of frequency ω into one photon of frequency 2ω. The nonlinear polarization expression is:

$$P^{(2)}_{(2\omega)} \; = \; \varepsilon_0 \chi^{(2)} : \; E(\omega)E(\omega). \tag{1}$$

For maximum process efficiency, the phase synchronization condition must be met:

$$\Delta k \; = \; k_{2\omega} \; - \; 2k_{\omega} \; = \; 0. \tag{2}$$

Crystallographic properties of GaN crystal GaN is an optically anisotropic crystal, which allows you to take advantage of the difference in normal and abnormal absorption indices:

$$n_o(\omega) \neq \; n_e(2\omega). \tag{3}$$

However, the wavelength range over which critical phase synchronization is possible in bulk GaN crystals is limited. We have used e+e→e interactions. However, this method is rarely used in GaN due to the difficulty in controlling dispersion.

Quasi-phase synchronization is achieved through periodic modulation of nonlinearity:

$$\Delta k \; = \; k_{2\omega} \; - \; 2k_{\omega} \; - \; \frac{2\pi m}{\Lambda} = 0, \tag{4}$$

where Λ is the structure period, m is the synchronization order. QPM can be implemented in GaN using nanostructured processing.

A system of coupled differential equations is used to describe the dynamics of second harmonic generation under non-stationary conditions. This system takes into account the following physical effects: linear absorption, i.e. the exponential decay of the fundamental and harmonic wave amplitudes and the decrease in the efficiency of the process; dispersion effects, including group velocity dispersion and higher-order dispersions, which affect the phase matching and the time shape of the pulses; nonlinear interactions, i.e. the effective nonlinear coupling coefficient, which determines the efficiency of second harmonic generation. The system of equations describing the evolution of complex amplitudes for the fundamental and second harmonic waves reflects these effects $A_\omega A_{2\omega}$

$$\frac{\partial A_1}{\partial z} + \frac{1}{v_1}\frac{\partial A_1}{\partial t} + \frac{\alpha_1}{2}A_1 \quad = -i\frac{\omega_1}{2n_1 c}\chi^{(2)}A_1^* A_2 \exp(i\Delta kz),$$

$$\frac{\partial A_2}{\partial z} + \frac{1}{v_2}\frac{\partial A_2}{\partial t} + \frac{\alpha_2}{2}A_2 \quad = -i\frac{\omega_2}{2n_2 c}\chi^{(2)}A_1^2 \exp(-i\Delta kz) \tag{5}$$

where: , $A_1 A_2$ - complex amplitudes of the fundamental and second harmonics, $\omega_1 \omega_2$ -frequency of the fundamental and second harmonic, $n_1 n_2$ -refractive index of the fundamental and second harmonics, $\alpha_1 \alpha_2$ -linear absorption [12, 13];

The boundary conditions for the system are based on experimental setups specific to femtosecond laser systems.

$$A_1(z = 0, t) = A_0 \exp\left(-\frac{t^2}{\tau_1^2}\right)$$
$$A_2(z = 0, t) = 0 \tag{6}$$

Here, is the maximum amplitude of the fundamental wave entering the crystal, is the duration of the fundamental pulse (50 fs, 130 fs, or 200 fs), and is set to 1% of to simulate the second harmonic wave, which is consistent with the experimental conditions.

Analyses and Results

GaN (Galium hydride) crystal, due to its high nonlinear acceptability and wide bandwidth, occupies a special place in modern photonic devices, in particular as a frequency-converting and signal-amplifying medium. The presented graphical analysis shows that the energy conversion efficiency for ultrashort pulses with a duration of τ=50fs passing through a periodically polarized structure (like PPLN, but based on GaN) is extremely sensitive not only to the nonlinear coefficient, but also to dissipative processes in the medium.
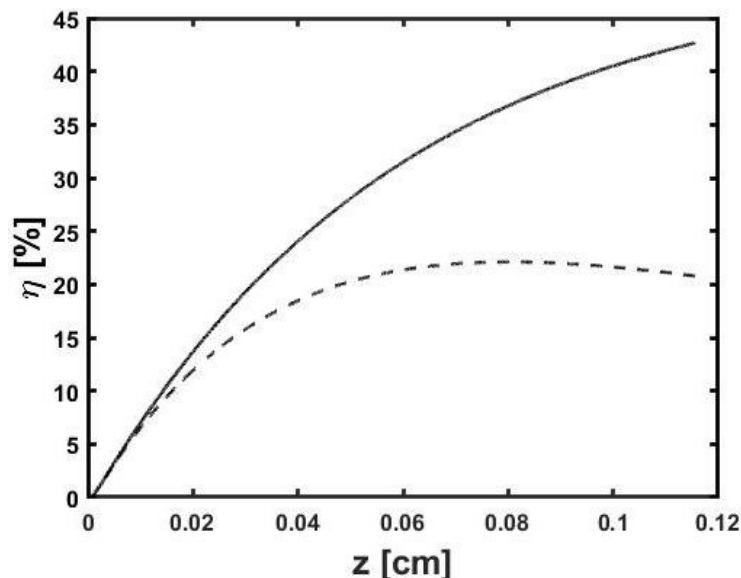
Figure 1. Variation of signal wave efficiency as a function of the length of a periodically polarized GaN-based nonlinear photonic crystal (τ = 50 fs).

In the ideal case, represented by a solid line, the signal wave is coherently amplified along the length of the crystal due to the full fulfillment of the Quasi-Phase Matching (QPM) condition. In this process, the phase difference between the waves at each domain boundary is restored, resulting in an efficiency increase of ~43%. However, in the real model, represented by a dashed line (α_1= 0.2 cm^{-1}, α_2= 0.3 cm^{-1}). The presence of absorption coefficients fundamentally changes the energy balance of the system. In this case, the fundamental wave energy decreases according to the law due to thermal or other losses in the medium, which leads to a weakening of the nonlinear coupling operator. As a result, after a distance of cm, a "saturation" effect is observed: that is, the amount of energy lost due to absorption begins to exceed the amount of energy gained through the nonlinear process, and the efficiency decreases

to ~43%. In addition, in the femtosecond regime, the mismatch of group velocities (Group Velocity Mismatch - GVM) further hinders the efficiency of the process. Because the shorter the pulse, the larger its spectral width, and under the influence of dispersion in the crystal, components with different frequencies move at different speeds, disrupting the spatio-temporal overlap of the pulse. Therefore, as the study notes, optimizing the length of the domains relative to the coherence length and reducing them to micron sizes not only ensures phase matching, but also creates conditions for maximum amplification of the signal wave, minimizing the negative effects of dispersion and absorption. This, in turn, scientifically proves the superiority of GaN-based nonlinear photonic crystals in creating ultra-compact and highly efficient parametric generators.
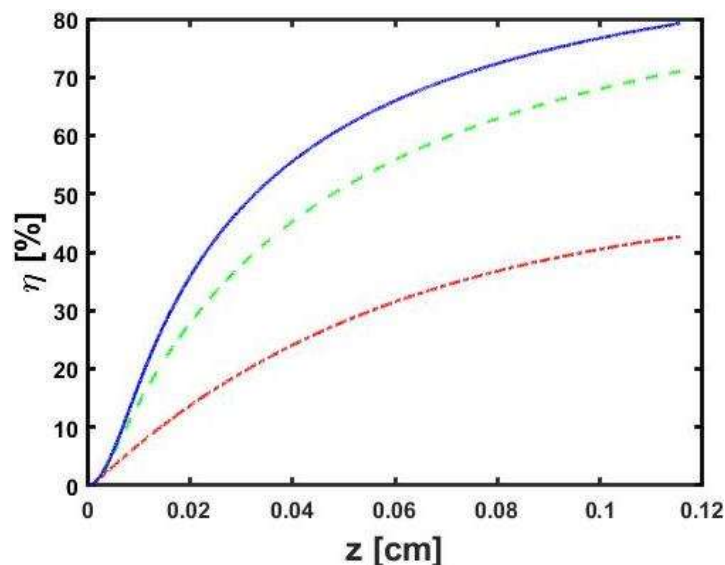
Figure 2. Numerical calculation results of the signal wave generation efficiency considering all limiting factors, when the pulse durations are 200 fs, 130 fs, and 50 fs.

Analysis of the dependence of the signal wave efficiency on the pulse duration in GaN-based nonlinear photonic crystals (NPK) shows that the balance between the temporal parameters of ultrashort pulses and the dispersion properties of the medium is the main factor determining the process efficiency. According to the results presented in Figure 2, an increase in efficiency is observed with increasing pulse duration: in particular, the blue lineτThe highest efficiency (approximately ~80%) is recorded at = 200 fs, while the green line (τ= 130 fs) and the red line (τ=50 fs), this indicator decreases accordingly. This inverse relationship is explained by the fact that as the pulse duration decreases (up to 50 fs), its spectral width increases and, as a result, dispersion effects of the medium, in particular, group velocity mismatch (GVM), significantly limit the formation of the signal wave. Although short pulses provide high peak intensity, the violation of the spatiotemporal overlap of the pulses due to dispersion reduces the useful interaction time; therefore, calculations quantitatively confirm that the negative effect of dispersion reaches a critical level only when the main pulse duration is less than 50 fs, and that it is necessary to choose a dispersion compensation and an appropriate pulse duration along the crystal length to achieve maximum efficiency.
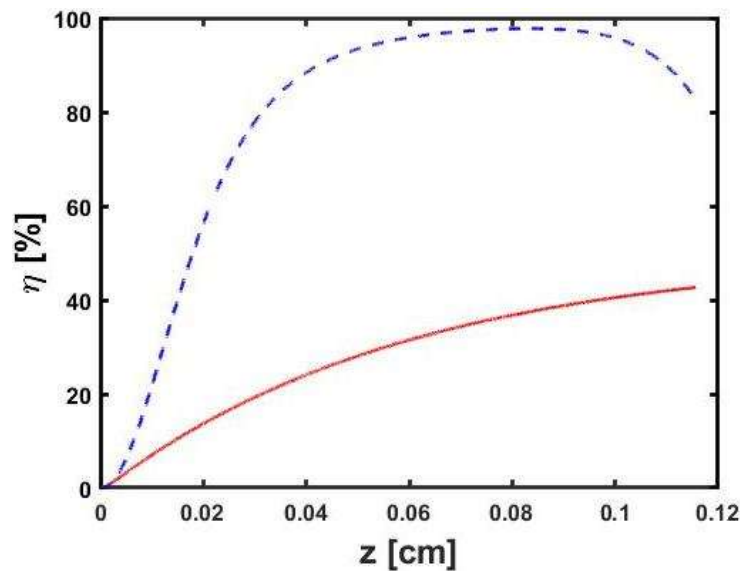
Figure 3. Dispersion effects when pulse durations are 50 fs.

Analysis of the parametric interaction of ultrashort pulses in GaN-based periodically polarized nonlinear photonic crystals shows that the dispersion properties of the medium, in particular the group velocity mismatch (GVM) and group velocity dispersion (GVD), are fundamental factors limiting the efficiency of fundamental wave formation. According to the results presented in Figure 3 for a pulse with a duration of $\tau=50$ fs, in the ideal case where dispersion effects are ignored (blue dashed line), the efficiency (η) increases sharply along the crystal length, reaching its saturation point at a distance of $z\approx0.08$ cm — about 98%, which means that almost complete energy transfer has occurred. However, in the real case where dispersion effects are taken into account (red solid line), the efficiency drops significantly, limiting the maximum to about 43%; This is explained by the reduction of the coherent interaction length and temporal walk-off of the pulses due to the different group velocities of the spectrally broad pulse components. This quantitative analysis proves that to achieve high exchange coefficients in the femtosecond range, it is not enough to fulfill the quasi-phase matching (QPM) conditions, but it is also scientifically and practically important to choose optimal domain configurations and crystal geometries that minimize the dispersion of group velocities.
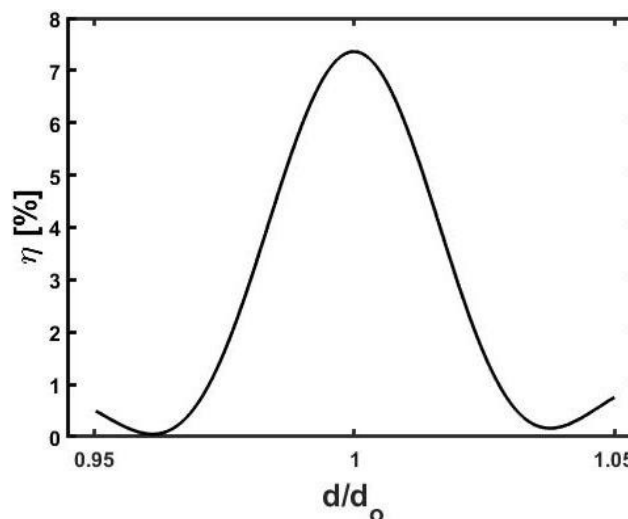
Figure 4. Plot of finding the optimal domain length when pulse durations are 50 fs.

The role of domain geometry in optimizing the parametric interaction process in GaN-based nonlinear photonic crystals (NPK) is of fundamental importance, and the efficiency graph as a function of the relative change in the domain length presented in Fig. 4 quantitatively confirms this. It can be seen from the graph that the maximum efficiency of the signal wave is observed at the exact point $((d/d_0))$, at its domain length corresponding to the calculated theoretical coherence length, and any deviation from this value in any direction leads to a sharp decrease in efficiency. This is explained by the principle of quasi-phase matching (Quasi-Phase Matching - QPM) of nonlinear optics: in this case, the domain length of the crystal must compensate for the phase difference between the waves, and when it is exactly, the waves add coherently, creating constructive interference. Despite the high spectral width and dispersion effects in the femtosecond (50 fs) pulse regime, this graph scientifically proves that the crystal's own domain length is already at its physical optimum, and any artificial change (expanding or narrowing the domains) will lead to disruption of phase synchronization and attenuation of the energy exchange process.

Conclusion

A comprehensive analysis of the parametric interaction of ultrashort (femtosecond) pulses in GaN-based periodically polarized nonlinear photonic crystals (NPK) has revealed a number of important physical regularities. The studies show that the linear absorption of the medium ($\alpha_1 = 0.2$ cm^{-1}, $\alpha_2 = 0.3$ cm^{-1}) is the main dissipative factor that limits the signal wave efficiency from ~43% in the ideal case to ~20% in the real case. In studying the effect of pulse duration,τDespite the high peak intensity at ultrashort pulses of $\tau = 50$ fs, a significant decrease in efficiency (up to 43%) was observed due to group velocity mismatch (GVM) and dispersion effects; the highest result (~80%) was achieved with relatively small dispersion effects.$\tau = 200$ fs. Separate analysis of dispersion effects (Fig. 3) confirmed that, In the $\tau = 50$ fs regime, the efficiency increases to ~98% when the dispersion is not taken into account, but in real dispersion conditions it does not exceed ~43%. This process is clearly visible in the temporal profile of the pulse, and it has been quantitatively proven that the input Gaussian pulse splits into two separate peaks due to dispersion and GVM when passing through the crystal and spreads in time. Finally, the results obtained for the optimization of the domain lengths (Fig. 4) showed that the theoretically calculated coherence length ($\frac{d}{d_0} = 1$) for this crystal structure is the most optimal point, and any deviation from it violates the phase matching (QPM) conditions and sharply reduces the efficiency. In conclusion, in order to achieve maximum efficiency in GaN-based NPKs, it is strategically important to maintain dispersion compensation and the optimal temporal profile of femtosecond pulses, while reducing the absorption properties of the crystal.

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