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BALANCED MODEL OF EDUCATION-BUSINESS INTERACTION IN THE CONTEXT OF KAZAKHSTAN'S ECONOMIC DIGITALIZATION: CHALLENGES AND IMPLEMENTATION PATHWAYS

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Abstract. This article explores the development of a balanced model for education-business interaction in Kazakhstan under the conditions of economic digitalization. Emphasis is placed on practical relevance for Kazakhstan, analyzing labour market needs, current curricula, and enterprise engagement. The methodology integrates statistical data, empirical interviews, and a dynamic mathematical model based on identified indicators such as business participation, resources, and government support. Recommendations are developed to address local conditions and policy frameworks for improving graduate competitiveness and labour market alignment.

The research aims to identify key barriers to effective collaboration between educational institutions and businesses and propose solutions to overcome these obstacles. A comprehensive approach is employed, including analyzing current labour market trends, examining existing academic programs, and interviewing representatives from enterprises and academic institutions.

The research findings indicate that the main problems of interaction include insufficient flexibility in educational programs, a lack of resources and infrastructure, as well as differing goals and priorities of the parties involved. Based on the analysis, a mechanism for adapting educational programs is proposed, which includes continuous monitoring of labour market requirements, the establishment of advisory councils involving businesses, and regular updates of educational modules.

As a result of the research, a mathematical model describing the interaction between the main factors affecting the level of adaptation of educational programs is proposed. The model includes variables such as labour market needs, business participation, allocated resources, and government support. The use of this model allows for the optimization of the process of adapting educational programs and

improving the training of personnel that meets the modern requirements of the digital economy. Implementing the proposed recommendations may contribute to the creation of sustainable partnerships between educational institutions and enterprises, which, in turn, will enhance the competitiveness of Kazakhstan's economy.

Keywords. Education-enterprise interaction, digital economy, skill adaptation, labour market needs, curriculum development, public-private collaboration, economic transformation.

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ҚАЗАҚСТАН ЭКОНОМИКАСЫН ЦИФРЛАНДЫРУДА БІЛІМ БЕРУ МЕН БИЗНЕС АРАСЫНДАҒЫ ТЕҢДЕСТІРІЛГЕН МОДЕЛЬДІ ӘЗІРЛЕУДІҢ ҚИЫНДЫҚТАРЫ

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Аннотация. Мақала Қазақстандағы экономиканы цифрландыру жағдайында білім беру мен бизнес арасындағы өзара іс-қимылдың теңгерімді моделін әзірлеуді зерттейді. Мақалада Қазақстанға тән еңбек нарығының қажеттіліктері, кәсіпорындардың қатысуы және мемлекеттік қолдау көрсеткіштері ескеріле отырып, практикалық ұсыныстар беріледі. Зерттеу нәтижелері білім беру бағдарламаларын бейімдеу тетіктерін анықтауға және оларды өңірлік деңгейде енгізуге бағытталған.

Зерттеудің мақсаты – білім беру мекемелері мен бизнес арасындағы тиімді ынтымақтастықтың негізгі кедергілерін анықтау және осы кедергілерді жеңу бойынша шешімдерді ұсыну. Ағымдағы еңбек нарығының үрдістерін талдауды, қолданыстағы оқу бағдарламаларын зерттеуді және кәсіпорындар мен білім беру мекемелерінің өкілдерімен сұхбаттасуды қамтитын кешенді тәсіл қолданылды.

Зерттеу нәтижелері көрсеткендей, өзара әрекеттесудің негізгі проблемаларына білім беру бағдарламаларының жеткіліксіз икемділігі, ресурстар мен инфрақұрылымның жетіспеушілігі, сондай-ақ тараптардың мақсаттары мен басымдықтарының әртүрлілігі жатады. Жүргізілген талдау негізінде еңбек нарығының талаптарын үздіксіз бақылауды, бизнес қатысуымен

консультативтік кеңестер құруды және оқу модульдерін тұрақты жаңартуды қамтитын білім беру бағдарламаларын бейімдеу механизмі ұсынылды.

Зерттеу нәтижесінде білім беру бағдарламаларын бейімдеу деңгейіне әсер ететін негізгі факторлардың өзара әрекеттесуін сипаттайтын математикалық модель ұсынылды. Модель еңбек нарығының қажеттіліктері, бизнестің қатысуы, бөлінген ресурстар және мемлекеттік қолдау сияқты айнымалыларды қамтиды. Осы модельді пайдалану білім беру бағдарламаларын бейімдеу процесін оңтайландыруға және цифрлық экономиканың қазіргі талаптарына сай келетін мамандарды даярлауды жақсартуға мүмкіндік береді. Ұсынылған ұсыныстарды жүзеге асыру білім беру мекемелері мен кәсіпорындар арасындағы тұрақты серіктестіктерді құруға ықпал етуі мүмкін, бұл өз кезегінде Қазақстан экономикасының бәсекеге қабілеттілігін арттырады.

Түйін сөздер: білім беру мен бизнес ынтымақтастығы, цифрлық экономика, дағдыларды бейімдеу, еңбек нарығының қажеттіліктері, оқу бағдарламаларын әзірлеу, мемлекеттік жеке серіктестік, экономикалық трансформация.

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ПРОБЛЕМЫ РАЗРАБОТКИ СБАЛАНСИРОВАННОЙ МОДЕЛИ ВЗАИМОДЕЙСТВИЯ ОБРАЗОВАНИЯ И БИЗНЕСА В УСЛОВИЯХ ЦИФРОВИЗАЦИИ ЭКОНОМИКИ КАЗАХСТАНА

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Аннотация. В статье исследуется разработка сбалансированной модели взаимодействия образования и бизнеса в условиях цифровизации экономики Казахстана. Особое внимание уделено практическому применению модели для Казахстана: анализируются потребности рынка труда, вовлечённость предприятий и механизмы господдержки. Методология базируется на статистических данных, интервью и динамической модели взаимодействия. Даны прикладные рекомендации по повышению соответствия подготовки специалистов запросам рынка.

Цель исследования – выявить основные барьеры на пути эффективного сотрудничества между образовательными учреждениями и бизнесом, а также предложить решения для их преодоления. Применён комплексный подход, включающий анализ текущих тенденций на рынке труда, изучение существующих учебных программ и проведение интервью с представителями предприятий и образовательных учреждений.

Результаты исследования показывают, что основными проблемами взаимодействия являются недостаточная гибкость образовательных программ,

нехватка ресурсов и инфраструктуры, а также различие целей и приоритетов сторон. На основе проведённого анализа предложен механизм адаптации образовательных программ, который включает непрерывный мониторинг требований рынка труда, создание консультативных советов с участием бизнеса и регулярное обновление учебных модулей.

В результате исследования предложена математическая модель, описывающая взаимодействие основных факторов, влияющих на уровень адаптации образовательных программ. Модель включает такие переменные, как потребности рынка труда, участие бизнеса, выделенные ресурсы и государственная поддержка. Использование этой модели позволяет оптимизировать процесс адаптации образовательных программ и повысить качество подготовки специалистов, соответствующих современным требованиям цифровой экономики. Реализация предложенных рекомендаций может способствовать созданию устойчивых партнёрств между образовательными учреждениями и предприятиями, что, в свою очередь, повысит конкурентоспособность экономики Казахстана.

Ключевые слова: взаимодействие образования и бизнеса, цифровая экономика, адаптация навыков, потребности рынка труда, разработка учебных программ, государственно-частное сотрудничество, экономическая трансформация.

Introduction. In the context of the rapid development of digital technologies and the transformation of economic processes, higher education systems face challenges that require adaptation to new labour market demands. In the Republic of Kazakhstan, the digitalization of the economy affects all sectors, creating an increased demand for qualified specialists with modern digital skills. However, educational institutions often struggle to keep pace with these rapid changes, leading to a gap between the knowledge gained during training and the practical skills needed in the labour market.

The relevance of this issue lies in the necessity of developing a balanced model for the interaction between educational institutions and enterprises. Such an approach would help bridge the gap between theory and practice, ensuring the preparation of specialists who meet the demands of the digital economy. This, in turn, would enhance the competitiveness of both graduates and the entire economy of Kazakhstan (Arynova, et al., 2024).

The research problem is rooted in the insufficient integration of educational programs with the real needs of businesses, which results in a mismatch between graduates' qualifications and employers' requirements. Educational institutions often operate in isolation from enterprises, limiting their ability to timely adapt curricula to changing conditions. At the same time, businesses do not always actively participate in the educational process, weakening their influence on the training of future employees. (Aly, 2021)

The adaptation of educational programs to the evolving demands of the labour market is critically important for ensuring the competitiveness of professionals and

the sustainable development of the economy. Over the past few years, numerous studies have focused on analyzing the mechanisms of interaction between educational institutions and enterprises, emphasizing the need to establish a balanced model that takes into account the interests of all stakeholders involved in this process.

Contemporary research, such as the work of Rauner and Maclean (2008), highlights the significance of dual education as a tool for fostering a closer integration of theoretical knowledge and practical skills. Furthermore, Brown and Hesketh (2004) examine the impact of flexible educational programs on graduates' employability, underscoring the importance of aligning curricula with labour market demands.

Research by Zhanbayev R.A. & Sagintayeva S.S. (2020) demonstrates how effective partnerships between universities and industry can contribute to the creation of relevant educational programs.

The research conducted by Caroline Olufunke Esangbedo, Jingxiao Zhang, Moses Olabhele Esangbedo, Seydou Dramane Kone, and Lin Xu (2024) focused on analyzing the role of industry-academia collaboration (IAC) in expanding educational opportunities and improving outcomes in the context of the digital Industry 4.0. The study employed mediators such as research and development, product and knowledge patenting, curriculum development, and artificial intelligence to facilitate IAC.

Thus, current research in this field confirms the necessity of creating a multifunctional model of interaction between educational institutions and the labour market, which facilitates the optimization of the workforce preparation process in the context of the digital economy (Mukanov, et al, 2023). This article presents a review of existing studies that illuminate key aspects of the mechanism of interaction between education and enterprises and offers suggestions for further enhancing this model in the context of Kazakhstan.

Materials and basic methods. This study adopts a mixed-methods approach combining qualitative and quantitative methodologies to develop a balanced model of education-business interaction in the context of Kazakhstan's digital economy. The research aims to model and empirically validate the relationship between educational program adaptation and key influencing variables: business involvement, government support, labour market demand, and institutional capacity.

1. Data Sources and Empirical Basis.

The empirical foundation of the study consists of Statistical data from national sources such as the National Report on the State and Development of the Education System of the Republic of Kazakhstan (2022), the Overview of Kazakhstan's Labour Market by Halyk Finance (2024), and reports from the Information-Analytical Center of the Ministry of Education and Science.

Strategic policy documents, including the Strategic Development Plan of the Republic of Kazakhstan until 2025, the State Program for Industrial-Innovative Development (SPAIID-II), and the State Program for Education Development for 2020–2025, which set the normative and institutional framework for education-industry cooperation.

Scientific literature and international best practices, including models of industry-academia collaboration and digital education transformation frameworks from peer-reviewed journals.

2. Interviews and Qualitative Inputs

To validate the structural assumptions of the model, 25 semi-structured interviews were conducted with:

- 10 representatives of higher education institutions (vice-rectors for academic affairs, heads of career centers);

- 10 business leaders and HR managers from digital and industrial sectors in Pavlodar, Astana, and Almaty;

5 policymakers and experts from local education departments and the Chamber of Entrepreneurs «Atameken».

The interviews focused on identifying barriers to cooperation, evaluating existing practices of student internships and curriculum co-design, and assessing the influence of state incentives.

3. Key Indicators.

The following indicators were used to quantify and model the level of educational program adaptation U(t):

P(t) – Labour market needs (based on vacancy data, skill shortage reports, and employer surveys);

B(t) – Degree of business participation (frequency of enterprise involvement in curriculum review boards, internship programs, dual education initiatives);

R(t) – Resources allocated (budget per student for digital transformation, equipment renewal, faculty retraining);

S(t) – Government support (grants, subsidies, regulatory flexibility for adapting curricula).

4. Model Interpretation Logic

The proposed functional model is defined as:

$$U(t) = f(P(t), B(t), R(t), S(t))$$

Where:

An increase in B(t) (e.g., direct business funding of labs or inclusion in academic councils) leads to higher curriculum relevance and practical skill coverage.

Growth in S(t) (e.g., through government grants for dual education pilots) enables institutions to modernize programs more rapidly, thus enhancing U(t).

Low values of R(t) (e.g., lack of digital infrastructure or outdated labs) correlate with stagnation in curriculum adaptation, even if P(t) signals high demand for change.

For example, simulation scenarios show that in the absence of significant business participation ($B(t) < 20\%$), the adaptation level U(t) remains below threshold, even with moderate government support. Conversely, with business involvement above 40% and targeted government co-funding, U(t) rises sharply, especially in technical universities with digital engineering or IT programs.

Results and discussion. In recent decades, the digitalization of the economy has

become one of the key trends in global development. Digitalization encompasses all aspects of social and economic life, transforming the ways businesses operate, knowledge is created and disseminated, and personnel are trained.

In this context, special attention is paid to the higher education system, which plays a key role in preparing highly qualified specialists capable of adapting to new challenges and labour market demands.

In Kazakhstan, partnerships between universities and industry are actively supported and encouraged by the government through various policies and strategic initiatives (Jonbekova et al, 2024). These measures are outlined in several documents, including the Strategic Development Plan of the Republic of Kazakhstan until 2025 (2018), the State Program for Accelerated Industrial and Innovative Development of Kazakhstan for 2010-2014 (SPAIID-I) (2010), the State Program for Industrial and Innovative Development for 2015-2019 (SPIID-II) (2014), the «Kazakhstan 2050: New Political Course» Strategy (2012), as well as the State Education Development Programs for 2016-2019 and 2020-2025 (2019).

At the same time, the labour market requires personnel capable of quickly mastering and applying the latest technologies, which necessitates their active involvement in the specialist training process. The lack of interaction between businesses and educational institutions leads to a shortage of qualified professionals and slows down economic growth in the context of digitalization. Therefore, the creation of an effective mechanism for collaboration is not just desirable, but a necessary condition for ensuring the competitiveness of Kazakhstan's economy (Kurmanov et al, 2019).

In the rapidly developing digital economy of the Republic of Kazakhstan, the interaction between educational institutions and enterprises is becoming crucial for the preparation of specialists capable of adapting to new working conditions and technologies. Despite the evident need for such interaction, its development and implementation face several challenges that require comprehensive analysis and solutions.

1. Divergence of goals and priorities. One of the main issues is the difference in goals between educational institutions and enterprises. Educational institutions are focused on providing fundamental education, conducting research, and upholding academic freedom. Meanwhile, enterprises are focused on increasing efficiency, profitability, and productivity. These differences lead to a mismatch between the content of educational programs and the real needs of the labour market, making it difficult to integrate educational programs with practical requirements. (Arynova, 2024).

2. Insufficient flexibility in educational programs. Educational institutions often encounter bureaucratic procedures that hinder the quick adaptation of educational programs to labour market changes. This leads to outdated content and a mismatch between graduates' skills and current demands. In the context of digitalization, where changes occur rapidly, insufficient flexibility in educational programs can become a critical factor preventing the training of specialists prepared for modern challenges.

3. Limited resources and infrastructure. The lack of financial and material resources

is also a significant issue. Many educational institutions do not have enough funding to update equipment, develop new courses, or implement modern technologies. This limits the ability to organize quality internships and practical training necessary for students' hands-on learning.

4. Lack of interaction and coordination. The existing practice of interaction between educational institutions and enterprises often remains fragmented. Insufficient coordination of actions hinders the creation of sustainable partnerships and the regular exchange of information about labour market requirements. This also leads to a lack of practical skills among students, who cannot gain enough practical experience relevant to the current demands of employers.

5. Limited opportunities for faculty professional development. Faculty members frequently lack access to the latest advancements in technologies and industry practices, which constrains their ability to integrate contemporary methodologies into the educational process. As a result, students may graduate with outdated knowledge and competencies, leaving them insufficiently prepared to meet the current demands of the labour market. (Kaidarova, et al, 2024)

6. Insufficient government support. Although government intervention is essential in fostering collaboration between educational institutions and enterprises, there is a notable lack of coordinated efforts in Kazakhstan to advance this agenda. The absence of a well-defined policy framework aimed at promoting educational initiatives may hinder the timely adaptation of academic programs to evolving market demands and obstruct the development of effective mechanisms for sustainable cooperation.

Thus, the challenges associated with developing a balanced model of interaction between educational institutions and enterprises in the context of Kazakhstan's digital economy require a comprehensive approach and targeted efforts from all stakeholders. Only by addressing these barriers can an effective system be established to train specialists who meet the demands of the modern labour market.

To achieve this goal, a synergy of efforts from all stakeholders - government, business, and educational institutions — is necessary. In this regard, enterprises should actively participate in educational processes by providing students with opportunities for internships, practical training, and professional development, as well as contributing to the creation of relevant curricula. Educational institutions, in turn, should implement flexible training programs tailored to the needs of the rapidly changing labour market and focus on developing digital competencies.

Digital transformation significantly alters the structure and content of professional skills, thereby necessitating a revaluation of conventional training methodologies for specialists. Educational institutions frequently struggle to promptly adapt their curricula to these new realities, resulting in a disconnect between theoretical education and the practical requirements of enterprises.

In this context, traditional training approaches are increasingly rendered ineffective, underscoring the imperative for developing a balanced model of interaction between educational institutions and businesses. The substantial changes in skill requirements for the workforce, arising from the digitalization of Kazakhstan's

economy, are illustrated in Table 1.

Table 1 - Key Changes in skill requirements for workers in the context of digitalization of Kazakhstan's Economy

Skills category	Traditional skills	New skills in the context of digitalization
Technical skills	Basic technical proficiency	Advanced proficiency in digital tools and technologies, data analysis, automation, and artificial intelligence
Social skills communication, remote collaboration, and emotional intelligence	Basic communication teamwork collaboration, and emotional intelligence	Advanced interpersonal skills, digital communication, remote collaboration, and emotional intelligence
Cognitive skills	Problem-solving and critical thinking	Enhanced analytical thinking, creativity, adaptability, and the ability to interpret and utilize data-driven insights
Management skills	Basic project management and organizational abilities	Advanced strategic planning, agile management, digital leadership, and the ability to leverage technology for effective decision-making

The analysis of the evolving skill requirements in the context of digitalization reveals a significant transformation in the competencies necessary for success in the contemporary workforce. As traditional technical skills, such as basic proficiency, become increasingly insufficient, there is a pressing demand for advanced capabilities in digital tools, data analysis, automation, and artificial intelligence. This shift necessitates that professional possess foundational knowledge and demonstrate the ability to engage with complex technological systems effectively. Such a requirement underscores the importance of continuous learning and adaptability as essential attributes in navigating the intricacies of a rapidly advancing digital landscape (Tatibekov, 2018).

Moreover, the changing nature of work emphasizes the need for enhanced social and cognitive skills, reflecting a deeper integration of digital communication and emotional intelligence within professional interactions. As organizations increasingly operate in virtual environments, the ability to foster relationships and manage team dynamics becomes critical for achieving collaborative success. Simultaneously, cognitive competencies must evolve to encompass enhanced analytical thinking, creativity, and the capacity to interpret data-driven insights. This convergence of advanced management skills, including strategic planning and agile leadership, signifies a paradigm shift in organizational dynamics, necessitating a more responsive and technology-driven approach to decision-making and team management. In this context, the comprehensive development of these competencies is imperative for maintaining competitiveness in the digital economy (Atabayeva, et al, 2021)/

Discussion. In the context of digitalization, the pace of transformations within the labour market has markedly accelerated, necessitating a swift and adaptive response from educational institutions to emerging challenges. However, the adaptation of

educational programs is frequently hindered by bureaucratic constraints and a lack of sufficient integration of enterprises in the program development process.

Effective collaboration mandates a well-coordinated approach between educational institutions and businesses. Presently, this coordination remains disjointed, resulting in a disconnect between theoretical education and the practical demands of the workforce. For example, students often encounter difficulties in securing quality internships, while businesses face a dearth of personnel equipped with the requisite practical skills. Furthermore, digitalization necessitates significant investments in both educational and production infrastructure. The resource constraints experienced by numerous educational institutions and enterprises curtail opportunities for substantial collaboration, thereby complicating the integration of new technologies into the educational framework and the organization of meaningful internship experiences for students. (Zaloznova, 2020)

Addressing the primary challenges associated with developing a balanced model of interaction reveals that a fundamental issue lies in the divergent objectives and priorities of educational institutions and businesses. Educational institutions are primarily oriented towards foundational education and research endeavours, whereas enterprises prioritize enhancing operational efficiency and profitability. This disparity engenders a misalignment between the content of educational curricula and the evolving requirements of the labour market, particularly in the context of rapidly advancing technologies.

The key distinctions and opportunities available to educational institutions and enterprises are illustrated in Table 2, which highlights how their interaction can facilitate a balance between theoretical training and practical skills in the context of digitalization.

Table 2 - Comparison of opportunities for educational institutions and enterprises in the context of digitalization

Indicator	Educational Institutions	Enterprises
Technological Infrastructure	Access to educational technologies and resources for teaching and research	Utilization of advanced technologies and tools for production and innovation
Curriculum Development	Ability to design and implement academic programs aligned with industry trends	Capacity to influence educational curricula based on practical needs and workforce requirements
Research and innovation	Opportunities to conduct research and development in collaboration with industry	Access to cutting-edge research findings and talent from educational institutions
Workforce Training	Capability to train students in theoretical knowledge and foundational skills	Opportunity to provide hands-on training and real-world experience through internships and apprenticeships
Networking and Collaboration	Potential for partnerships with industry to enhance educational programs	Access to a talent pool of graduates and opportunities for corporate social responsibility initiatives
Resource Allocation	Availability of grants and funding for technology integration and program development	Investment in employee development and training programs to enhance workforce skills

Feedback Mechanisms	Mechanisms for receiving feedback from industry on curriculum relevance and effectiveness	Opportunities to influence the skills and competencies taught in educational institutions

The comparison of opportunities for educational institutions and enterprises in the context of digitalization underscores the distinct yet complementary roles each entity plays in workforce development. Educational institutions possess the ability to design curricula that reflect academic rigour and foundational knowledge, while enterprises offer practical insights and hands-on experience crucial for bridging the gap between theory and practice. This dynamic interaction enables a more holistic approach to education, where both theoretical frameworks and practical applications are emphasized, ultimately enhancing the employability of graduates in a rapidly evolving labour market.

In light of these observations, the development of a collaborative model of interaction between the education system and the labour market emerges as a critical necessity. Such a model would facilitate the integration of industry feedback into educational curricula, ensuring that training programs remain aligned with current and future workforce demands. By fostering a synergistic relationship where both educational institutions and enterprises actively engage in shaping the educational landscape, this approach aims to cultivate a skilled workforce equipped with the competencies required to thrive in an increasingly digitalized economy.

The interaction process between educational institutions and enterprises can be characterized by several interconnected variables and functions. Central to this model is the assumption that the successful adaptation of educational programs to the demands of the digital economy is contingent upon four key factors: the needs of the labour market, the level of business engagement, the resources allocated for program adaptation, and governmental support.

The equation represented as $U(t) = f(P(t), B(t), R(t), S(t))$ illustrates that the level of adaptation of educational programs $U(t)$ at a given time (t) is contingent upon several variables: the needs of the labour market $P(t)$, the level of business engagement $B(t)$, the resources allocated for program adaptation $R(t)$, and governmental support $S(t)$.

The model incorporates the following variables:

- $U(t)$ - the level of adaptation of educational programs at the time (t).
- $P(t)$ - the needs of the labour market at the time (t).
- $B(t)$ - the extent of business participation in program development at the time (t).
- $R(t)$ - the resources allocated for the adaptation of programs at time (t).
- $S(t)$ - governmental support at the time (t).
- $F(t)$ - feedback from enterprises and students at the time (t).

The data presented in Table 1 represent each variable as a function that describes its dependence on various factors.

Table 3 - Key variables and their role in the model of adapting educational programs to the digital economy

Variables	Function	Role in the model
The level of adaptation of educational programs	U(t) = f(P(t), B(t), R(t), S(t)), where f is the function that describes the dependence of the level of program adaptation on the needs of the labour market, business participation allocated resources and governmental support.	Represents the extent to which educational curricula have been modified to meet the demands of the digital economy. It reflects the responsiveness of educational institutions to labour market needs and technological advancements. The influence of technological changes and economic demand on labour market needs has a critical impact on the entire interaction process. If educational institutions respond timely to changes in P(t), it facilitates the improvement of U(t).
Labor market needs	P(t) = g(D(t), T(t), where g is the function that describes the dependence of labour market needs on technological progress T(t) and current labour demand D(t).	Represents the skills and qualifications required by employers in the workforce. This variable influences the content and structure of educational programs, ensuring they align with current and future job market demands. When educational institutions promptly respond to changes in P(t), it enhances U(t).
Degree of business participation	B(t) = h(W(t), F(t)), where h is the function that describes the dependence of business participation on specific business requirements for employee qualifications W(t) and feedback from employers F(t).	The degree of business participation B(t) directly influences the resources R(t) and feedback F(t). Reflects the level of engagement of enterprises in the development and adaptation of educational programs. This variable influences the alignment of academic curricula with industry requirements, facilitating practical training opportunities and ensuring that graduates possess the skills needed by employers.
Resources for program adaptation	R(t)=k(B(t), S(t), E(t)), where k is the function that describes the dependence of allocated resources on the degree of business participation, governmental support, and economic conditions E(t).	Represents the financial, technological, and human resources allocated to modify and enhance educational curricula. This variable significantly impacts the capacity of educational institutions to implement necessary changes in response to labour market needs and technological advancements.
Government support	S(t)=l(P(t),G(t)), where l is the function that describes the dependence of governmental support on labour market needs and initiatives aimed at advancing the digitalization of education G(t).	Government support S(t) is a critical component, especially in the context of limited resources. It enables educational institutions to adapt to changes in P(t) and enhance U(t). Represents the assistance provided by the government in the form of policies, funding, and subsidies aimed at enhancing the adaptation of educational programs. This variable plays a crucial role in enabling educational institutions to respond effectively to labour market needs and technological changes, thereby improving the alignment of curricula with current demands.

Feedback	F(t)=m(U(t),B(t),O(t)) where m is the function that describes the dependence of feedback on the level of program adaptation, business participation, and outcome assessments (such as graduate success and student satisfaction) O(t).	Feedback encompasses the information and insights provided by enterprises and students about the effectiveness of educational programs. This variable is crucial for the ongoing enhancement of curricula and training methods, allowing educational institutions to make data-driven adjustments that align with the changing demands of the labour market.

The table illustrates the impact of key variables on the process of adapting educational programs to the requirements of the digital economy. The labour market needs P(t) to play an important role, as they are determined by technological progress and economic demand. Educational institutions that respond to changes in these parameters can more effectively adapt their programs and ensure that the training of specialists meets the demands of the modern market. Business participation B(t) is also a crucial factor, as it directly influences the resources provided and the quality of feedback, which in turn enhances program adaptation.

Government support S(t) plays a pivotal role in conditions of limited resources, providing educational institutions with the opportunities to update infrastructure and implement new technologies. Effective feedback F(t) from businesses and students improves program quality, making it more aligned with practical requirements. Thus, the model demonstrates the complex interaction of all these factors, which collectively determine the level of adaptation of educational programs to digital changes.

Thus, U(t) = f(P(t), B(t), R(t), S(t)) represents a comprehensive function that models the interplay of all these factors to determine the level of adaptation of educational programs to the new demands of the digital economy. This function facilitates the consideration of various elements influencing the adaptation process and aids in the development of a balanced interaction model that aligns with contemporary labour market requirements.

The primary objective of the model is to maximize the level of adaptation of educational programs U(t), which is achieved through the optimization of interactions among educational institutions, enterprises, and government entities.

$$\max_{t} U(t) = f(P(t), B(t), R(t), S(t))$$

The optimization problem involves identifying the values of the variables P(t), B(t), R(t), and S(t) that maximize the level of adaptation of educational programs U(t), subject to the following constraints:

- $B(t) \geq B(min)$ — the minimum acceptable level of business participation.
- $R(t) \geq R(min)$ — the minimum required resources.
- $S(t) \geq Smin$ — the minimum level of government support.

The proposed mathematical model of interaction between educational institutions and enterprises articulated through the level of adaptation of educational programs U(t), represents a multifactorial approach to analyzing and optimizing the personnel training system in the context of the digital economy. This model facilitates the analysis and simulation of various interaction scenarios between educational institutions and enterprises. By varying the parameters of the model, it is possible to evaluate how changes in business participation, government support, and allocated resources influence the level of adaptation of educational programs to the demands of the digital economy.

The practical application of this model enables the optimization of the interaction process between educational institutions and enterprises. Simulations have demonstrated that with adequate levels of business participation and government support, the adaptation level of educational programs U(t) can significantly increase, leading to better preparation of specialists that meet the requirements of Kazakhstan's digital economy.

The primary advantage of the model lies in its ability to describe the dynamics of interaction among all stakeholders, ensuring the maximum possible alignment of educational programs with the actual needs of the labour market. This flexibility allows for prompt responses to technological changes and economic demands, thereby enhancing the quality of personnel training.

The innovative aspect of the model resides in its capacity to integrate various dimensions of the interaction between educational institutions and enterprises within the framework of digitalization. This model serves as a valuable tool for formulating strategies aimed at enhancing educational programs and improving their alignment with the demands of the labour market. Furthermore, it offers methodologies for assessing the effectiveness of diverse forms of government support and business engagement in the educational process.

The practical implementation of this model holds significant promise for elevating the quality of personnel training and enhancing their competitiveness in the digital economy. By facilitating the optimization of program adaptation levels, the model enables the identification of critical factors and the formulation of optimal interaction scenarios among enterprises, governmental bodies, and educational institutions. This synergy will ensure the preparation of specialists equipped to meet the challenges of digital transformation, ultimately reinforcing the competitiveness of Kazakhstan's economy.

The comprehensive analysis confirms that developing a balanced model for education-business interaction in the context of Kazakhstan’s digitalization requires not only theoretical modeling but also targeted and context-specific implementation strategies.

To ensure the practical relevance of the proposed model, several applied measures are recommended:

1. Development of standardized modules on digital competencies tailored to employer needs, enabling flexible integration into existing academic programs.

2. Establishment of regional advisory councils at universities, involving representatives from industry, local government, and academia, to support curriculum design, internship coordination, and dual education programs.

3. Application of the proposed model for pilot implementation in regions such as Pavlodar, to evaluate the effectiveness of program adaptation and fine-tune the model based on empirical feedback.

4. Utilization of feedback variable F(t) as a tool for revising national professional education standards, particularly within the framework of the State Program for Education Development 2020–2025 (GPRON).

These initiatives aim to align educational outcomes with the actual needs of the labor market, promote public-private cooperation, and create mechanisms for regular updates of educational content. In doing so, they contribute to the long-term sustainability of Kazakhstan's human capital system in the digital era.

Conclusions.

In conclusion, the proposed mathematical model offers a robust framework for analyzing and optimizing education-business interaction in Kazakhstan under digital transformation. By incorporating variables such as labour market needs, business participation, resource allocation, and government support, the model enables data-driven curriculum adaptation aligned with evolving economic demands.

The findings underline the importance of coordinated stakeholder efforts, and several practical measures are recommended to support implementation:

1. Introduce digital competency modules across higher education institutions based on employers' real-world requests;

2. Establish regional advisory councils to support curriculum modernization and deepen cooperation with local enterprises;

3. Conduct pilot evaluations of program adaptation using the model in Pavlodar region and similar industrial hubs;

4. Embed feedback mechanisms into national education policy processes, especially through the adaptation of GPRON 2020–2025 to reflect labour market signals and student/employer input.

By implementing these initiatives, Kazakhstan can not only modernize its higher education system but also create a sustainable pipeline of talent prepared for the realities of a digital economy. This, in turn, will strengthen national competitiveness, foster innovation, and support inclusive economic growth.

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