https://doi.org/10.33271/nvngu/2024-6/119

V. D. Zalizko[*1,2],
orcid.org/0000-0001-5362-8270,
A. M. Cherniak[1],
orcid.org/0000-0002-4958-783X,
D. W. Nowak[3],
orcid.org/0000-0001-7448-6101,
V. Y. Artemov[1],
orcid.org/0000-0002-5290-4496

1 – National Academy of Security Service of Ukraine, Kyiv, Ukraine
2 – Zurich University of Teacher Education, Zurich, Switzerland
3 – Poznan University of Economics and Business, Poznan, the Republic of Poland
* Corresponding author e-mail: zwd@ukr.net

ASSESSING UKRAINIAN EDUCATION SECURITY IN THE CONTEXT OF ARTIFICIAL INTELLIGENCE INTEGRATION FOR ACCELERATED POST-WAR RECOVERY

Purpose. Integral assessment of the security situation in the Ukrainian education system under the intensive implementation of Artificial Intelligence (AI) technologies and identification of promising scenarios for the post-war reconstruction of Ukraine, using the example of rural education.

Methodology. The scientific research was based on general scientific methods, supplemented by a comprehensive econometric analysis of the main indicators of educational security in Ukraine. Optimisation and integral evaluation methods were also used, which do not require the involvement of experts from various fields of educational activity. The key tool in the integrated multi-factor evaluation method is the module of intelligent economic-mathematical modeling and forecasting of optimistic, realistic, and pessimistic scenarios for the implementation of digital initiatives for the post-war recovery of the educational system of Ukraine, which is implemented through the method of principles, the "t-criterion" in the calculation of scalar thresholds based on IBM SPSS Modeler, AI-Prophet, Cloud Pak for Data, and R-Studio AI.

Findings. The work highlights the key factors influencing the level of security of the Ukrainian rural education system and defines the corresponding integrated index of educational security, which in further research can play a key role in strengthening the economic security of the national economy in the era of post-war reconstruction of the country and the formation of a new digital economy in Ukraine. Based on the obtained integrated assessment of the security of the educational system, the authors have identified probable trajectories for the transformation of educational processes in the context of the use of AI technologies. Key scenarios for the improvement of tactical and strategic management tools in the education sector are proposed in order to accelerate the processes of high-quality digital transformation aimed at the post-war recovery of Ukraine.

Originality. Based on the developed innovative digital platform "Central European Network for Sustainable and Innovative Economy", an open source program IIS-GPT 3 was created, which, unlike the existing analogues, integrates new algorithms for the use of AI technology for forecasting key security indicators based on SPSS and AI-Prophet. This made it possible to carry out an independent integral assessment, modelling and forecasting of the transformation of the processes of strengthening the educational security of Ukraine in the context of post-war reconstruction.

Practical value. The conducted research proves the relevance of the modern national educational policy of digitization and indicates the potential benefits, challenges, and risks, particularly regarding the implementation of a digital environment with AI elements "Dream", which can become a game changer in Ukrainian education. The research materials form a scientific basis for further systematic analysis of the key post-war imperatives of educational security in Ukraine.

Keywords: *educational security of Ukraine, artificial intelligence (AI), digital transformation, digitalization, post-war reconstruction*

Introduction. The pandemic in 2019–2020 and the military actions in 2022–2024 have intensified the use of online technologies in all sectors of the national economy. Domestic education was particularly transformed, as a large part of the rural territory of Ukraine became unsuitable for full-time education due to the lack of quality bomb shelters and other security infrastructure in educational institutions. Millions of students were forced to leave their local schools and opt for distance learning. This contributed to the asymmetric digitization of educational processes in cities and villages bordering the temporarily occupied territories (Kherson, Odesa, Donetsk, Kherson, Luhansk oblasts and the Autonomous Republic of Crimea). It was during this period that developers of distance learning technologies (Table 1) using artificial intelligence (AI) became active.

Table 1 shows only 10 % of the most popular programs, and new educational technologies based on AI are being created every day. Thus, a dangerous saturation of information and educational technologies, almost all of which are based on AI technology, has developed in the field of education. In this situation, students have adapted much faster than teachers and have begun to use AI, particularly for the purpose of cheating [1]. In the first months of active AI use by students, we observed serious challenges to the security of education, as pla-

Table 1

Systematisation of key AI-based educational technologies used in schools

No.	Name	Characteristic
1	Cognii	Facilitation of feedback between parents, teachers and students through chatbots. Assessment of student writing
2	IBM Watson Education	Personalization of the study plan for each student and monitoring of the progress/regression of the student in studies. The possibility of forming individual recommendations regarding the development of a child's educational competencies
3	Century Tech	
4	eSpark Learning	
5	Khan Academy	Translation of ready-made lessons into different languages, selection of video material and tasks. Systematization of video lessons on a certain topic, formula or theorem
6	TeacherTube	
7	QuizGPT, Kahoot *AI*	Assessment through game-based testing. Forming questions and checking answers
8	Quizlet	
9	Wordwall	
10	Learning	
11	Education Copilot	Programs that help create presentations, interactive personalized workshops and multimedia content. Creating an environment of mutual relations between students and teachers. They understand many languages (in particular, German and Ukrainian) and perform verbal tasks quite clearly
12	Gemini, Fetchy	
13	Assistments Socratic Consensuns, MATHia	A specialized mathematical program for optimizing the process of personalized learning of problem solving
14	Wolfram, HIX Tutor Mathful	Highly specialized mathematical programs (Math Solver, SymbMath, GeoGebra)
15	ClipDrop	Image editing, creating presentations
16	Wepic	
17	Tome	
18	Gamma App	

giarism and the substitution of real student work with virtual AI results were recorded at the national level. This caused the first wave of dissatisfaction with AI, which can be formulated in the form of the following hypothesis H1: "AI poses a threat to the security of education, and the use of these technologies should be limited in all educational institutions". In this article, we will try to refute this thesis by proving the opposite.

Literature review. In general, not enough studies have been conducted that directly relate to the assessment of the security of education in Ukraine in the context of the use of AI, so the number of publications is correspondingly limited. The available scientific publications can be divided into two groups: 1) AI studies that point to the positive aspects of the use of AI; 2) scientific publications that provide a comprehensive assessment of the convergent relationships between national security and AI.

The first group includes the vast majority of foreign studies, among which, for example, a comprehensive study [2] analysed more than 100 scientific works on the subject and noted the growing interest in AI in the world. The authors in [3 and 4] found a high level of safety and reliability in modelling, designing and implementing intensive AI systems in the educational process. A significant number of studies, in particular for tick-tock education with AI in [5], indicate the local advantages of creating educational content based on artificial intelligence and vividly describe the possibilities of extending the learning trajectory to increase motivation, personalisation and creativity of the educational process [6].

In the second group, in a global sense, issues of quantitative determination of the role of educational security in Ukraine in the context of ensuring national interests and digitalisation of key learning processes are studied. In particular, domestic scientists have scientifically established "the existence of dynamic convergent relations between national security, digitalisation, education and national security" [7]. The purpose of many studies was to establish the existence and nature of the relationship between the education of the population and the level of national security of the country and its components [8] and [9]. Scientists mathematically evaluated the correlations between the digitalisation of educational processes and the integral index of strengthening of national security of Ukraine and showed how "moral and political ideals, social values, the level of general culture, professional training, as well as the initial skills of social activity, the foundations of political culture are instilled" [9, 10]. Among foreign publications, there is no tendency to study the issue of safety in education as a whole. Most of them are limited to the study of individual problems and risks [11].

The conducted review was not intended to cover all publications on the selected research topic, but it provides valuable information about the current state of the problem of assessing the security situation in the Ukrainian educational system under the intensive implementation of artificial intelligence (AI) technologies. Additionally, the analysis conducted [12, 13] shows that domestic studies [14] still address the outlined problems in a rather limited way, and several issues related to the assessment of the security situation in the Ukrainian education system during wartime, as well as the possibilities for implementing AI for the post-war restoration of education in Ukraine and the accelerated change of technological systems, have not been disclosed.

After the launch of AI chats, some scientists and prominent business figures issued open letters warning about the dangers of AI and calling for a halt to research in this area, but they did not provide any scientific evidence or mathematical assessments. In fact, AI technologies have nothing to do with human intelligence, as AI represents a new stage in the logical development of machine learning and neural networks, which has accelerated due to the transition of computers in 2020 to the performance limit of exaFLOPS (10^{18}). Most operations that used to take months to compute are now performed in seconds because the performance has increased by a billion times. Therefore, AI is the new black swan, and revolutionary changes in business, government, manufacturing, and education are inevitable. To clarify a unified categorical framework, we present a systematization of AI definitions (Table 2).

As we can see from Table 2 and other publications [2, 15, 16], the essence of the AI working process is not revealed, so we will briefly describe the AI working process. When we formulate a question for AI and get an answer, it is not a thought process, but a search for correlation coefficients between existing words, which measures the overall spatial autocorrelation of the dataset. AI compares how similar one item is to another and finds the maximum probability of occurrence for a sequence of new words. AI builds responses based on linguistic constructs using Bayes' rule, prior probability and Viterbi rule. Therefore, in order to effectively use AI in the formation of personalised creative scenarios in AI learning, we need to use the correct contextual words and create the most probable sequence of tags given by the correct sequence of words selected according to a certain criterion. Basically, we integrate the Markov model, the method of objective evaluation of the weighting by the entropy weight, as well as the generalised Moran index *I*

Table 2

Systematization of AI definitions

Characteristic	Source
A branch of computer science that focuses on the development of intelligent machines capable of performing tasks that require human intelligence. A branch of computer science that focuses on the development of intelligent machines capable of performing tasks that require human intelligence	Chat Bing
This is the branch of science that deals with the creation of programs and systems capable of performing tasks that normally require human intelligence. Such systems are designed to perform tasks that require information analysis, reasoning, pattern recognition, language understanding, planning, decision making, and even interaction with the environment	Chat GPT
It is a branch of computational linguistics and computer science that focuses on the development of intelligent machines capable of performing tasks that normally require human intelligence	Chat Clear
These are cyber-physical systems, intelligent autonomous robots, characterised by: 1) the ability to be autonomous and exchange data; 2) the ability to learn from experience; 3) the availability of minimal financial support; 4) the ability to adapt to the external environment; 5) the absence of life	European Parliament "Civil Law Norms on Robotics" dated February 17, 2017

$$I = \frac{n}{s_0} \cdot \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_i z_i z_j}{\sum_{i=1}^{n} z_i^2} \frac{1}{\sum_{i=1}^{n} z_i^2};$$

$$z_i = x_i - x_s; \quad S_0 = \sum_{j=1}^{n} w_{i,j},$$

where n is the total number of objects; $w_{i,j}$ – the spatial weight (entropy) between objects; x_s – the mean (more on modelling basics and probability distributions [16, 17]).

As the research continues, we propose to rely on the fact that AI is not an analogue of human mental processes, so first the arbitrary text is broken down into smaller units called tokens – these are words, prefixes, suffixes and punctuation marks. After the tokenisation process, each token is assigned a unique vector based on one-hot encoding technology, in which all coordinates except one are zero (an example of the tokenisation of a question for AI is given in Table 3). It is important to evaluate the possible ways of using AI to accelerate the recovery of the education system of Ukraine, which has suffered significant destruction (Table 3).

After the question tokenization procedure (Table 3), the computer uses different probabilistic models to search for similar codes, ensuring that the word "theorem" is understandable to the AI in all languages, as this word has a unique code [0; 1; 0]. The models mentioned above (Markov and Moran) are not the only ones; other skip-gram models adapted to attention mechanisms are often used. In this article, we will focus on issues exclusively related to assessing the level of educational security in Ukraine and outline the pathways for post-war recovery based on the consistent use of AI technologies, employing one-hot encoding and Markov and Moran models.

Results. To achieve this goal, the structure of this article is divided into three modules: 1) consideration of the theoretical and methodological bases upon which the assessment will be conducted; 2) mathematical assessment of the integral level of

Table 3

Scheme of text tokenization by AI technologies

Sentence	Tokens		
	1	2	3
Prove Fermat's theorem (Cyrillic has a different scheme)	Prove	theorem	Fermat's
Code of One-hot encoding	001	010	100
Number of characters	6	7	5
Number of spaces	2		
Syntactic signs	0		

educational security in Ukraine; 3) outlining probable scenarios for the post-war recovery of the educational sector using AI technologies in the context of determining the homeostatic plateau, where a relatively new component of Ukraine's economic security – educational security – is formed by combining the main features of primary, secondary, and higher education. In this article, we will consider only the first two levels and will conduct a separate study for higher education, as well as for urban areas. In this context, it is proposed to introduce an integral index of educational security, using rural areas as an example, which should be determined by the following decomposition, as shown in Fig. 1.

Educational security as an indicator of the economic security of Ukraine has been used relatively recently (since 2013 [18]), but in [19], it is limited to two indicators of educational security. In modern conditions, educational security occupies an important place in the structure of ensuring the economic security of Ukraine. It is through this component of economic security that its interrelation with the socio-economic development of the districts is most clearly manifested. Due to the absence of the Law "On Educational Security of Ukraine" in MP-13 [18], the determination of the level of educational security in Ukraine is limited to monitoring the following I_IES indicators. Here and in the future, the following notations will be used, which will be applied in the context of rural areas:

I_{IES} – educational security;

Z11 – the percentage of children aged 3–5 enrolled in pre-school educational institutions;

Z12 – the percentage of buildings of pre-school educational institutions in need of major repairs;

Z13 – the percentage of school-age children (6–18 years) enrolled in general secondary education;

Z14 – the percentage of population aged 25–60 with tertiary education;

Z15 – average years of education of population aged 25 and over;

Z16 – the share of secondary school buildings that require major repairs;

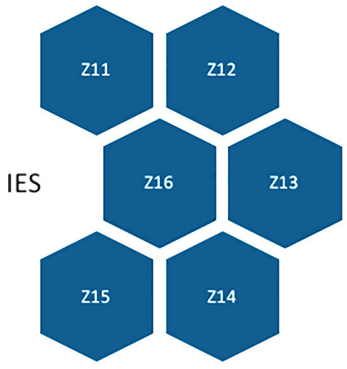

Fig. 1. Decomposition of the key components necessary for the scalar representation of the integral index of educational security I_{IES}

Z17 – index of digitization of the educational process in Ukraine.

Therefore, for the quantitative and qualitative determination of tactical and strategic directions for the sustainable development of the educational sector of Ukraine, it is proposed to use the extreme properties of partial derivatives for continuous functions, due to their absolute value of gradients, which respectively characterize the components Z11–Z17. In our work, we traditionally use the mathematical theory of integral evaluation through reliable approximants [20], which enables the combination of two approaches into one integrated method. The proposed approach effectively applies the theory of entropy to determine the weight of indicators, autocorrelation to establish relationships between territories and indicators, and approximation of statistical data series using spline polynomials (to smooth out "statistical traps").

Considering the objective problem with the availability of statistical data, it is proposed to use the Structured Analysis and Design Technique methodology, with the main criterion for forming an educational assessment borrowed from the method of principal components. We will sequentially perform the following steps of the algorithm for multivariate data analysis using PCA.

First, let us define the value of Z17, as this indicator is relatively new and includes the following components: Z17.1 – availability of a school online library; Z17.2 – provision of STEM laboratories (STEAM); Z17.3 – availability of a website with dedicated classrooms for teachers and students; Z17.4 – share of parents who receive information about their children's educational success from digital sources; Z17.5 – the level of self-assessment of the organization of the electronic educational environment (excluding electronic document management systems for providing financial and administrative reporting); Z17.6 – the level of provision of digital systems for administrative and state statistical reporting ("DISO", ISUO, PAC "AIKOM"); Z17.7 – availability of a sufficient amount of modern computer, office, and other software in educational institutions; Z17.8 – provision of students during distance learning with modern computers, video cameras, microphones, and licensed software; Z17.9 – presence of problems for teachers and students due to poor access to high-speed Internet; Z17.10 – share of teaching staff who have a sufficiently high level of abilities and skills for the effective use of modern ICT and AI; Z17.11 – availability of prepaid specialized educational systems in educational institutions, particularly with AI; Z17.12 – share of educational classes in which AI is used during the academic year.

The next step is the standardization and normalization of statistical data characterizing Z11–Z17 to the continuous segment (0; 1) using the following formula

$$z_i = \begin{cases} \dfrac{x_i - x_{i,\max}}{x_{i,\max} - x_{i,\min}} & \text{if} \quad x_i \gg x_s, \quad i \in N, x_{i,\max} \\ \dfrac{x_i}{x_{i,\max}} & \text{if} \quad x_i > x_s, \quad i \in N, x_{i,\max} \\ \left(\dfrac{x_i}{x_{i,\min}}\right)^{-1} & \text{if} \quad x_i < x_s, \quad i \in N, x_{i,\min} \neq x_i \neq 0 \\ -\dfrac{x_i - x_{i,\max}}{x_{i,\max} - x_{i,\min}} & \text{if} \quad x_i \ll x_s, \quad x_{i,\max} \neq x_{i,\min} \end{cases}, \quad (1)$$

where z_i is normalized statistical values of indicators (indicators) x_i, which characterize the indicators Z1–Z17; $x_{i,\min}$ and $x_{i,\max}$ – respectively, the smallest and largest values.

Formula (1) uses a unique system of discrete division of indicators into stimulators and destimulators. The essence of this system is to compare the indicators with the reference value *x* sub *s*. If all the indicators of each of the indicators Z1–Z17 are significantly better than the reference value $x_i \ll x_s$, then we have a group of "strong stimulants". Accordingly, when $x_i \gg x_s$, we have "strong destimulators", and the group of indicators $x_i < x_s$, "light destimulators". If these values fall into a set of negative numbers, we suggest shifting the coordinate plane of the dynamic statistical series so as to satisfy the inequality $z_i > 0$. As a result of the normalisation, we obtain the values of the indicators in the interval (0; 1), while maintaining the accuracy of the research carried out. An important feature of our evaluation method is the convenience of using a neural network and artificial intelligence to estimate the entropy level of each metric based on strong light.

Based on the data in [21, 22], as well as our own interview results, we obtained the following Table 4.

It is worth commenting on the value of Table 4 because, despite the fact that nearly 75 % of teachers stated they were equipped with devices, after clarifying the information, it was found that the devices (tablets and laptops) were outdated both morally and technically and did not always have licensed software. Considering that almost 100 % of the institutions have their own websites, we noted that only 15 % of them are interactive and have functional corporate accounts. Statistical data (Table 4) was obtained based on the analysis of official reports and a joint study with the International Innovative School (IIS), which covered about 1,500 students and teachers from different regions of Ukraine. Thus, by consistently applying formula (1) to each indicator Z1–Z17, which has different units of measurement and nature of origin (stimulator and destemulator), we obtain the following Table 5, based on the software capabilities of IBM Watson, R-studio and SPSS.

In Table 5, there are two destimulators Z12 and Z16, but to calculate their absolute values formula (1) was used, which takes into account the deterioration of the situation with the number of educational institutions in need of major repairs (the more educational institutions in need of major repairs, the smaller the value of the corresponding index). Given the lack of effective AI technologies in education in the period 2000–2020, we take into account the corresponding index of digitisation of the educational process only from 2021. Considering the state of war and the resulting restrictions, our research did not use data from uncontrolled rural areas, and since it is difficult to obtain accurate statistical data for the years 2021–2024, we used modern approximants (2) and data from the calculations of the predictive model to obtain relevant information with AI (SPSS and AI-Prophet). After the publication of the official statistical data, the results of the study will not lose their relevance and may be clarified in the future.

For the approximation, we will use the first estimates of the form-preserving approximation of periodic functions. Approximants for predicting the dynamic series of the integral index of educational security have a "bell-shaped shape", and therefore we use Whitney's theorem, where an algebraic polynomial L of the second degree is constructed, for which a valid approximation with high accuracy

Table 4

Systematization of indicators of the index of information provision of educational institutions of Ukraine

No.	Z17.1	Z17.2	Z17.3	Z17.4	Z17.5	Z17.6
2020	0.2600	0.1800	0.6805	0.2800	0.1200	0.900
2021	0.2620	0.1850	0.6000	0.2900	0.1250	0.9500
2022	0.2700	0.1890	0.6305	0.3000	0.1500	0.9700
2023	0.1800	0.1600	0.6200	0.4400	0.1900	0.9990
No	Z17.7	Z17.8	Z17.9	Z17.10	Z17.11	Z17.12
2020	0.6300	0.4430	0.6600	0.2500	0.4505	0.0200
2021	0.6345	0.4650	0.6700	0.2600	0.4900	0.0405
2022	0.6400	0.4930	0.7005	0.2900	0.5105	0.1205
2023	0.6350	0.4960	0.4000	0.3300	0.5500	0.1600

Table 5

Matrix of normalised scalars of the integral index of educational safety of Ukraine

Years/ Indicators	Z11	Z12	Z13	Z14	Z15	Z16	Z17*
2000	0.1800	0.3146	0.9904	0.1868	0.7831	0.4188	–
2001	0.2028	0.3243	0.9904	0.3877	0.7947	0.4237	–
2002	0.2251	0.3346	0.9904	0.4665	0.8063	0.4286	–
2003	0.2485	0.3456	0.9904	0.4642	0.8179	0.4336	–
2004	0.2697	0.3573	0.9910	0.4881	0.8252	0.4388	–
2005	0.2780	0.3698	0.9910	0.5060	0.8496	0.4441	–
2006	0.2992	0.3832	0.9910	0.4630	0.8484	0.4495	–
2007	0.3196	0.3977	0.9910	0.4529	0.8566	0.4551	–
2008	0.3308	0.4133	0.9910	0.4604	0.8513	0.4608	–
2009	0.3276	0.4301	0.9910	0.5012	0.8723	0.4666	–
2010	0.3384	0.4484	0.9910	0.5046	0.8791	0.4726	–
2011	0.3488	0.4683	0.9910	0.5279	0.8849	0.4788	–
2012	0.3788	0.4901	0.9910	0.5168	0.8914	0.4851	–
2013	0.4348	0.5140	0.9900	0.5167	0.8994	0.4916	–
2014	0.4401	0.4310	0.9890	0.5203	0.9074	0.4866	–
2015	0.4533	0.4072	0.9880	0.5240	0.9154	0.4685	–
2016	0.4588	0.3858	0.9870	0.5277	0.9234	0.4638	–
2017	0.4609	0.3666	0.9860	0.5313	0.9314	0.4476	–
2018	0.5600	0.3492	0.9860	0.5350	0.9394	0.4431	–
2019	0.5640	0.3333	0.9857	0.5387	0.9474	0.4284	–
2020	0.5645	0.3134	0.9855	0.5423	0.9554	0.4068	–
2021*	0.5600	0.3100	0.9805	0.5425	0.9550	0.4015	0.4021
2022*	0.5540	0.2902	0.9750	0.5437	0.9545	0.4000	0.4101
2023*	0.5050	0.2740	0.9400	0.5410	0.9505	0.3500	0.4342
2024*	0.4950	0.2700	0.9115	0.5420	0.9500	0.3400	0.4404

* *Given the existing statistical limitations, data for 2021–2024 were obtained by approximating previous values using AI-Prophet and SPSS*

$$\|f - L\| < C(Y)W_2(f, p/2), \quad (2)$$

where f is the function that describes the dynamic series of the integral index of educational security from Fig. 2; L – an algebraic polynomial approximant that approximates the function f with high accuracy equal to the product of the second modulus of continuity $W_2(f, p/2)$ and constants $C(Y)$ (for details on the classical inequality of this type, see the article [20]). By automating the modelling and short-term forecasting process using AI-Prophet technology, we obtained the necessary data for 2021–2024.

The next step is to carry out the weighting and spatial differentiation of the economic security of the education sector of Ukraine. Since the feasibility of spatial estimation using the matrix method was established in previous studies (in particular, in [14 and 20]), we find the vector-matrix of variances D_i and the matrix of absolute values of factor loadings A_{ij} (using axis rotation and quartimax normalization, which establishes

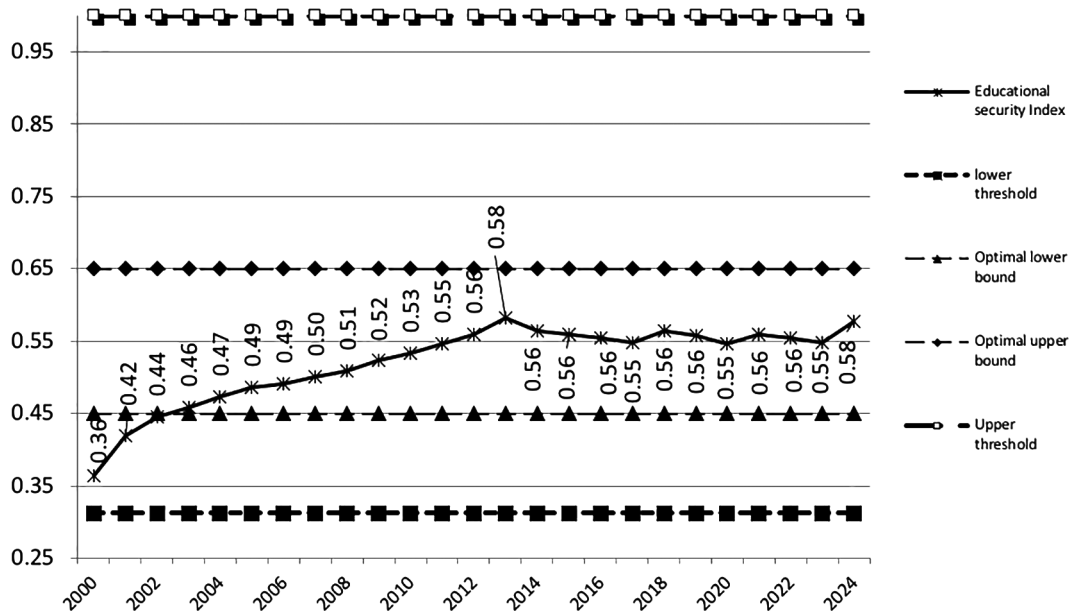

Fig. 2. A dynamic series of integral values of the educational security index of Ukraine from 2000 to 2024

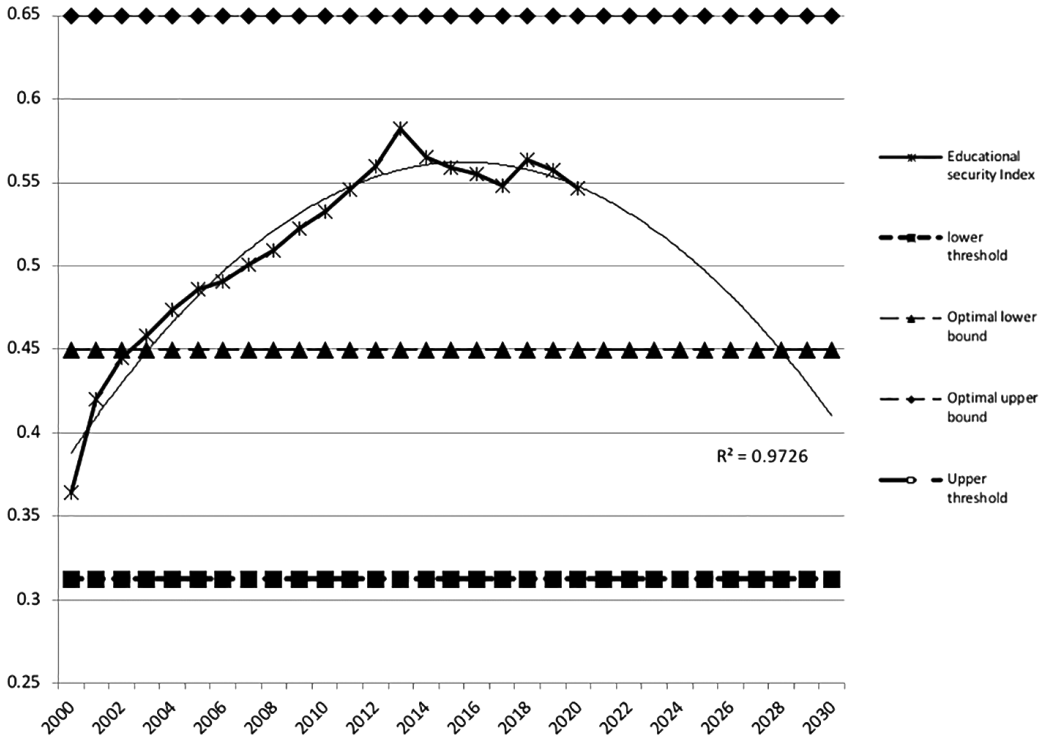

Fig. 3. A realistic forecast of the likely dynamics of the integral index of educational security of Ukraine from 2000 to 2030

simpler correlations between relevant variables and factors) separately for each of the 6 groups of indicators shown in Fig. 3.

Let us define matrices A_{ij} and D_i, using the following formulas

$$A_{ij} = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1j} \\ a_{21} & a_{21} & \dots & a_{2j} \\ \dots & \dots & \dots & \dots \\ a_{i1} & a_{i2} & \dots & a_{ij} \end{pmatrix};$$

$$D_i = \begin{pmatrix} d_1 \\ d_2 \\ \dots \\ d_j \end{pmatrix};$$

$$i = 1, 2, ..., 6; \quad j = 2, 3, ..., 21,$$

where a_{ij} are absolute values of matrix elements after axis rotation and quartimax normalization; d_j – the value of variances. At this stage and in the future, we will use the automatic determination of the absolute values of the elements of each matrix, using the *R* programme Mod(A_{ij}) – matrix(nrow = *i*. data = = *c*(1, 2, ..., *j*)). As a result, we will have the following tabular view of the matrix A_{ij} (Table 6).

Since some elements of the matrix go to zero, we write the variance matrix in the form

Table 6

Matrix of absolute values after axis rotation and quartimax normalization

0.988	0.000	0.041	0.147	0.011	0.001
0.994	0.027	0.057	0.072	0.052	0.016
0.242	0.968	0.066	0.000	0.000	0.000
0.680	0.178	0.711	0.000	0.000	0.000
0.981	0.146	0.066	0.023	0.105	0.001
0.997	0.046	0.027	0.048	0.036	0.018

$$D_i = \begin{pmatrix} 76.523 \\ 15.778 \\ 6.9526 \\ 0.492 \\ 0.2436 \\ 0.009 \end{pmatrix}.$$

Thus, the educational security index can be constructed and viewed slice-by-slice in 2D scatterplots for the available rotations, including only quartimax 90 % and varimax 10 % normalized and skewed rotations. In this case, the normalization of the quartimax is aimed at orthogonal (perpendicular) rotation, maximizing the sum of all values raised to the power of 4, which satisfies the criteria of a simple structure in Thurstone geometry, according to which those with the maximum level of entropy should be selected from the equivalent indicators.

The third step of the proposed algorithm involves multilevel determination of scalar weight values for each indicator. To find the weight of each factor in the corresponding group, let us calculate

$$L = A_i \times D_i = \begin{pmatrix} d_1a_{11} + d_2a_{12} + ... + d_ja_{1j} \\ d_1a_{21} + d_2a_{22} + ... + d_ja_{2j} \\ ..... \\ d_1a_{i1} + d_2a_{i2} + ... + d_ja_{ij} \end{pmatrix} =: \begin{pmatrix} \alpha_1 \\ \alpha_2 \\ ... \\ \alpha_j \end{pmatrix}.$$

We will write the scalar values L based on the capabilities of IBM SPSS Modeler, Cloud Pak for Data, and R-Studio AI software.

$$L = \begin{pmatrix} 75.981 \\ 76.927 \\ 34.277 \\ 59.829 \\ 77.888 \\ 77.211 \end{pmatrix}.$$

Next, we will form a matrix of weights for the indicators of each of the indicators Z11–Z16

$$Y_i^{(1)} := kY_i, \quad k = \left(\sum_j \alpha_j\right)^{-1} = \begin{pmatrix} 0.189 \\ 0.191 \\ 0.085 \\ 0.149 \\ 0.194 \\ 0.192 \end{pmatrix}. \qquad (2)$$

This makes it possible to determine the scalar values of the integral index of educational security $I = I_{IES}$ in multiplicative form

$$I = \prod_{j=1}^{6} z_j^{\alpha_j}, \quad \sum_j \alpha_j = 1, \quad \alpha_j > 0. \qquad (3)$$

The final values of the corresponding dynamic series for the final compilation of statistical data are presented in the form of Table 7 and Fig. 2, which shows the dynamic series of values of the integrally researched index of educational security of Ukraine from 2000 to 2020. Technical calculations were carried out on the basis of official statistical data of the State Statistics Service of Ukraine and the National Academy of Sciences of Ukraine [21] using the software IBM Statistica AI, R-Studio and Microsoft Excel 2021.

In this study, we specifically use the multiplicative form of calculating integral indices, as in previous studies [14] and [20] we identified several disadvantages of the additive form that should be considered when using mathematical and economic decision analysis. In future articles, we will explain in detail the influence of the entropy of each index component value (*NP, NO, VO, VP, D*), first using the multiplicative form (3). Unlike the additive form, this method accounts for the relationships and dependencies between the different index components and better describes situations when threshold values of the index are reached. This form is highly sensitive to negative changes in the sub-indices, which is justified, given that, in war conditions, many socio-economic and educational aspects are interrelated. For example, in certain areas of the occupied Autonomous Republic of Crimea, all components\ (Z_{11}\)–\(Z_{16}\) were at a very high level, but military aggression effectively destroyed the level of educational security in this region, as confirmed by real-world events. A similar situation occurred after the military invasion of southern Ukraine. In all areas, without exception, normal educational activities ceased at the onset of hostilities.

Fig. 2 and Table 4 show not only the integral values of the educational security index but also its main components: *NP* – the lower threshold value, after which the system self-destructs; *NO* – the lower optimal value, beyond which there is sustainable system development; *VO* – the upper optimal value, up to which the system develops sustainably; *VP* – the upper threshold value, beyond which the system experiences accelerated development; *D* – the first-order difference between the actual indicators and the optimal value.

To carry out **the final step,** it was necessary to calculate the integral convolution of all databases, which is done in two stages: first, for individual groups of indicators, and second, at the level of integral indices for those groups. We applied modern mathematical methods in economics (the principal component method to determine weighting factors, the "t-test" to justify thresholds, etc.), and the multiplicative form for calculating the integral index of economic security in rural areas and its main components. Factor analysis of the subjectivity in weighting coefficients for each component of the index was conducted using approved standards or by comparing reference values, which minimizes the negative influence of individual experts on the final index and the interpretation of results. Moreover, the multiplicative form (3) enables the detection of minimal changes in the weighting coefficients of the components, which could lead to significant changes in the integral indicator of educational security over time.

Considering the requirements of martial law across Ukraine, we can provide detailed information on the damage to Ukraine's educational infrastructure. By systematizing data from open sources, we can draw the following preliminary conclusions as of 2024: 1) the enrolment rate of children aged 3–5 in preschool educational institutions has decreased by 5–10 %; 2) the number of preschool and secondary school buildings in need of major repairs has increased by 25 %, with approximately 4,000 educational institutions destroyed; 3) the general secondary education coverage of school-age children (6–18 years) has decreased by 10–15 %; 4) the proportion of individuals with higher education in the population aged 25–60, and the average length of education for those aged 25 and older, has decreased by 5 %. The number of male graduate students has particularly decreased since 2023, when a decree on mandatory military permission was adopted (data from open sources on Telegram, Viber, mass media, and our own survey of students' parents, etc.).

In a previous study [20], a counter-example was constructed, showing that in Jackson-type estimates for co-convex ap-

Table 7

Scalar values of the integral index of educational security of Ukraine (2000–2024)

Years/ Indicators	*I*	*NP*	*NO*	*VO*	*VP*	*D*	Years/ Indicators	*I*	*NP*	*NO*	*VO*	*VP*	*D*
2000	0.364	0.312	0.450	0.650	1.000	–0.636	2013	0.582	0.312	0.450	0.650	1.000	–0.418
2001	0.420	0.312	0.450	0.650	1.000	–0.580	2014	0.565	0.312	0.450	0.650	1.000	–0.435
2002	0.445	0.312	0.450	0.650	1.000	–0.555	2015	0.559	0.312	0.450	0.650	1.000	–0.441
2003	0.458	0.312	0.450	0.650	1.000	–0.542	2016	0.555	0.312	0.450	0.650	1.000	–0.445
2004	0.474	0.312	0.450	0.650	1.000	–0.526	2017	0.548	0.312	0.450	0.650	1.000	–0.452
2005	0.486	0.312	0.450	0.650	1.000	–0.514	2018	0.564	0.312	0.450	0.650	1.000	–0.436
2006	0.491	0.312	0.450	0.650	1.000	–0.509	2019	0.557	0.312	0.450	0.650	1.000	–0.443
2007	0.501	0.312	0.450	0.650	1.000	–0.499	2020	0.547	0.312	0.450	0.650	1.000	–0.453
2008	0.510	0.312	0.450	0.650	1.000	–0.490	2021	0.559	0.312	0.450	0.650	1.000	–0.441
2009	0.523	0.312	0.450	0.650	1.000	–0.477	2022	0.555	0.312	0.450	0.650	1.000	–0.445
2010	0.533	0.312	0.450	0.650	1.000	–0.467	2023	0.548	0.312	0.450	0.650	1.000	–0.452
2011	0.546	0.312	0.450	0.650	1.000	–0.454	2024	0.578	0.312	0.450	0.650	1.000	–0.422
2012	0.560	0.312	0.450	0.650	1.000	–0.440							

proximation of functions by algebraic and trigonometric polynomials, the dependence of constants \(C\) on a set of statistical data is significant. This mathematical representation of the L spline is ideal for use with IBM SPSS Modeler, which, based on artificial intelligence and machine learning, identifies key indicators of the Integrated Index of Educational Security and performs predictive analytics as part of the IBM Cloud Pak for Data – a container platform for data and AI. This enabled the creation and execution of a predictive model for the homeostatic plateau across a dynamic range of values for the Integrated Index of Educational Security in Ukraine from 2000 to 2030 (Fig. 3).

Built on the basis of IBM SPSS Modeler, the spline looks like this

$$L = 0.4611 + 0.0233x - 0.000645x^2.$$

It best approximates the function of statistical data f and indicates that with an unchanged management model in 2028, the educational sector of Ukraine will cross the lower optimal value of its development and after 2030 will rapidly approach the border of irreversible destructive changes. During the simulation, the results of PIZA tests for 2018 and 2022 are entered into Cloud Pak for Data AI, which partially confirms the theoretically obtained negative dynamics of changes in the integral index of educational security of Ukraine.

The above makes it possible to visualize a safe homeostatic plateau (Fig. 4), being on which we ensure the sustainable development of education and accelerate the post-war reconstruction of Ukraine.

Achieving indicators of the integral index of education of the homeostatic plateau will provide current and future generations with quality education. In fact, one of the best ways to achieve the Millennium Development Goals in the context of affordable and quality education is the active integration of AI into educational processes, which has already helped to stabilize the index of educational security (Fig. 2).

Conclusions and suggestions. The systematic analysis of the main indicators of the development of Ukraine's educational sector, using rural areas as an example, clearly shows that the traditional educational system should not be restored during post-war reconstruction, as it is based on outdated technological principles. The identified material and technical losses highlight the necessity for mass digitalization of education and validate the steps taken toward implementing the digital environment, including elements of AI such as the "Mriya" system with its own operating system, connected to the state register of the Ministry of Education and Culture. Since the "Mriya" project is funded by Switzerland under the EGAP program, we propose expanding this system to create a unified digital space for secondary, vocational, and higher education, which aligns with the principle of continuous learning.

In our view, the first steps toward implementing this project should involve public discussions among teachers, parents, and students to understand the needs of all parties. At different stages of implementation, students, teachers, and parents will be able to monitor educational results and predict future development steps based on AI.

This study accounts for the limitations of available statistical data and uses the Structured Analysis and Design Technique methodology to generate a forecast (Fig. 3), based on an incomplete set of factors \(Z11–Z17\). After the war, it is planned to significantly supplement these factors with many new indicators, including the qualitative and quantitative composition of teachers, the presence of Olympiad winners, the results of PISA and NMT competitions, and technical support, which will enhance the validity of the forecast.

It is important to note that this research focuses on rural areas, where the material, technical, and personnel base has historically been underdeveloped. During post-war reconstruction, it will be impossible to provide high-quality teachers in every village, making digitalization and the creation of digital teacher clones one of the solutions to this challenge. Our systematization of key AI-based educational technologies used in Ukrainian schools (Table 1) points to new learning methods for students, emphasizing self-development and the use of AI technologies, which open up new opportunities. An example is the Ukrainian IIS-GPT 3 educational platform, developed by the licensed International Innovation School (iis.org.ua). Over the past three years, this school has achieved a nearly 40 % improvement in education quality and student success, while the cost of education has steadily decreased, as AI technologies and digital teacher clones do not require salaries or vacations and can respond to student queries 24/7.

This innovative approach will gradually reduce the number of teachers, ensuring that only top professionals remain in the profession, receiving higher salaries and state support. However, in primary schools, AI use has not shown high results, as children aged 5–9 need human interaction and emotional connection. High learning outcomes in primary schools were strongly correlated with the involvement of parents and teachers. The study revealed a clear difference between primary and secondary education, where AI played a more prominent role than teachers. Additionally, it was found that large class sizes, rather than teacher competency alone, negatively impacted educational safety in primary schools. The optimal class size was experimentally determined to be 12 students per class with one teacher.

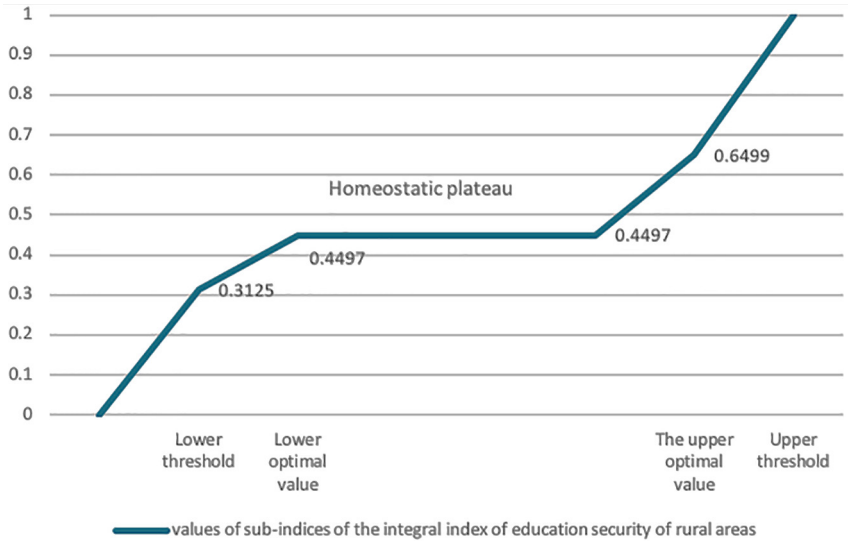

Fig. 4. Homeostatic plateau of educational security of Ukraine on the example of rural areas

Thus, we have highlighted the problems and potential prospects for ensuring the safety of Ukraine's educational system. We have identified the key issues facing rural areas and developed a dynamic series for the integral index of educational safety, which points to digital transformation as the main priority for Ukrainian education, particularly through the integration of AI technologies.

The key scenarios for improving tactical and strategic management in the education sector include: providing schools with high-quality internet and technical educational tools (computer equipment), activating the "Mriya" application to automate not only educational processes but also management processes, and accelerating high-quality digital transformation, which is critical for Ukraine's post-war recovery.

Overall, this study refutes hypothesis H1 and brings Ukraine closer to achieving its Digital Agenda for educational digitalization, ensuring that every student, regardless of their place of residence, has equal access to educational services, information, and knowledge, with AI-based advantages for future generations.

To conduct further research, which will cover a wider range of educational levels (rural and urban areas, education in megacities, and education in border and occupied territories), it is necessary to create a scientific consortium to study new factors of educational security. Additionally, it is essential to consider predictions derived from the classical Jackson-type inequality for co-convex approximation of functions by algebraic polynomials, which are well-suited for use with IBM SPSS Modeler and Cloud Pak for Data.

Acknowledgements. *The article was written within the scientific project of SNF and Zurich Pedagogical University "Creative scenarios of using AI in mathematics lessons" and "Central European Network for Sustainable and Innovative Economy" (No. PPI/APM/2019/2/00047/U/00001/IIC) at the Poznań University of Economics.*

References.

1. Lee, V., Pope, D., Miles, S., & Zarate, R. (2024). Cheating in the age of generative AI: A high school survey study of cheating behaviors before and after the release of ChatGPT. *Computers and Education: Artificial Intelligence, 7*, 1-10, 100253. https://doi.org/10.1016/j.caeai.2024.100253.

2. Alfredo, R., Echeverria, V., Jin, Y., & Yan, L. (2024). Human-centred learning analytics and AI in education: a systematic literature review. *Computers and Education: Artificial Intelligence, 6*, 100215. https://doi.org/10.1016/j.caeai.2024.100215.

3. Dyvan, K., Srinivasa, S., Suri, G., Agarwal, S., & Ram, P. (2023). Creating educational content based on artificial intelligence and expanding the learning path to increase student engagement. *Computers and Education: Artificial Intelligence, 4*, 100-110. https://doi.org/10.1016/j.caeai.2022.100110.

4. Weissman, S., Ayalon, M., & Leikin, R. (2023). Unravelling Tutors' Conceptions of Teaching Mathematics in Virtual School Using a Goal-Action Model. *International Journal of Science and Mathematics Education, 21*, 1521-1543. https://doi.org/10.1007/s10763-022-10300-7.

5. Vizcaíno-Verdú, A., & Abidin, C. (2023). TeachTok: Teachers of TikTok, micro-celebrification, and fun learning communities. *Teaching and Teacher Education, 123*, 103978. https://doi.org/10.1016/j.tate.2022.103978.

6. Beege, M., Schroeder, L., Heidig, S., Rey, G., & Schneider, S. (2023). The instructor presence effect and its moderators in instructional video: A series of meta-analyses. *Educational Research Review, 41*, 100564. https://doi.org/10.1016/j.edurev.2023.100564.

7. Samusevych, Y., Novikov, V., Artyukhov, A., & Vasylieva, T. (2021). Convergence trends in the "economy – education – digitalization – national security" chain. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (6), 177-183. https://doi.org/10.33271/nvngu/2021-6/177.

8. Zhivko, Z., & Kuharska, L. (2019). Education in the country's national security system. *Academic notes of the University "STEP", 2*(54), 206-211. https://doi.org/10.31732/2663-2209-2019-53-205-211.

9. Panfilov, O., & Savchenko, O. (2021). Education as a factor to support the National security of the state. *Bulletin of Yaroslav Mudryi National Law University, 1*(48), 146-156. https://doi.org/10.21564/2075-7190.48.224807.

10. Chiou, E., Schroeder, N., & Craig, S. (2020). How we trust, perceive, and learn from virtual humans: The influence of voice quality. *Computers & Education, 146*, 103756. https://doi.org/10.1016/j.compedu.2019.103756.

11. Karan, B., & Angadi, G. (2023). Potential Risks of Artificial Intelligence Integration into School Education: A Systematic Review. *Bulletin of Science, Technology & Society, 43*(3-4), 67-85. https://doi.org/10.1177/02704676231224705

12. Rossiter, A., Nortcliffe, A., Griffin, A., & Middleton, A. (2015). Using student generated audio to enhance learning. *Journal of the Higher Education Academy, 4*(302), 52-61. https://doi.org/10.11120/ened.2009.04020052.

13. Désiron, J., & Schneider, S. (2024). Listen closely: Prosodic signals in podcast support learning. *Computers & Education, 216*, 105051. https://doi.org/10.1016/j.compedu.2024.105051.

14. Alekseieva, K., Novikova, I., Zalizko, V., Bediukh, O., & Gupta, S. (2023). Prognosis Assessment of the Role of Digital Platforms in Providing the Internationalization of the Knowledge Economy. Technological Forecasting & Social Change (the article uses my forecasting methodology and algorithm, preprint for printing in 2023). *IJERR, 31*(1), 1-11. https://doi.org/10.52756/10.52756/ijerr. 2023.v31spl.001.

15. Hwang, G.-J., & Tu, Y.-F. (2021). Roles and Research Trends of Artificial Intelligence in Mathematics Education: A Bibliometric Mapping Analysis and Systematic Review. *Mathematics, 9*(584). https://doi.org/10.3390/math9060584.

16. Zhou, C., & Zhang, W. (2024). Computational Thinking (CT) towards Creative Action: Developing a Project-Based Instructional Taxonomy (PBIT) in AI Education. *Education Sciences, 14*, 134. https://doi.org/10.3390/educsci14020134hjjj.

17. Scutari, M., & Denis, J.-B. (2021). *Bayesian Networks: With Examples in R* (2nd ed.). Chapman and Hall/CRC. https://doi.org/10.1201/9780429347436.

18. *Methodology for calculating the level of economic security of Ukraine: order of the Ministry of Economy of Ukraine No. 60 dated 03.2.2007.* Retrieved from https://zakononline.com.ua/documents/show/117663___531337.

19. Verkhovna Rada of Ukraine (n.d.). *On the approval of Methodological recommendations for calculating the level of economic security of Ukraine. Ministry of Economy of Ukraine 29.10.2013, Order No. 1277.* Retrieved from https://zakon.rada.gov.ua/rada/show/v1277731-13#Text.

20. Leviatan, D., & Shevchuk, I. (2023). Coconvex Approximation of Periodic Functions. *Constructive Approximation, 57*, 695-726. https://doi.org/10.1007/s00365-022-09597-y.

21. *Statistical Yearbook of Ukraine for 2022. State Statistics Service of Ukraine* (2022). Retrieved from https://ukrstat.gov.ua/druk/publicat/kat_u/2023/zb/11/year_22_u.pdf.

22. *Public report of the Head of the State Education Quality Service of Ukraine for 2023. State Education Quality Service of Ukraine* (2023). Retrieved from https://sqe.gov.ua/wp-content/uploads/2024/02/Zvit_Golovi_SQE_16.02.2024.pdf.

Оцінювання безпеки освіти України в контексті інтеграції ШІ для прискореного післявоєнного відновлення

В. Д. Залізко[*1,2], *А. М. Черняк*[1], *Д. В. Новак*[3], *В. Ю. Артемов*[1]

1 – Національна академія Служби безпеки України, м. Київ, Україна

2 – Цюріхській педагогічний університет, м. Цюріх, Швейцарія

3 – Познанський економічний університет, м. Познань, Республіка Польща

* Автор-кореспондент e-mail: zwd@ukr.net

Мета. Інтегральне оцінювання безпекової ситуації в українській системі освіти в умовах інтенсивного впровадження технологій штучного інтелекту (ШІ) та висвітлення перспективних сценаріїв післявоєнної відбудови України на прикладі сільської освіти.

Методика. В основу наукового дослідження були покладені загальнонаукові методи, що доповнені комплексним економетричним аналізом основних індикаторів

безпеки освіти України. Також використані методи оптимізації та інтегрального оцінювання, що не потребують залучення експертів із різних сфер освітньої діяльності. Ключовим інструментом у використаній методиці інтегрального багатофакторного оцінювання є модуль інтелектуального економіко-математичного моделювання та прогнозування оптимістичного, реалістичного й песимістичного сценаріїв упровадження цифрових ініціатив для післявоєнного відновлення освітньої системи України, що реалізовано через метод головних, «t-критерію» під час розрахунку скалярних порогових значень на основі IBM SPSS Modeler, AI-Prophet, Cloud Pak for Data та R-Studio AI.

Результати. У роботі висвітлені ключові фактори, що впливають на рівень безпеки української системи сільської освіти, та визначено відповідний інтегральний освітній індекс безпеки, який у подальших дослідженнях може відігравати ключову роль у зміцненні економічної безпеки національного господарства в епоху післявоєнного відновлення країни та становлення нової цифрової економіки України. На основі отриманої інтегральної оцінки безпеки освітньої системи авторами виділені ймовірні траєкторії трансформації освітніх процесів у контексті використання технологій ШІ. Запропоновані ключові сценарії удосконалення тактичних і стратегічних інструментів управління освітньої галуззю для прискорення процесів якісної цифрової трансформації, спрямованої на післявоєнне відновлення України.

Наукова новизна. На основі розробленої інноваційної цифрової платформи Central European Network for Sustainable and Innovative Economy була створена програма з відкритим кодом IIS-GPT 3, до якої, на відміну від існуючих аналогів, інтегровані нові алгоритми використання технології ШІ для прогнозування ключових безпекових індикаторів на основі SPSS і AI-Prophet. Це уможливило проведення незалежного інтегрального оцінювання, моделювання та прогнозування трансформації процесів зміцнення освітньої безпеки України в контексті післявоєнного відновлення.

Практична значимість. Проведене дослідження доводить актуальність сучасної вітчизняної освітньої політики цифровізації та вказує на потенційні переваги, виклики й ризики, зокрема щодо імплементації цифрового середовища з елементами ШІ «Мрія», яке може стати геймченджером в українській освіті. Матеріали дослідження формують наукову базу для подальшого системного аналізу ключових післявоєнних імперативів освітньої безпеки України.

Ключові слова: *безпека освіти України, Штучний інтелект, цифрова трансформація, цифровізація, післявоєнне відновлення*

The manuscript was submitted 09.07.24.