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THEORETICAL AND METHODOLOGICAL FOUNDATIONS FOR DESIGNING EDUCATIONAL RESOURCES OF AGRICULTURAL HIGHER EDUCATION INSTITUTIONS IN CRISIS SITUATIONS

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THEORETICAL AND METHODOLOGICAL FOUNDATIONS FOR DESIGNING EDUCATIONAL RESOURCES OF AGRICULTURAL HIGHER EDUCATION INSTITUTIONS IN CRISIS SITUATIONS

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Authors:
Dzhedzhula O., Novitska L., Vasylenko V., Diachynska O.

Editor:
Olena Dzhedzhula, doctor of pedagogical sciences, professor, head of the department of mathematics, physics and computer technologies. Vinnytsia National Agrarian University, Vinnytsia, Ukraine.

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ABSTRACT

The monograph is devoted to a comprehensive study of the theoretical and methodological foundations of designing educational resources for agricultural higher education institutions in crisis situations in Ukraine. The authors examine the transformation of the value characteristics of education during wartime, identifying the potential of digital technologies for training competent, critically thinking, and socially responsible specialists under crisis conditions.

The purpose of the study is to substantiate the theoretical and methodological foundations for the effective design of educational resources for agricultural universities in crisis situations; to determine the negative impact of crises on the professional training of future agrarians; to develop a structural and functional model of educational resources for agricultural universities under crisis conditions; and to design specific teaching methods for academic disciplines that reveal their applied nature based on information technologies.

The first chapter of the monograph presents a conceptual analysis of modern trends in the development of education, with emphasis on the changing role of universities, the emergence of new information and communication technologies, expanded access to learning resources, and the growing importance of soft skills and metacompetencies. The need to develop digital literacy, ethical information handling, critical content perception, and the ability to work in conditions of intensive information flow is highlighted.

The second chapter, devoted to blended and distance learning under martial law, analyzes the practical experience of Ukrainian universities. The authors emphasize that distance education has generally proven effective, though it has revealed several issues: a shortage of electronic materials, the absence of a unified informational and educational environment, and insufficient digital competence among many instructors. The necessity of developing national standards for distance education, establishing electronic educational centers, and ensuring equal access to technologies for all participants in the educational process is substantiated.

A special place in the monograph is occupied by the development of a model for designing educational resources for agricultural education, presented in the third chapter. A cyclical approach is proposed, including needs analysis, design, development, implementation, evaluation, and resource adjustment, which ensures their relevance, quality, accessibility, and practical significance. The importance of collecting qualitative and quantitative data, using analytical tools, flexible content updating, and adapting educational resources to the real conditions and needs of the agricultural sector is emphasized.

The monograph also highlights the prospects for developing the educational environment of agricultural universities through the integration of innovative technologies – artificial intelligence, virtual and augmented reality, the Internet of Things, blockchain-as well as through the development of micro-credentials and open educational resources. It is emphasized that such innovations will allow the creation of personalized, immersive, and high-tech learning models capable of preparing specialists for real-world challenges in the agricultural sector during crises.

The fourth chapter of the monograph focuses on mathematical modeling of biological systems in the training of agrarians. The Leslie model, the Lotka-Volterra model, the logistic model, the Gompertz model, and the Chanter model are analyzed in detail, demonstrating their effectiveness in predicting, assessing, and optimizing biological, ecological, and production processes. The importance of incorporating mathematical models into decision-support systems for the development of precision agriculture and ecosystem management is underlined.

In summary, the authors conclude that building a modern system of educational resources for agricultural universities requires deep adaptation to conditions of uncertainty, modernization of digital infrastructure, improvement of the regulatory framework, and strengthening partnerships with agribusiness and international organizations. The proposed theory and methodology represent a practically oriented and scientifically grounded response to contemporary challenges, capable of ensuring a high-quality training system for future specialists and enhancing the role of agricultural education in the reconstruction and innovative development of Ukraine.

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1. Value characteristics of education and its transformation in modern realities

Abstract. The purpose of this paper is to analyze the value characteristics of modern higher education and to explore its transformation in the context of globalization and digitalization of society. Education is not only the transmission of knowledge but also the cultivation of worldview, ethical orientation, cultural identity, and the ability for critical thinking. High-quality training of specialists in higher education is the foundation for economic development and societal stability. Education guides individuals toward respect for human dignity, freedom of choice, and self-realization. It shapes the citizen as an active participant in public life.

Higher education ensures social mobility, societal cohesion, integration of different cultures and values, and contributes to the formation of democratic citizenship. It serves as a channel for transmitting cultural traditions, national identity, and intercultural dialogue. The training of qualified professionals promotes innovation and sustainable economic development.

In modern realities, this value is being transformed in accordance with global, social, and technological changes. Digital technologies are radically changing teaching methods, making education more accessible, personalized, and mobile. Modern education is increasingly focused not only on knowledge but also on the development of practical skills, soft skills, critical thinking, and emotional intelligence. Today, the priorities include accessibility of education for all, regardless of social, economic, or physical status.

The importance of international cooperation, mobility of students and educators, and interdisciplinary approaches to learning is also growing.

The issues of educational transformation and its impact on the future of society are addressed in the works of Hurevych R. [11], Horokhivska T. [10], Lokshyn O. [18, 19], Kovalenko S. [14], Sokol M. [24], and other researchers. Among foreign scholars, it is worth mentioning Ken Robinson (UK), known for his critical views on traditional education (particularly his TED Talk *"Do schools kill creativity?"*, where he explores

how education must transform to meet the needs of a creative and innovative society) [12].

In his books *"21 Lessons for the 21st Century"* and *"Homo Deus"*, Yuval Noah Harari (Israel) analyzes how artificial intelligence, automation, and changes in the economy are transforming education. The scholar believes that the key skills of the future are flexibility of thinking, emotional intelligence, and the ability to learn throughout life [29].

However, the dynamic development of society requires ongoing research into strategic directions in higher education to ensure the training of professionals meets the evolving societal demands.

To achieve the research objective, test the hypothesis, and accomplish the outlined tasks, a comprehensive set of scientific methods was used:

Theoretical methods included: analysis of philosophical, methodological, psychological, and pedagogical literature related to the research problem; examination of regulatory and methodological documents in the field of education to define the conceptual terminology of the study; clarification of the nature of education in foreign countries and in Ukraine; content analysis of educational programs for professional training of higher education students at agrarian universities; analysis, comparison, and synthesis of scientific ideas, knowledge, and facts; systematization of approaches to addressing the research problem; generalization of empirical material; data ranking; hypothesis construction; thought experiments and modeling.

Empirical methods included: pedagogical observation of the educational process in agrarian institutions of higher education; diagnostic interviews, surveys, questionnaires; expert interviews, testing; self-assessment by participants of the educational process; quantitative data analysis and reliability testing of experimental results.

Practical Significance. The practical significance of the research lies in its potential to inform justified decisions regarding education system reforms, funding priorities, and curriculum updates. Proposed directions for adapting educational programs to labor market demands are outlined. The analysis of professional and technological development trends helps to anticipate which specialties will be in demand in the future, thereby preparing graduates with high competitiveness.

The study allows the identification of weaknesses in the education system and helps to improve its quality — such as outdated teaching methods, lack of practical training, or insufficient digital skills among students. Analyzing trends in higher education development enables timely responses to global challenges such as digitalization, artificial intelligence, and the need for lifelong learning.

Value/Originality. The research findings can be used by higher education institutions to shape effective educational policies. A scientifically grounded rationale is proposed for flexible changes to curricula in order to ensure the competitiveness of university graduates.

Introduction

Over the past decades, we have witnessed rapid changes in all spheres of life — the economy, technology, culture, and social structure. Along with these transformations, higher education is also evolving, as it is inherently linked to the needs of society and the labor market.

The goal of modern education is to meet the needs of both individuals and society for professional educational services of an appropriate level, taking into account labor market demands; to ensure equal access to quality education; and to foster a creative, spiritually enriched individual, considering their personal needs and abilities [1].

In Ukraine, the main factors influencing the further development of higher education include demographic changes (a declining birth rate and a reduction in the working-age population due to the war with Russia), increased demand for a skilled workforce, deepening discrepancies between the demand for highly qualified professionals and the current level of their training, and a decline in the quality of professional education caused by the loss of skilled specialists from the workforce as a result of the war. Additionally, the development of production based on the implementation of new technologies, materials, and equipment, as well as the growing role of social partnership, significantly shape the direction of educational transformation.

Among the key areas in which modern higher education is transforming under the influence of societal development, researchers highlight the impact of digital technologies, the orientation toward practical skills, and the focus on soft skills. It is appropriate to examine the value-based characteristics of education and its transformation within the context of a globalized labor market environment. This is of particular significance for Ukraine. In the 21st century, quality education has become one of the main factors of sustainable national development, competitiveness, and security.

In the context of globalization and the intellectualization of the economy, the integration of Ukraine's higher education system into the European and global educational space is not only desirable but a necessary precondition for the modernization of the entire education system. This process opens new opportunities for students, educators, and researchers, contributes to the modernization of the educational environment, and enhances the international image of Ukrainian education.

Ukraine possesses the intellectual potential to become a full-fledged participant in the global educational community — what is crucial now is to realize this potential through strategic vision and deliberate action. Ukraine has been a participant in the Bologna Process for over 15 years, which marked an important step toward educational integration. Therefore, the transformation of its value characteristics should be studied in the context of the historical foundations of the development of modern higher education.

1.1 Historical Preconditions for the Development of Modern Pedagogy and Shifts in Priorities in Higher Education

Given Ukraine's aspirations for European Union membership, it is important to examine the historical development of European higher education and outline the gradual shift in civilization's educational priorities. The evolution of European higher education can be divided into several stages.

The first stage (Medieval universities, 12th–15th centuries) marked a transition from the spontaneous formation of early archetypes of medieval universities — closely linked to specific professions — to the more structured and territorially expanded institutions of the late Middle Ages. The first universities, such as the University of Bologna (founded in 1088) and the University of Paris (founded in 1150), were created as self-governing corporations of students and teachers. They were composed of faculties (theology, law, medicine, arts), and teaching was based on the scholastic method, which emphasized logic and dialectics. These universities were closely tied to the Catholic Church, which controlled many aspects of their operations [12, 18].

The second stage (Renaissance and Early Modern Period, 15th–17th centuries) saw universities begin to include classical texts by ancient authors in their curricula, leading to the development of humanism. New sciences and research methods emerged, giving rise to disciplines such as astronomy and physics. Universities began to play an increasingly significant role in scientific discoveries. The social role of universities grew as they came to represent key aspects of national identity, and they were often drawn into the dynastic and religious conflicts of the era. Political changes and the Industrial Revolution fostered a new socio-economic order that transformed universities and revitalized other forms of higher education.

The Enlightenment era (18th century) was marked by the secularization of education and widespread reforms. Universities gradually freed themselves from church influence, becoming more autonomous and secularized. Many European universities implemented reforms aimed at improving teaching and scientific research. For instance, German universities such as the University of Göttingen introduced new models of learning and academic inquiry.

Finally, after 1914, World War I and the Great Depression brought profound shifts in the cultural, economic, social, and political foundations of higher education. This period saw the rise of the Humboldtian model of the university, developed by Wilhelm von Humboldt, which combined research and teaching. This model became a prototype for many European universities.

This stage was characterized by the expansion of the university system: institutions began to admit more students and create new faculties — particularly in technical fields — to meet the needs of the industrial revolution. Conditions were created for mass access to higher education and for the integration of science and production into education.

The crisis of the early 1970s interrupted this multifaceted development and posed challenges for higher education institutions in terms of funding, access, and differentiation. This led to growing tensions between the ideology of higher education, the organizational structure of universities, the accessibility of education, and funding mechanisms. These issues remain central to current debates on the theory and practice of higher education.

In 1999, the Bologna Process was launched with the aim of creating a common European Higher Education Area. This led to the harmonization of academic programs and greater mobility for students and faculty. The implementation of the Bologna principles also oriented higher education toward the adoption of modern information technologies. Universities increasingly integrate digital technologies into the educational process, including online courses and distance learning.

1.2 The Competency-Based Approach as a Methodology for Specialist Training in the 21st Century

The implementation of the competency-based approach in higher education has fundamentally changed the goals of professional training for future specialists. It can be argued that the Bologna Process played a historic role in the new concept of higher education.

The early 1990s were characterized by crisis phenomena in higher education, which were global in nature and affected many countries around the world. This crisis was caused both by problems in the global economy and by the mismatch between higher education and the demands of society. During this time, in many countries, funding for higher education was significantly reduced, which led to a decline in the quality of education, lower salaries for faculty, and increased tuition fees for students.

This caused greater social inequality in access to higher education. At the same time, in the 1990s the number of people wishing to obtain higher education rose sharply. This demand led to the oversaturation of higher education institutions, resulting in an insufficient quantity of resources and teachers to ensure a quality educational process [9,11].

Most universities could not adapt in a timely manner to rapid changes in the labor market and in society, which caused a discrepancy between what was taught in universities and what was required by the labor market. This aggravated the problem of unemployment among graduates. Globalization led to increased competition among universities in different countries. Many European universities began to lag behind American and Asian universities, which became an additional challenge for the higher education system.

The fall of communist regimes in Eastern Europe and the collapse of the USSR led to significant social and economic changes which affected the education system. There arose a necessity to reform educational systems that had been created under planned economies, and to adapt them to the new conditions of a market economy. These factors together created a crisis situation in the higher education system that required serious reforms and new approaches to management, financing, and organization of the educational process. The Bologna Process was one response to these challenges, aimed at modernizing and integrating European higher education.

In the early 1990s in Europe there existed many different higher education systems, which made mutual recognition of diplomas and mobility of students and faculty between countries difficult. The Bologna Process was aimed at harmonizing these systems and creating a unified European Higher Education Area.

In a world where competition among educational institutions is growing, Europe needed to establish a system that would correspond to modern challenges and be globally competitive. One of the main goals of the Bologna Process is to promote international mobility of students and faculty, which is an important factor in forming a unified European community. The emergence of the European Union and the drive for integration supported the development of the idea of a common educational space, which aimed to provide comparability of qualifications and the creation of common standards in education.

Thus, the Bologna Process was initiated in order to make European higher education more coherent, accessible, and competitive, with the goal of promoting mobility and integration within Europe.

In Bologna in 1999, representatives of 29 countries agreed on a common vision of the European Higher Education Area (EHEA). They emphasized that this vision was politically relevant to each of the participating countries, and transformed it into operational objectives, as embodied in the Bologna Declaration. Key elements of the European Higher Education Area envisaged at that time included: European countries with different political, cultural, and academic traditions being able to cooperate to achieve a shared goal; European students and graduates being able to move easily from one country to another with full recognition of qualifications and periods of study and access to the European labor market; European higher education institutions having the ability to cooperate and exchange students/staff based on trust and confidence, as well as transparency and quality; European governments embedding their national higher education reforms into the broader European context; higher education in the European region increasing its international competitiveness and engaging in dialogue and improving collaboration with educational systems in other regions of the world [21].

Over the past 25 years, thanks to voluntary convergence and an intergovernmental approach, the Bologna Process has led to the building of the foundation of the European Higher Education Area — a shared structure that includes the overarching qualifications framework of the EHEA, a common credit system (ECTS), shared principles of student-centered learning, European standards and guidelines for quality assurance, a common register of quality assurance agencies, a shared approach to recognition, and a common set of methodologies and sustainable achievements established by European higher education institutions.

The Bologna Process is a dynamic progression from the Sorbonne Declaration to the European Higher Education Area, which today defines the future of higher education in EU countries.

It is advisable to study the history of the Bologna Process's transformation. The ministers of education who participated in the celebration of the 800th anniversary of the University of Paris (The Sorbonne Joint Declaration, 1998) shared the opinion that the segmentation of the European higher education sector was outdated and harmful. The decision to take part in a voluntary process of creating the European Higher Education Area (EHEA) was formalized a year later in Bologna by 30 countries (the Bologna Declaration, 1999) [9]. At its inception, the Bologna Process targeted strengthening the competitiveness and attractiveness of European higher education, fostering student mobility and employability opportunities by introducing the bachelor's and postgraduate structure with clear programs and degrees. Quality assurance also played an important role from the very start of the Bologna Process. However, various ministerial meetings since 1999 have expanded this agenda and refined the tools developed. The bachelor/master degree structure was changed to a three cycle system, which now includes the concept of qualification frameworks with an emphasis on learning outcomes. The concept of the social dimension of higher education was introduced, and qualifications recognition is now clearly seen as central in European higher education policy. Thus, the evolution of the main objectives of the Bologna Process occurred in a certain sequence.

The Sorbonne Declaration was signed in 1998 by the ministers of four countries: France, Germany, the United Kingdom, and Italy. The aim of the Declaration was to create a common education system within the envisaged European Higher Education Area where mobility should be ensured both for students and graduates as well as for staff. Moreover, the new European Higher Education Area was intended to enhance the advancement of qualified specialists in the labor market. The aims of the Sorbonne Declaration were confirmed in 1999 through the Bologna Declaration, where 30 countries expressed their willingness to commit to strengthening the competitiveness of the European Higher Education Area, emphasizing the need for further development of independence and autonomy for all higher education institutions. All provisions of the Bologna Declaration were established as measures of a voluntary harmonization process rather than provisions of a mandatory contract. To implement the Bologna Declaration, every two years ministerial conferences were held, in which the ministers expressed their vision through appropriate communiqués.

Thanks to the Prague Communiqué in 2001, the number of member countries grew to 33, and objectives were expanded in terms of lifelong learning, student involvement as active partners, and increasing the attractiveness and competitiveness of the European Higher Education Area. In addition, participating ministers committed to further development of quality assurance and national qualifications frameworks. This aim is related to the goal of lifelong learning, since it is considered an important element of higher education which must be taken into account in building new education systems. It is also worth noting that the social dimension theme was introduced for the first time in the Prague Communiqué. The next ministerial conference took place in Berlin in 2003. Thus, the Berlin Communiqué raised the number of countries to 40 members. The main provisions of that communiqué concerned broadening the objectives in terms of linking the European Higher Education Area with the European Research Area, as well as promoting quality assurance in education. Another important aspect mentioned in the Berlin Communiqué related to the establishment of certain structures to support the process between two ministerial meetings. This agreement contributed to the creation of the Bologna Follow-Up Group, the Board and the Bologna Secretariat. In this communiqué, ministers also agreed that each of the participating countries should establish a national structure for follow-up action.

In the Bergen Communiqué 2005, the importance of partnership including stakeholders – students, higher education institutions, academic staff and employers – was emphasized, along with further enhancement of research, especially in the third cycle – doctoral programmes. Moreover, this communiqué stressed ministers' desire to ensure more accessible higher education together with increasing the attractiveness of the EHEA for other parts of the world. The London Communiqué 2007 expanded the number of participating countries to 46. In that communiqué attention was focused on assessing progress up to that point in terms of mobility, degree structure, recognition, qualification frameworks (both general and national), lifelong learning, quality assurance, the social dimension, and also setting priorities for 2009, namely: mobility, social dimension (which was defined here for the first time), data collection, employability, the EHEA in a global context, and summing up. For 2010 and beyond it was emphasized that there is a need for continued cooperation, considering this as an opportunity to reformulate the vision and values of higher education.

The Leuven/Louvain-la-Neuve Communiqué. In the Leuven/Louvain-la-Neuve Communiqué of 2009, main directions of work for the next decade were identified with emphasis on: the social dimension, lifelong learning, employability, student-centred learning and educational mission, international openness, mobility, education, research and innovation, as well as data collection, funding of higher education and tools of multi-dimensional transparency. These main working areas demonstrated a new orientation of the Bologna Process toward a more in-depth approach to reforms that ensures the completion of the Process implementation. Another change, in terms of internal mechanisms, concerned the procedure of presidency in the Bologna Process: from the previous arrangement where the presiding country in the Bologna Process was the country holding the EU presidency, to the situation in which two countries preside — one being the country holding the EU presidency and the other a non-EU country — named in alphabetical order, starting from July 1, 2010.

Budapest/Vienna Communiqué. In March 2010, during the Budapest-Vienna ministerial conference the EHEA was expanded to 47 members. The Budapest-Vienna conference was the anniversary conference marking the tenth anniversary of the Bologna Process [9]. On that occasion the European Higher Education Area was officially launched, meaning that in terms of a shared European higher education structure the goal set in the Bologna Declaration was achieved. However, the existence of the EHEA itself did not mean that all the aims agreed upon by the ministers participating in the Bologna Process had been accomplished. Thus, in 2010 the Bologna Process and the European Higher Education Area entered a new phase, namely consolidation and operationalization, especially in light of significantly differing responses to implementation of the Bologna Process in Europe [4, 23].

The Bucharest Communiqué. The main message of the Bucharest ministerial conference, held on 26-27 April 2012 with the participation of 47 European ministers responsible for higher education, was that higher education reform can help return Europe to the right path and create sustainable growth [9]. Ministers agreed to focus on three main goals in the face of a likely economic crisis: to provide quality higher education to more students, to better equip students with skills that enable employability, and to increase student mobility. The 47 countries adopted a new European strategy to increase mobility with the specific goal that at least 20 percent of those who finished higher education in Europe by 2020 would have the opportunity to study or do an internship abroad.

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Yerevan Communiqué. The Yerevan ministerial conference took place on 14 15 May 2015 [9]. During the conference several policy measures were adopted: the Standards and Guidelines for Quality Assurance in the European Higher Education Area (ESG) were revised; the European Approach for Quality Assurance of Joint Programmes was adopted; the ECTS Users' Guide was reviewed as an official EHEA document. The Yerevan Communiqué recognized that the vision of the Bologna Process had successfully inspired the European Higher Education Area. Nevertheless, to realize the full potential of the EHEA it was necessary to continuously upgrade higher education systems and increase more widespread involvement of academic communities. The need for reviewing the original vision and consolidating the structure of the EHEA was emphasized.

EHEA governance and working methods must evolve to meet new challenges. Common objectives implemented in all participating countries include: increasing the quality and relevance of teaching and learning; fostering graduate employability throughout their working lives; creating more inclusive systems; implementing coherent structural reforms.

The reasons for introducing the competency-based approach into the educational process in universities have social and economic roots. The modern labor market demands from university graduates not only theoretical knowledge, but also practical skills and competencies that allow them to work effectively in a professional environment. This concerns both specialized professional skills and general competences, such as critical thinking, communication, and the ability for self-development. Rapid technology development changes job requirements and creates new professions. Universities must adapt their curricula to these changes in order to equip students with relevant knowledge and skills.

In a globalized world, competition in the labor market is increasing. To ensure that university graduates can successfully compete for jobs, they must have a high level of professional competency. Universities are increasingly aligning with international education standards, which requires them to develop competencies that are recognized and in demand internationally.

Employers more often look for specialists who already possess the necessary competencies to carry out professional duties from day one. They expect universities to prepare students for real working conditions, providing them with appropriate knowledge and skills. Thus, the formation of professional competency in modern universities is a key component of preparing students for successful careers, ensuring their competitiveness in the labor market and adaptation to the demands of the contemporary world.

Professional competency is the combination of knowledge, skills, abilities, and personal qualities that enable an individual to perform tasks effectively within a given profession. Nowadays, increasing attention is being paid to the development of personal qualities. It includes several components (see Fig. 1).

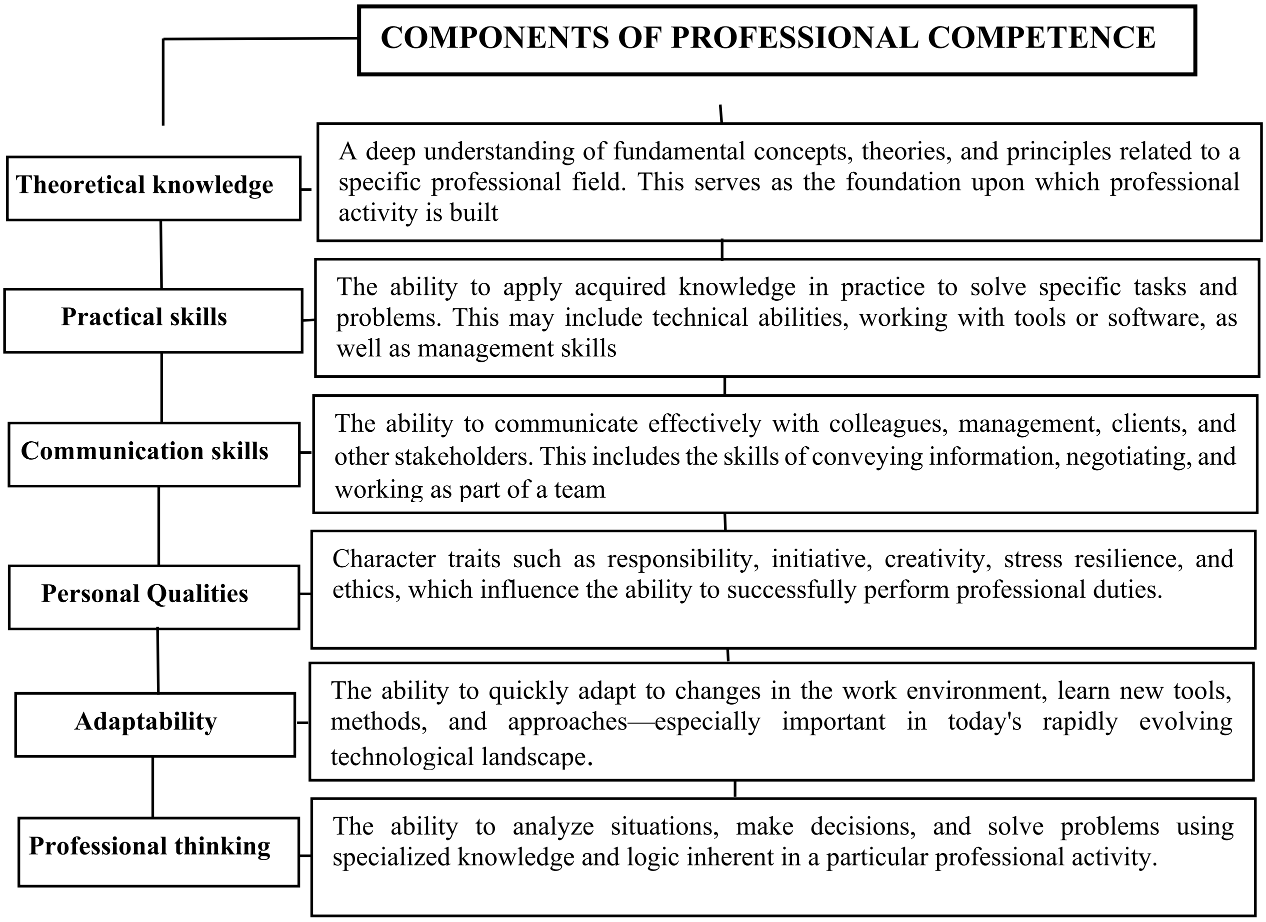

Figure 1. Components of professional competence
Source: generalized by the author based on [1, 4, 6]

Thus, professional competency encompasses not only knowledge and skills, but also broader aspects including personal development, the ability to interact with others, and adaptability to changes. It is a key factor in successful professional activity and career development.

Today young people often ask: “Why pursue higher education?” After all, there are many examples of successful people without a university degree, such as Bill Gates. However, it is important to recognize that while exceptions like Gates exist, they are more the exception than the norm. For every person who finds success without higher education, there are many others who struggle due to a lack of the skills and knowledge necessary for employment and successful life management. Although unique paths may lead to success, obtaining higher education is often considered the most reliable and safest way to achieve success. Therefore, it is necessary to discuss with students the numerous advantages of higher education, while also emphasizing some legitimate concerns that often arise in people, especially today, during the war with Russia. For most people, university is a crucial stage in their personal and intellectual growth. It is a period of self-discovery, diverse experiences, and acquisition of knowledge that lays the foundation for future aspirations [6]. It provides people with tools to navigate the complexities of the world and achieve various goals. Below we highlight some key areas in which the university has a direct impact, each of which makes a significant contribution to personal development. At the same time, it should be emphasized that higher education has value, but its importance can vary depending on specific circumstances, goals, and field of activity. We consider it important to emphasize the following points.

1. Career opportunities. In many professions higher education is a necessary condition for employment or career advancement. A degree may become a gateway to better-paid and more prestigious positions. Attending university and choosing the right specialization can lead to expanded career growth opportunities, since many professions require academic degrees that can be obtained through higher education. Individuals who hold higher education have better employment prospects than those with lower educational attainment. Studies on higher education issues convincingly show that those with a bachelor's or higher degree demonstrate higher rates of employment than those without higher education.

2. Knowledge and skills. University education provides not only specialized knowledge but also develops critical thinking, research, communication, and problem-solving skills. These are useful in both professional and personal life. Universities provide students with a structured environment for acquiring specialized knowledge and developing the necessary skills for their chosen fields. Through rigorous academic programs, hands-on learning, and exposure to the latest developments, universities help students become experts and succeed in their careers. Furthermore, by offering direct access to active researchers and real-world practices,

students gain access to cutting-edge information, promoting innovation and adaptability.

3. Network of contacts. Universities often become places where one can find like-minded individuals, mentors, and future colleagues. The network built during one's studies can be very useful in later career stages. Sometimes who you know is just as important as what you know. Thus, in addition to providing knowledge and skills, colleges and universities also offer great opportunities to build one's social network, which may lead to internships, job opportunities, projects, or mentorship. From interacting with peers and alumni to learning from experienced faculty at leading institutions around the world and engaging with professionals in specific fields, students have opportunities to build sustainable partnerships in college and beyond, which can have long-term positive impact on their careers.

4. Social status. For some people, holding a diploma is an important aspect of social status and self-realization. The reasons for this are both historical and sociocultural. Education is perceived as a symbol of intellect and knowledge. A diploma is traditionally regarded as proof that a person has gone through a certain intellectual path, acquired knowledge and skills, knows how to think critically and work on oneself. This automatically increases their authority in the eyes of society. In many countries (especially post-Soviet ones) higher education has historically been a sign of social prestige. A person with a diploma is perceived as "educated", "cultured", "successful". Parents and family often view attainment of a degree as a required step in the child's "formation". In many fields a diploma is a formal requirement (for example, medicine, education, law) or an informal filter used by HR professionals, even when real skills are more important. Without a degree certain "doors" remain closed — therefore it becomes a symbol of "access" to career growth. As shown by a survey of graduates of Vinnytsia National Agrarian University, almost all graduates associate obtaining the diploma with completing an important life stage, with confirmation of their efforts, perseverance, intellect, feeling that one is "not worse than others", meeting societal or family expectations. It should be noted that a diploma helps a person feel belonging to a certain group (scholars, professionals, educated people),

higher self-esteem, confidence in their ability to influence life and the surrounding world.

5. Contribution to community and society. Colleges and universities, overall, make significant contributions to society through innovative research and discoveries. They serve as centers of breakthroughs, where brilliant minds unite to address pressing problems and expand the boundaries of knowledge. Researchers can solve important issues in unconventional ways. For example, what if brain tumors could be treated painlessly at home without anesthesia? It may sound impossible, but researchers at Stanford Medical Center are developing a small wireless device that one day may do exactly that. Another example – Johns Hopkins University was the institution that ensured the flyby of the New Horizons spacecraft past Pluto, while MIT developed a heat engine with no moving parts [8]. Thus, the possibilities can be considered boundless.

6. Personal growth and self-sufficiency. Finally, colleges and universities are often dynamic environments that provide more than subject-matter knowledge. While students definitely gain experience in their chosen areas, these institutions also help students develop essential life-skills. In addition to mastering complex concepts, students learn time management, problem solving, communication, teamwork and various other domains. Thus, higher education institutions endow them with practical skills and competencies necessary for thriving in a diverse and multifaceted world.

7. Alternatives. However, it is important to note that higher education is not always the only path to success. In many fields such as technology, entrepreneurship, arts, etc., people achieve considerable success without a university degree. Alternatives such as professional courses, self-directed learning, or hands-on experience can also be effective.

8. Time and cost. Higher education can be quite expensive and require significant time, so it is important to weigh the costs and benefits for each individual situation.

So, higher education may have great value, but it is not the only path to success and is not always necessary to achieve one’s life goals.

Despite the clear significance and numerous benefits of higher education, some factors may cause young people to hesitate about entering university. Below we consider some common criticisms and concerns young people may have about higher education, which should not be silenced but discussed openly with youth.

Higher education faces substantial criticism, especially about rising tuition fees burdening students with long-term debt. Recent data show that over the past two decades there has been a significant increase in tuition and fees at private universities, with a rise of 134%. Public universities charging tuition have experienced an even greater increase of 141% [12].

Against the backdrop of fast-changing global labor markets, concerns remain about the adaptability of traditional degrees. Traditional university programs may not equip graduates with effective means for responding to the dynamic transformation of the modern labor market, influenced by technological advances and shifting industrial "landscapes". Clearly, students may hesitate whether to choose universities that do not meet current job requirements or do not deliver the skills needed in the market, which may lead to difficulties in securing relevant positions and the necessity of continuous upskilling to maintain competitiveness.

Strategies to address higher education challenges should also be topics for discussion with prospective students. First, to alleviate the financial burden of tuition, one can suggest exploring scholarship opportunities and financial aid packages offered by universities and external organizations. Scholarships can significantly reduce the overall cost of education and make higher education more accessible. Moreover, many institutions provide grants and work-study programs offering financial assistance and opportunities for gaining work experience simultaneously. Alternatively, part-time, online, or distance education options may offer more cost-effective pathways to obtaining a degree or completing required courses.

When choosing a university, prospective students should examine the relevance of the program to the specialization chosen. It is important to guide young people toward selecting programs that emphasize practical skills, hands-on experience, industry partnerships that offer internships or collaborative learning opportunities.

Such experience provides real exposure and helps bridge the gap between the academic environment and industry. Although a university undoubtedly offers numerous benefits such as enhanced career prospects, skill development, and personal growth, the sharp rise in tuition and uncertainty around the usefulness of certain degrees have cast doubt on the value of this investment. Ultimately, it is important to remember that personal ambitions and circumstances also shape the value of a university education. The key is to make informed decisions that resonate with the long-term goals of the young individual.

Another important point is to recognize that education does not end with the diploma. Therefore, one should be prepared for continuous learning, professional development, and upskilling to remain competitive and mobile in an ever-changing labor market.

1.3 Transformation of the Process of Education, Learning, and Development in Higher Education

The processes of education, learning, and personal development are considered the primary objects of pedagogy, which are also closely correlated with the general trends of societal development. Higher education pedagogy examines various aspects of the educational process, the interaction between teachers and students, as well as the conditions, methods, and tools that contribute to effective learning and upbringing. Pedagogy as a whole encompasses all aspects of educational activity, starting from preschool education and extending to adult education. The main focus is on the development of personal qualities, moral values, intellectual abilities, and social skills of pupils, students, or learners.

Modern pedagogy also pays attention to such aspects as individualized learning, inclusive education, integration of information technologies into the learning process, critical thinking, creativity, emotional intelligence, and preparation for life in a globalized world.

The object of modern pedagogy has undergone significant changes compared to previous centuries. The main transformations are presented in Table 2.

Table 2

Key Transformations of the Object of Pedagogy

Essence of the Object of Pedagogy in Past Centuries	Essence of the Object of Modern Pedagogy
Pedagogy was largely focused on upbringing, the formation of moral and religious values, and preparing youth to fulfill social roles defined by traditional societal structures.	Modern pedagogy places greater emphasis on the development of intellectual abilities, critical thinking, and creative skills of students. Education is now viewed as a means of personal development and preparation for active participation in social life.
Education was standardized, oriented towards the “average” student. All students received the same material and teaching methods.	Modern pedagogy emphasizes the individualization of learning approaches, taking into account the needs, interests, abilities, and developmental pace of each student. This includes the application of differentiated learning, flexible curricula, and teaching methods.
The education system often excluded certain groups of the population, such as girls, children with special needs, or children from poor families.	Today, pedagogy is oriented towards inclusion, ensuring equal access to quality education for all students, regardless of their social status, physical or intellectual abilities.
In past centuries, the main teaching tools were books, written assignments, and oral lectures	Modern pedagogy integrates information and communication technologies into the learning process. The use of digital tools, online resources, multimedia materials, and interactive platforms has become an essential part of education.
Pedagogy of past centuries was mainly oriented towards national or regional values and knowledge.	Modern pedagogy considers global challenges and opportunities, focusing on intercultural education, preparation for life in a multicultural world, the development of tolerance, and understanding of global processes.

Source: summarized by the author based on [4, 9, 11]

Thus, the main changes are related to a shift in focus from upbringing to learning, the individualization of education, inclusion and equality, the technologization of education, globalization, and intercultural education. These changes reflect the evolution of society and the changing needs and expectations placed on the educational system. In accordance with the object of pedagogy, the goal of higher professional education is to prepare highly qualified specialists capable of effectively performing their professional duties and contributing to the development of their fields. This goal encompasses several key aspects:

- Acquisition of professional knowledge and skills: students receive in-depth theoretical knowledge and practical skills necessary for carrying out specialized tasks in a particular professional field.
- Development of critical thinking and an innovative approach: higher education aims to develop students' ability to analyze information, critically evaluate problems, make well-reasoned decisions, and find innovative solutions to complex issues.
- Preparation for scientific and research activities: part of the goal of higher education is to prepare students to conduct scientific research, develop new knowledge and technologies, and participate in academic activities.
- Formation of professional ethics and responsibility: higher education seeks to instill in students high moral standards, professional ethics, and social responsibility, which are essential for the successful performance of professional duties.
- Preparation for adaptation in a rapidly changing environment: as the modern world changes quickly, higher education must equip students with the knowledge and skills to adapt to new challenges and technologies, be flexible, and engage in lifelong learning.
- Intercultural and global competence: Higher education is aimed at developing students' ability to work in international environments, understand and respect cultural differences, and function effectively in a globalized world.

Thus, the purpose of higher professional education is not only to acquire specific professional skills but also to form a well-rounded individual ready for continuous professional growth and active participation in societal life.

Since the main purpose of higher professional education is aimed at the professional formation of future specialists and their personal development, three main vectors are distinguished in the functions of higher professional education: educational, developmental, and formative. Each of these vectors can be detailed as follows:

- Theoretical function: the formation of pedagogical theories, principles, and concepts that explain the processes of education and learning.

- Research function: the study and analysis of pedagogical phenomena, development of new teaching methods and technologies.
- Practical function: implementation of scientifically grounded methods and technologies in educational practice to enhance the effectiveness of teaching and upbringing.
- Predictive function: forecasting trends in the development of education, identifying possible directions for its improvement.
- Normative function: the development of pedagogical norms, standards, and recommendations for educational practice.
- Social function: ensuring the socialization of the individual, the formation of value orientations, behavioral norms, and social roles.

These functions are interconnected and aimed at the comprehensive development of the individual throughout the process of learning and education.

With the development of society, the functions of higher professional education are also transforming, driven by global changes in society, the economy, and technology. In the past, higher education primarily focused on transferring knowledge and information within a specific field. Today, the emphasis has shifted to the development of competencies, which include not only knowledge but also the ability to apply it, critical thinking, creativity, problem-solving skills, and communication abilities.

Modern higher education is becoming increasingly globalized, with an emphasis on international cooperation, student and faculty mobility, and the integration of intercultural aspects into academic programs. This enables students to gain experience in various cultural contexts and increases their competitiveness in the global labor market.

Higher education actively incorporates digital tools and platforms, enabling the implementation of distance learning, interactive teaching methods, virtual labs, and simulations. The use of technology also supports the personalization of education, allowing students to learn at their own pace and according to their individual needs.

The role of the teacher is evolving from a traditional source of knowledge to a facilitator and mentor who supports students' independent learning, assists in the development of their projects, and helps shape their professional and personal competencies.

Given the rapid development of technology and changing labor market demands, higher education is increasingly oriented toward preparing students for lifelong learning. This includes the development of postgraduate education programs, certification courses, and short-term learning formats that allow professionals to continuously update their knowledge and skills.

Higher education also actively integrates elements of entrepreneurial thinking into educational programs to prepare students for launching their own projects, businesses, and innovations. This includes entrepreneurship and management courses as well as support for student startups and entrepreneurial initiatives.

Modern educational programs are more focused on developing students' sense of social responsibility, ethical behavior, and environmental awareness. This is reflected in course topics, research projects, and practical activities aimed at solving social issues and promoting sustainable development.

Higher education increasingly includes interdisciplinary approaches that allow students to acquire knowledge from various fields and apply it to complex projects. This contributes to the formation of specialists capable of working effectively in today's complex and rapidly changing world.

These transformations reflect higher professional education's adaptation to new challenges and the needs of modern society, ensuring the preparation of students who are ready for successful careers and active participation in social life.

The competency-based approach in education has contributed to the development of the concept of lifelong learning, which is now also seen as a global trend. Lifelong learning develops, on one hand, as a pedagogical concept and, on the other, as a practical phenomenon linked to the formation of specific competencies.

Lifelong learning accompanies the process of growing a person's educational (both general and professional) potential throughout life. This process is supported by a system of state and public institutions and meets the needs of both individuals and society. The goal of lifelong learning is the formation and development of an individual during periods of physical and socio-psychological maturation, as well as during aging, when compensating for lost capacities becomes a priority.

A system-forming factor of lifelong learning is the societal need for the continuous personal development of each individual. This determines the organization of a multitude of educational structures — primary and parallel, basic and additional, state and public, formal and informal. Their interconnection, mutual influence, subordination by levels, coordination of goals and purposes, and interaction among them transform this entire array into a unified system. For a democratic state, lifelong learning is a leading form of social policy aimed at ensuring favorable conditions for the general and professional development of every individual. For society as a whole, lifelong learning serves as a mechanism for the expanded reproduction of its professional and cultural potential, a condition for the development of social production, and a driver of socio-economic progress in the country.

For the global community, lifelong learning is a means of preserving, developing, and mutually enriching national cultures and universal human values. It is also an important factor and condition for international cooperation in the field of education and in addressing the global challenges of today.

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1.4 Tasks of Higher Professional Education and Their Transformation in Contemporary Realities

The tasks of higher education pedagogy lie in studying, shaping, and improving educational processes in universities. These tasks are interrelated and aim to ensure high-quality and effective teaching and upbringing both in society at large and in its specific spheres (professional, personal, etc.). However, the historical development of society alters the tasks of higher education. For example, let us consider the tasks of education in the Middle Ages and compare them with those of contemporary higher professional education.

In the Middle Ages, pedagogy primarily fulfilled religious-moral and ideological tasks, serving the interests of the Church and feudal society. It was not an independent science, as it is today, but rather part of theology and philosophy. Religious education was a priority goal, aimed at cultivating deep faith in God and obedience to the Church, acquainting students with the fundamentals of Christian doctrine, the Bible, lives of saints, and nurturing in the spirit of Christian morality — humility, obedience, chastity, mercy. Considerable attention was paid to moral and ethical formation: virtues such as obedience, submission to God's will and authority, patience, and modesty. Devotion to tradition was accompanied by suppression of individualism and critical thinking. Education aimed to prepare monks, priests, theologians, and also civil officials, scribes, physicians, and jurists — but always on a religious foundation. Latin was the basis of education, allowing reading of the Bible and classical texts. The process of preserving and transmitting knowledge significantly differed from modern methods. Pedagogy supported the goal of preserving the classical heritage, but only insofar as it aligned with Christianity. Knowledge was transmitted by memorization, copying books, dictation reading. Accordingly, upbringing aimed at service to the feudal-religious ideology. Education was meant to reinforce the existing social order: the monarch's power was divinely ordained, hierarchy was god-pleasing. Pedagogy helped cement each individual's role within their social "estate": clergy, feudal lords, peasants. Notable figures of medieval pedagogy include Augustine of Hippo (ideas about nurturing the soul, the significance of divine will), Thomas Aquinas (the combination of Christian faith and reason, education as a path to knowing God), Alcuin, John Scotus Eriugena (who promoted education in monasteries and royal courts). Thus, medieval pedagogy had a sacred, conservative character, with its principal aim being the cultivation of obedient Christians and the preservation of a stable social order.

The tasks of higher education pedagogy in the contemporary world have undergone radical changes. In the National Doctrine of Education Development, it is proclaimed that the goal of state policy is to create conditions for the development of personality and creative self-realization of each citizen of Ukraine. The main goal of higher education is made concrete in three directions:

1. First direction — creating conditions for individuals to master knowledge and skills in the professional sphere, acquire qualifications or requalify, enabling participation in socially useful labor according to their interests and abilities. At the same time, higher professional education may be viewed as a means of personal self-realization, since professional activity most fully reveals a person's abilities, and as a means of social self-protection, stability, and adaptation to market economy conditions.
2. Second direction — fostering socially active individuals who in their lives are guided by universal (honor, conscience, justice) and culturally national (diligence, freedom, tolerance, etc.) values and capable of creative professional activity, new production, economic, social relations, and able to take responsibility for the results of their actions.
3. Third direction — satisfying urgent and future production needs for qualified specialists whose level of preparation would meet the demands of scientific, technical, and social progress; professionals who are mobile, possessing broad professional and general educational competences.

Thus, the issue of the future specialist's higher education centers on ensuring their personal development. The directions named above define the principal tasks of higher education pedagogy. The main tasks of higher education pedagogy are:

1. Development of theoretical foundations of education: higher education pedagogy studies the patterns of learning and upbringing and formulates principles, methods, and approaches to educational activity.
2. Formation of personality: a central purpose of higher professional pedagogy is the comprehensive development of personality, cultivating moral, ethical, and intellectual qualities in future specialists.
3. Organization of the educational process: higher education pedagogy designs structures and models for organizing the learning process in institutions,

choosing teaching and upbringing methods according to students' age, psychological and sociocultural characteristics.

4. Training of pedagogical personnel: developing and improving systems for preparing instructors, mentors, and enhancing their professional competencies.

5. Analysis and evaluation of educational effectiveness: higher education pedagogy investigates learning and upbringing outcomes, assesses the effectiveness of various methods and forms of instruction.

6. Adaptation of education to modern conditions: higher education pedagogy continuously updates its approaches considering changes in society, scientific and technological progress, cultural traditions, and social demands.

In the modern era, didactics continues to evolve, adapting to changes in the higher education environment. New technologies, globalization, and societal changes demand constant adaptation and the development of new approaches to teaching. Current didactic research focuses on individualization of learning, integration of digital technologies, and development of students' critical thinking. Contemporary didactics is characterized by considerable evolution prompted by scientific and technological progress, societal changes, and the growth of pedagogical thought. In modern didactics, special attention is given to students' individual characteristics, their needs, abilities, and rates of learning. Personalized educational plans and approaches allow each learner to move along their own path. Instructors adapt tasks and methods to each student's level and learning style. This supports more effective assimilation of knowledge and development of abilities.

A hallmark of modern didactics is its emphasis on the competency-based approach. Contemporary didactics aims not only at transmitting knowledge but at developing not only professional but also transferrable competencies such as critical thinking, communication, collaboration, problem solving, digital literacy, etc. Learning is oriented toward preparing students for real life and professional activity. Competence development often occurs through integrated classes in which knowledge from different subjects is combined to solve concrete tasks. This allows students to see the connections between disciplines and real life applications.

The use of computers, the internet, mobile applications, interactive whiteboards, and other digital technologies has become an integral part of modern learning. ICT enables creation of interactive materials, delivery of distance learning, and increased accessibility of education. Models of learning based on Massive Open Online Courses (MOOCs) and educational platforms like Google Classroom or Moodle facilitate dissemination of knowledge and access to educational resources on a global scale.

Combining traditional (in-person) learning and online (distance) formats has become a popular approach, offering flexibility and adaptation to different conditions, including during pandemics or remote working environments. Students are engaged in designing and executing educational projects, allowing them to apply knowledge in practice, develop teamwork and independence.

At the current stage of social development, approaches to quality control in higher education have changed. Assessment has become more process-oriented and focused on supporting learning. Formative assessment implies continuous feedback, adjustment of the learning process, and helping students achieve better results.

Modern didactics orients teaching activity toward partnership and collaboration, assuming more horizontal relationships between instructors and students. The teacher acts not just as a source of knowledge but as a mentor who supports and fosters the student's development.

Thanks to globalization, students and lecturers have opportunities to participate in international exchange programs, cooperate with foreign universities, and access knowledge from all over the world. Contemporary didactics targets developing students' ability to understand and respect other cultures, which becomes an important skill in a globalized world. Another key feature is equal access to education. Modern didactics actively implements an inclusive approach, ensuring equal opportunities for all students, including those with special educational needs, aiding their adaptation and integration into the university environment.

Thus, modern didactics is multifaceted, flexible, oriented toward personality development, ensuring equal access to quality education, and preparing students for the challenges of the contemporary world.

The educational process in higher education should be seen as a system organizing learning, upbringing, and development of students in higher education institutions. It includes a set of actions and measures aimed at acquiring knowledge, forming professional skills and competences, and developing personality. Education as a process is dynamic and systematic, aimed at personal development, acquisition of knowledge, abilities, and skills. This process includes not only information transfer from instructor to student, but also active interaction, independent inquiry, and the practical application of knowledge.

This process is guided by both national higher education standards and individual institutions' educational programs, which allow preparation of highly qualified specialists.

Among the main components of the educational process one can distinguish academic activity, research activity, upbringing activity, practical training, and technological aspects. Let us consider each of these components as a dynamic part of the educational process:

- Academic activity involves organizing lectures, seminars, and practical sessions. Out-of-class work includes preparation for classes and independent work (essays, research, projects). A special form of academic activity is assessment (tests, exams, quizzes, etc.).
- Research activity is an integral component of modern higher education. It helps develop research skills, critical thinking, independent analysis, and synthesis of knowledge. Student research activities include preparation of coursework and theses based on scientific inquiry in their specialization; writing a master's thesis (in which a student deeply investigates a problem and proposes a novel solution); participation in scientific conferences (presenting research, publishing abstracts); publishing scientific articles (individually or in coauthorship with faculty); involvement in research clubs; developing projects or startups; applying for grants; conducting experimental research

in laboratories or field conditions. Research involvement increases professional preparation and broadens knowledge and skills essential for future scientists and specialists.

• Upbringing activity in the university focuses on cultivating moral and ethical values, social and civic engagement of students. Instructors and mentors, through courses, discussions, and real life examples, foster behavior norms, integrity, mutual respect, tolerance, and honesty. Students learn ethics, human rights, civic education, and may engage in community work, volunteer projects, charity actions, fostering empathy, social responsibility, and awareness of aiding others. Participation in student self-government develops leadership and management skills.

Patriotic education is fostered through events tied to national holidays, cultural traditions and history; involvement in projects preserving historical heritage, national identity, and fostering patriotic consciousness.Emphasis is placed also on healthy lifestyle formation via sports, clubs, marathons, training and lectures on healthy nutrition, physical activity, prevention of harmful habits, mental health support via counseling, stress and burnout mitigation.

Cultural and aesthetic education involves student engagement in cultural events: theatre, literary evenings, exhibitions, film screenings, concerts. Universities support creative student groups (choirs, theatrical studios, music bands), fostering creativity.

In a technogenic world, ecological consciousness is vital. Hence, universities conduct ecological campaigns, highlight environmental protection issues, promote sustainable resource use, involve students in greening and cleanup initiatives.

Universities provide psychological support: counseling and personal development trainings help students manage adaptation to academic life, stress, motivation, self-esteem. Institutions actively implement measures ensuring equal opportunities for all students, regardless of social, ethnic, physical characteristics, and inclusive education to integrate students with special needs.

Thus upbringing activity aims at holistic development of the student, helping them become responsible, engaged citizens and professionals capable of making ethical decisions in their future life and career.

Practical training is a vital component aimed at developing professional skills and competences required for future work in their field. It bridges theoretical knowledge with real professional conditions, allowing students to gain practical experience. Types of practical training vary: internships in enterprises, institutions, organizations matching their specialization, enabling direct application of theoretical knowledge to professional tasks. Industrial practice enables gaining valuable field experience. Pre-diploma (capstone) practice occurs near the end of study, often before the diploma defense, deepening knowledge in the chosen domain and preparing materials for the thesis. Students work on concrete tasks tied to their diploma project or research topic.

Within academic settings, students perform lab work, practical tasks, and projects in university or specialized labs, applying knowledge from lectures in sciences, engineering, medicine, informatics, etc. Educational projects and internships become increasingly common: students may execute real projects with companies, preparing business plans, engineering designs, social programs. Internships in companies or government agencies deepen skills and may lead to employment post-graduation.

Dual education (blended work and study) is also spreading: a model combining theoretical university instruction with practical work on site. Students work in enterprises while continuing studies. This approach lets students simultaneously gain knowledge and hands-on experience under real production conditions.

Students may engage in research or practical projects funded by universities or external bodies, helping them develop research competencies. In some fields (medicine, education, aviation) practical training may include simulation exercises, replicating real-world professional situations (e.g. patient treatment, flight control, conducting lessons).

Students may also independently work on real projects or create startups during study, applying knowledge in practice, gaining experience in business or client interaction. Thus practical training gives students real experience necessary for successful adaptation to modern labor markets and professional growth.

Among the fundamental elements of education as a dynamic process, the following must be considered:

1. Educational goals: defining what is to be achieved in learning — which competences, knowledge, and skills should be formed. Goals may be general (personality development) or specific (mastery of particular disciplines).

2. Content of education: the material covered in the process, including scientific knowledge, cultural values, moral and ethical norms.

3. Methods and forms of instruction**:** the approaches and means by which knowledge and skills are acquired — lectures, seminars, practical tasks, interactive methods, projects, etc.

4. Subjects of the educational process: instructors and students. Both actively interact: the student is an active participant who does not only receive knowledge but contributes to constructing it.

5. Educational outcomes: not only accumulation of knowledge, but the development of the student’s personality — their thinking, creativity, capacity for critical analysis and self-development.

6. Feedback**:** a crucial element enabling evaluation of learning effectiveness: tests, assessments, discussions that allow instructor and student to appraise achieved outcomes.

In general, higher education as a process is characterized by continuity (education continues throughout life — lifelong learning, from early childhood to adulthood), social character (learning occurs in a social context and influences personal socialization), adaptivity (the educational process continuously changes under influence of scientific and technological progress and social needs), and cultural context (education helps transmit a society’s cultural and moral values).

Thus, education as a process is multifaceted, not only providing knowledge transmission but facilitating holistic development of individuals and society.

One of today's strategic directions in higher education is the approach of teacher-researchers to higher education as both science and art. Higher education as a science is an interdisciplinary field that studies the higher education system from pedagogical, social, economic, psychological, managerial, and other perspectives. This science analyzes, develops, and refines principles, methods, forms, and structures of the educational process that ensure preparation of qualified specialists and growth of society's scientific potential.

The main research directions of higher education as a science are presented in Table 3.

Table 3.

Research direction"	Contents
Higher education pedagogy".	Research on effective teaching methods and organizational forms. Development of advanced pedagogical technologies, interactive teaching methods, curriculum design, and student assessment. Study of innovative approaches to learning, including the use of distance learning technologies and inclusive education.
Philosophy and theory of education".	Study of the essence, goals, and mission of higher education in the context of societal development. Analysis of ideas and concepts of higher education in terms of their impact on society, culture, and the economy. Examination of ethical issues in higher education, such as academic integrity, equal access to education, and university autonomy.
Sociology of education	Research on the social role of higher education and its impact on social mobility, economic growth, and culture. Analysis of the social structure of universities, interactions between students and faculty, and the formation of academic communities. Study of the influence of education on social processes, professional values, and the career strategies of graduates..
Economics of higher education".	Research on the financing of higher education, the role of the state and the private sector in organizing educational processes. Study of the impact of higher education on economic development, workforce training, and innovation. Analysis of the economic efficiency of educational programs, the cost of education, and its return on investment for society and individuals.
Psychology of education	Research on the psychological aspects of learning, such as student motivation, cognitive processes, and personal development. Study of students' adaptation to new learning conditions and the formation of professional identity. Development of psychological support programs for students and faculty.

Continuation of table 3

Education management"	Research on models and practices of management in higher education institutions. Study of the role of leadership in education, organization of educational processes, and university governance. Analysis of higher education development strategies at the national and international levels, especially in the context of globalization..
Internationalization and globalization of education"	Research on the impact of globalization processes on higher education, student and faculty mobility, and international university cooperation. Study of trends in the internationalization of higher education, including exchanges, dual degree programs, and English-taught programs.
Innovations in higher education	Development of new approaches to organizing learning, such as distance learning, blended learning, and the use of artificial intelligence and big data in educational processes. Study of the impact of technologies on the creation of educational content and communication between faculty and students.
Academic culture and ethics	Research on issues of academic integrity, plagiarism prevention, and the development of ethical standards in scientific and educational activities. Analysis of interactions between faculty and students, and the formation of academic traditions.
Assessment and quality control of higher education	Development of quality assessment systems, accreditation of educational programs and institutions. Research on the impact of various assessment methods on the effectiveness of the educational process.

Source: summarized by the author based on [1, 3, 6, 8]

Higher education as a science studies various aspects of the functioning of higher education institutions and educational systems in general, focusing on finding effective approaches to improving the quality of education and adapting it to modern challenges and societal needs.

Considering higher education as an art emphasizes that the learning process in higher education institutions is not only a rational transmission of knowledge but also a deeply creative process that involves intuition, inspiration, and an individual approach. It is the art of teaching that shapes not only professionals but also creative, free individuals capable of critical and creative thinking. This perspective views the educational process as a creative and individualized activity that goes beyond the technical aspects of learning and requires a creative approach to teaching, learning, and managing the educational process. In this context, higher education is seen not merely as a mechanical transfer of knowledge but as a process that demands intuition, inspiration, innovation, and a personalized approach.

Teaching in higher education requires educators to adapt to different types of students, approach material creatively, and use innovative teaching methods. Educators do not simply transfer knowledge but create a unique learning environment that inspires students toward creativity, critical thinking, and independent research. Teaching can be likened to artistic performance, where the educator improvises and adapts depending on the situation, making the learning process lively and engaging. Higher education promotes not only professional skills development but also the formation of aesthetic taste, cultural understanding, and values important for students in the modern world.

Students may study not only purely technical disciplines but also integrate cultural, artistic, and philosophical elements that help them gain a deeper understanding of the world. Coursework and thesis work can take on a creative character, where students freely experiment with new ideas and approaches.

The interaction between teachers and students is a special "art of communication," where it is important to find a balance between guidance and freedom. Educators act as mentors, helping students find their own path and voice in the professional environment. The educational environment is viewed as a space for dialogue, where new ideas, thoughts, and creative approaches to problem-solving are born.

Education as art involves an active role for students in creating their own educational experience. Students become co-authors of the learning process, taking responsibility for their development and striving for individual achievements. The learning process ceases to be one-sided: students do not passively receive knowledge but actively shape their own path by exploring new ideas and approaches.

Higher education as art requires intuition and the ability to consider the emotional state of students. Educators must understand the emotional and psychological needs of their students to help them overcome challenges and obstacles. Teaching can be not only a rational process but also one that engages emotions, inspiration, and intrinsic motivation. Like artists, educators often need to improvise and adapt to various situations. Depending on the student group or circumstances, methods and approaches may change. Just as an artist adapts to changes in their work, educators constantly adjust the teaching process according to students' needs and current global events.

Innovative approaches to organizing learning, including the use of cutting-edge technologies such as virtual reality, interactive platforms, and artificial intelligence, can be regarded as the art of creating new forms of learning experiences.

Higher education is constantly transforming, opening new forms and methods that combine a creative approach with technological innovations.

Universities can be spaces where students experiment with their ideas, freely express themselves, and find new ways for self-expression in scientific and practical fields.

It is important that the educational process is not limited by formal requirements but creates opportunities for the development of students' unique talents and abilities.

The fundamental rules and guidelines that define an effective process of acquiring knowledge, skills, and competencies form the system of learning principles. They reflect the regularities of the learning process and help organize learning to be as productive as possible.

Changes occurring with societal development transform the system of learning principles. For example, in the Middle Ages, education was based on religious, philosophical, and authoritarian principles. Traditional principles at that time included theocentrism (God at the center), authority of tradition, scholasticism, Latin language, church monopoly on education, the seven liberal arts, mnemonics, and memorization. The principle of theocentrism defined serving God and the salvation of the soul as the primary goal of education. All knowledge was considered derived from divine revelation. The Bible and works of the Church Fathers were regarded as the main sources of knowledge.

According to the principle of authority of tradition, knowledge was perceived as immutable, passed down from ancient authors and church teachers. Great importance was given to authority figures — notably Aristotle, Augustine, and Thomas Aquinas. Students were not encouraged to engage in critical thinking.

The principle of scholasticism defined methodological approaches to education. The main teaching method in universities was based on combining logic (mainly Aristotelian) with theology. Education was conducted through disputations, syllogisms, and logical analysis.

Latin was recognized as the main language of education, science, and the church. All educational materials were written and taught in Latin. Knowledge of Latin was a mandatory requirement for access to higher education.

The principle of church monopoly on education was reflected in the fact that in the early Middle Ages, schools were organized in monasteries, cathedrals, and later universities. Secular education developed very slowly. The main teachers were monks and priests.

The principle of the seven liberal arts formed the basis of the curriculum: the trivium — grammar, rhetoric, dialectic (logic); the quadrivium — arithmetic, geometry, music, astronomy.

The principle of mnemonics and memorization reflects the essence of teaching methods. The primary method was rote learning. Repetition and declamation were the key to mastering the material.

Modern learning principles differ fundamentally from those mentioned above.

Adhering to learning principles is important as they ensure the effectiveness and quality of the educational process. Learning principles are fundamental rules or guidelines that help organize the learning process to promote the maximum development of students' knowledge, skills, and competencies.

The development of the personality of the future specialist can be considered the main task of higher education, which indicates the necessity of its humanization. Therefore, scholars particularly emphasize the principle of humanization of education as a foundational principle of higher education.

Classification of learning principles allows for a better understanding of which approaches can be applied at different stages of the educational process to ensure maximum learning efficiency. Various classifications can be combined depending on specific educational conditions, student levels, and learning objectives. There are several approaches to classifying learning principles, each highlighting different aspects of educational activity. Below are the most common classifications of learning principles (Table 4).

Table 4

Classifications of Learning Principles

Classification feature	Principles of learning
According to didactic requirements (traditional classification) This classification is based on the requirements for organizing the learning process.	Principle of scientific approach: Learning should be based on modern scientific achievements. Principle of systematicity and consistency: Educational material should be presented in a sequential and systematic manner. Principle of accessibility: Material should correspond to the students' level of preparation and gradually become more complex. Principle of visuality: Use of visual methods and tools to facilitate understanding of the material. Principle of consciousness and activity: Learning should be conscious, and students should actively participate in the process. Principle of knowledge retention: Material should be retained for a long time through repetition and reinforcement. Principle of connecting theory with practice: Knowledge should be applicable in real-life or professional situations.
According to the nature of the activities of the teacher and the student This classification focuses on the activity and interaction between the teacher and the students.	Principle of activity: Students should actively participate in the learning process, ask questions, engage in discussions, and solve problems. Principle of independence: Students should be capable of working independently with the material, thinking critically, and drawing conclusions. Principle of encouragement and motivation: The teacher should motivate students to learn and create conditions for the development of intrinsic motivation. Principle of individualization of learning: Learning should take into account the personal needs, abilities, and interests of each student.
According to the logic of the learning process Principles that reflect the stages and organization of the learning process.	Principle of gradual complication: Start with simpler concepts and gradually move to more complex ones. Principle of repetition: Ensure regular repetition of learned material for reinforcement. Principle of knowledge integration: Combine knowledge from different subjects to provide a holistic understanding of the issues. Principle of problem-based learning: Present students with problematic questions to develop critical thinking..

Continuation of table 4

According to the psychological aspects of learning Classification of principles based on psychological and pedagogical research.	Principle of considering age and psychological characteristics: Methods and approaches should take into account the age-related, cognitive, and emotional characteristics of students. Principle of positive motivation: Teaching should stimulate students' interest and desire to learn. Principle of fostering motivation for learning activities: Emphasis on developing students' intrinsic motivation to learn. Principle of developing self-control and self-assessment: Students should be able to independently evaluate their achievements and monitor the learning process.
According to the focus on content or form of learning Principles that emphasize the content or organization of the learning material.	Principle of meaningfulness: The material should be meaningful, meet scientific standards, and be relevant. Principle of formalization: The learning process should be clearly structured, with its stages interconnected. Principle of coherence: Different topics and aspects of learning should be interconnected.
Innovative principles of learning This classification corresponds to modern approaches to learning in conditions of rapid changes and technological innovations	Principle of learning through practice: Learning should be oriented towards solving practical tasks. Principle of technology use: Active implementation of modern technologies to enhance the effectiveness of the learning process. Principle of learning through research: Involving students in scientific research and project work as part of the educational process. Principle of flexibility and adaptation: The learning process should be flexible to adapt to students' needs and contemporary challenges.

Source: summarized by the author based on [3, 7, 9].

Let us examine in more detail some of the above-mentioned principles of learning.

Principle of scientific approach:The principle of scientific approach means that the educational material should correspond to modern scientific knowledge and be relevant to contemporary science and practice. This is important to ensure high-quality education and to prepare students capable of working in conditions of rapid changes in science and technology.

Principle of systematicity:Knowledge should be presented logically, sequentially, and in connection with previous experience. The principle of systematicity implies a logical and consistent organization of educational material, allowing students to gradually build their knowledge and understanding of the subject.

Adhering to this principle helps students better absorb new information and avoid confusion and chaos.

Principle of activity:Students should actively participate in the learning process, independently seek answers, and solve problems. The principle of activity stimulates students to engage actively in learning, develop critical thinking, and solve problems independently. Active learning promotes better retention and understanding of material as well as the development of creative thinking and self-directed work skills.

Principle of consciousness and retention:Knowledge should be deeply and reliably assimilated so that it can be used in various life situations. The principle of consciousness emphasizes the importance of a conscious approach to learning, where students understand the goals and significance of the material they study. Adhering to this principle fosters the development of independent thinking and the ability to work autonomously, which is crucial for professional growth.

Principle of individualization:The learning process should take into account the individual characteristics, abilities, and learning pace of each student. The principle of individualization requires considering the personal traits of each student: their learning pace, preparation level, interests, and motivation. This allows adapting the learning process to meet the needs of each student, ensuring more effective knowledge acquisition and development of individual abilities.

Principle of accessibility:Educational material should correspond to the students' level of preparation and development. It is important that the material is accessible for understanding by students considering their preparation level. The material should not be too difficult or too easy. Following this principle ensures gradual complication of material, allowing students to progress from simple concepts to more complex ones.

Principle of visuality:The use of visual aids (diagrams, charts, images) facilitates better knowledge assimilation. The principle of visuality means using visual materials, examples, and demonstrations during learning. This helps students better understand abstract concepts and imagine how they work in practice. The use of diagrams, charts, models, videos, etc., makes learning more comprehensible and accessible for students with different learning styles.

Principle of motivation:The learning process should support the student's intrinsic motivation for knowledge and development. The principle of motivation emphasizes the importance of stimulating students' internal desire to learn. Motivated students are more interested in learning and willing to put in more effort to achieve results. Motivation helps students not only acquire knowledge but also maintain interest in learning throughout the entire educational period.

These principles help create effective educational systems and teaching methods, providing optimal conditions for the development and self-realization of students.

1.5 Transformation of the Content of Education and Teaching Methods as Key Categories of Higher Education Pedagogy

The Content of Education is the totality of knowledge, skills, abilities, values, as well as ways of thinking and activities that a student must acquire during the learning process. It defines why and how to teach, and what is studied in higher education institutions.

The content of education constantly changes according to the demands of society. For comparison, let us consider the main features of the content of education in the Middle Ages. In the Middle Ages, the content of education was closely linked to religion, as well as to the needs of the church, the state, and feudal society. Education was based on the "seven liberal arts" (septem artes liberales), divided into two levels: the trivium and the quadrivium. The trivium (the initial level) included grammar (study of Latin); dialectic (logic) (basics of thinking and argumentation); rhetoric (the art of eloquence). The quadrivium (the higher level) involved the study of arithmetic (elementary mathematics), geometry (basic geometric knowledge), music (mainly music theory with a mathematical approach), and astronomy (mostly astrology based on ancient knowledge).

In modern understanding, the content of education reflects the following aspects: knowledge, skills and abilities, activity and thinking, value orientations. Knowledge is viewed from two perspectives:

1. Knowledge as a result of human cognitive activity, which includes the accumulation of information about the surrounding world, phenomena, events, processes, and patterns. Knowledge helps people understand reality and use this information to solve problems, make decisions, and improve their lives. Knowledge can be transmitted through education, experience, or media, and is an important part of the learning and development process of humanity.

2. Knowledge as a collection of information that a person acquires, accumulates, and uses to understand the surrounding world. It can result from personal experience, observation, learning, or research and forms the basis for further development and decision-making. Knowledge is a key element in the development of both the individual and society because it enables problem-solving, the creation of new technologies, and progress in various areas of life.

Both viewpoints do not exclude but complement each other. Knowledge can be conditionally divided into three types:

- Factual knowledge — specific data, facts, and information about the world (e.g., historical events, mathematical laws);
- Theoretical knowledge — systematized and generalized knowledge that explains connections between facts, principles, and patterns (e.g., theories in physics, sociology);
- Practical knowledge — skills and abilities necessary to perform certain actions or tasks (e.g., driving a car, playing musical instruments).

Skills and abilities characterize a person’s capacity to perform certain actions.

- Ability is the capacity to perform specific tasks or actions based on acquired knowledge. Ability is developed through learning or practice and is based on understanding the principles and rules governing the activity. Examples of abilities include solving mathematical problems, creating technical drawings for an engineer, or drafting technical plans. Abilities usually require cognitive effort and may involve analytical, creative, and other thinking processes.

- Skills are automated actions performed without constant conscious thought. Skills are formed through continuous practice and repetition. They generally require less conscious control and allow for quick and effective performance. For example, typing skills, driving a car, or playing a musical instrument. Skills often complement abilities — for instance, a person might have the ability to play chess (understanding rules and strategies) and the skill of quickly evaluating the situation and moving pieces. Thus, abilities imply conscious application of knowledge, while skills are automated actions performed with minimal cognitive effort. Both are related to practical actions and ways of applying knowledge.

The content of modern education also reflects activity and thinking, associated with the development of cognitive and creative abilities.

The content must reflect a connection to real life. Educational programs are often designed to address current societal tasks and challenges. They prepare students to solve real-world problems, stimulating analytical and critical thinking.

Modern educational content is aimed at forming competencies that meet societal and labor market demands. This includes professional skills (working with information, communication) as well as soft skills (collaboration, adaptability), requiring active engagement and critical thinking.

Many educational programs involve problem-based learning methods. Students are presented with real or simulated problems that require analytical thinking, creative solutions, and collaboration.

Student activity in the educational process increasingly includes interactive methods – group work, project activities, discussions. This stimulates not only active participation but also reflection on their own thinking and problem-solving approaches.

Curricula are more and more focused on developing critical thinking, which involves analyzing information, questioning ready-made solutions, and seeking alternative viewpoints.

Thus, the content of education not only reproduces activity and thinking but also actively shapes them, encouraging students' active participation in the learning process and the development of necessary competencies.

Value orientations play a key role in shaping the content of education, as they determine which ideas, beliefs, and principles should be conveyed through the educational process. Value orientations focus on moral education, civic and social values, cultural and ecological values, individual development and self-realization, inclusivity, and equality.

Therefore, the content of education often includes elements aimed at forming ethical norms and principles. This may be part of subjects like civic education, history, or literature, which emphasize moral dilemmas, values of honesty, justice, and equality.

Educational programs typically include aspects of civic responsibility, human rights, social justice, and tolerance. They aim to cultivate conscious citizens capable of actively participating in public life, respecting democratic principles, and upholding the rights of others.

Through education content, cultural traditions, language, historical heritage, and national identity are transmitted. This helps young people understand their place in the world and their belonging to a cultural community, fostering patriotism and respect for other cultures.

Increasing attention is given to forming ecological awareness in modern educational programs. Students are taught to responsibly treat natural resources, understand the importance of sustainable development, and protect the environment.

The content of education also reflects values of self-development, independent thinking, and responsibility for one's own life. Students are provided with tools to understand themselves, their strengths, and develop skills necessary to achieve personal and professional goals.

An important value is equal access to education and respect for diversity. This is reflected in programs supporting inclusive education, where all students, regardless of their abilities, have the right to quality education.

Thus, value orientations shape the content of education, giving it not only an informational but also an educational dimension, contributing to the development of a holistic, conscious, and responsible individual.

The content of education is regulated by state standards and curricula, which ensure uniformity of learning at all levels and serve as the basis for the creation of educational plans and textbooks.

Designing the content of education is the process of developing educational programs that ensure holistic and effective student learning. This process involves defining goals, content, methods, and means of teaching that meet the requirements of modern society and are aimed at forming key competencies. The algorithm for designing the content of education can be presented in the following stages: definition of learning objectives (General and specific educational goals are defined, reflecting the expected learning outcomes. These goals may be nationwide (at the level of national education standards) or determined by a particular educational institution.); analysis of the educational content (The selection of educational content is based on an analysis of current requirements in the educational field, taking into account scientific achievements, as well as the needs of society and students. The content must be relevant, practical, and correspond to the age and individual capabilities of the students.); selection and structuring of content (The selected content is structured according to levels of complexity, topics, or modules. It is important that the content is consistent and logically organized. The structure of the content includes: theoretical material (key concepts, principles, rules); practical tasks that promote skill development; and integrative elements (connections between different subjects).); orientation towards a competency-based approach (When designing the educational content, a competency-based approach is taken into account, according to which each subject or module should develop specific competencies. This enables students to apply their knowledge in real-life situations.); selection of teaching methods and forms (Forms and methods of teaching are tools that help implement the educational content in the learning process. The content defines which knowledge and skills need to be conveyed, while the forms and methods determine how to do this most effectively. The success of learning and the development of the necessary competencies in students depend on the right combination of these elements.); assessment of learning outcomes (It is necessary to develop an assessment system that effectively measures the achieved learning outcomes. Assessment should be both formative (to monitor the mastery of the material) and summative (to determine the overall level of achievement). Forms of assessment include: testing; practical tasks; portfolios; oral responses and presentations.); implementation and adjustment of the content (After the content is developed, it is implemented in the educational process. Subsequently, based on the analysis of results and feedback from students and educators, adjustments and improvements to the educational program may be made.).

Let us summarize the most common approaches to shaping the content of education in university pedagogical practice, each of which is aimed at achieving certain educational process goals and personal development.

Traditional (Academic) Approach. This approach focuses on transmitting knowledge accumulated by previous generations and is oriented toward the academic development of students. Its main characteristics include: educational programs are based on classical disciplines (mathematics, natural sciences, humanities, etc.); the primary attention is given to the assimilation of scientific knowledge and facts; learning is based on textbooks, lectures, and classical sources.

Competency-Based Approach. The main goal of this approach is to develop competencies in students—that is, a set of knowledge, skills, and abilities necessary for life and work in modern society. Its distinguishing features include: education content oriented toward real practical tasks; important integration of knowledge from different disciplines; the learning process focuses on developing critical thinking, teamwork skills, problem-solving, etc. The essence of the competency-based approach to designing educational content lies in focusing on the formation of specific competencies needed for successful activity in contemporary society. The primary goal is not so much the transmission of knowledge as the development of students' skills, abilities, and personal qualities that allow them to apply knowledge in practice, solve real-life situations, and succeed in various fields. The key features of the competency-based approach include: 1) results-oriented: emphasis is placed on achieving specific educational outcomes such as critical thinking, teamwork, and problem-solving, rather than merely the volume of knowledge acquired; 2) integrated knowledge: competency-based learning involves integrating knowledge from various disciplines to develop interdisciplinary competencies; 3) practical orientation: curricula are designed so that students can apply acquired knowledge and skills in real-life and professional contexts; 4) individualized learning: the approach takes into account the individual needs, abilities, and interests of each student, allowing different competencies to develop at different paces; 5) reflection and self-assessment: an important element is developing the ability for independent analysis of one's achievements, reflection on one's learning, and improvement of personal skills.

Thus, the competency-based approach to educational content design emphasizes preparing students for successful life and work through the development of key competencies, rather than merely acquiring theoretical knowledge.

Personality-Oriented Approach. This approach aims at developing the individual abilities and interests of students: educational content is formed considering students' individual needs and characteristics, learning is more flexible and varied, allowing adaptation of the program to the individual; students are involved in choosing subjects and forming educational trajectories. The essence of the personality-oriented approach in education is that the student's personality, with their individual needs, interests, abilities, and experience, is the central element of the learning process. This approach aims to develop the personality as a whole, independent, and self-sufficient individual capable of self-development and self-realization. The main aspects include: 1) individualized learning (the process is built considering each student's unique characteristics such as abilities, learning pace, cognitive style, preparation level, and personal interests; tasks may be adapted; different learning styles such as visual, auditory, kinesthetic are considered; each student can study material at their own level and pace); 2) development of independence and critical thinking (the approach fosters students' skills for independent thinking and decision-making; students are actively engaged, developing abilities to analyze, critically evaluate information, and solve problems); 3) focus on student motivation and interests (one of the key goals is creating conditions for the development of intrinsic motivation; teachers consider student interests and offer tasks that stimulate a desire to learn, e.g., students may choose project or research topics according to their preferences); 4) teacher’s role as mentor (the teacher is not just a source of knowledge but a mentor who helps the student acquire knowledge independently, develop their interests and abilities, supporting and guiding without imposing opinions); 5) humanization of the learning process (respect for the student's personality, rights to self-expression and self-development, creating a psychologically comfortable environment where each student feels valued, protected, and motivated); 6) development of life competencies (the approach helps students develop skills necessary for successful self-realization in life, including social skills, cooperation, responsibility, adaptability, and problem-solving); 7) consideration of the emotional sphere (attention to students' emotional state; the teacher supports positive self-esteem, helps overcome difficulties and conflicts, and stimulates emotional intelligence development); 8) alignment of learning with societal needs (since modern society demands adaptability, lifelong learning, and independence, this approach prepares students for these challenges by developing autonomy and flexibility in decision-making).

The personality-oriented approach places the student at the center of the educational process and aims to develop them as a unique individual. It creates conditions for individual development, encourages independence and responsibility, and supports motivation and interest in learning, contributing to successful knowledge acquisition and formation of necessary competencies for modern life.

Project-Based Approach. This approach is based on the concept of learning through project implementation: students study material by carrying out specific projects that require research, planning, and creative approaches; project activities develop independence, organizational skills, and responsibility. This approach ensures practical application of knowledge in real-life situations.

Systemic Approach. This approach views education as an integrated system where each component interacts with others. Educational content is formed based on a systematic approach to organizing knowledge and skills, considering comprehensive personality development: intellectual, social, emotional, moral. The systemic approach allows educators to analyze and design educational processes considering their structure, component interactions, and external influences. The pedagogical system is regarded as a whole, where all elements (teachers, students, teaching methods, educational materials, organizational structure) are interconnected and influence one another. The educational process has a specific structure, distinguishing elements such as goals, content, methods, forms of organization, and learning subjects. Components interact closely, for example, changing teaching methods affects the effectiveness of achieving educational goals. The system is built around achieving pedagogical objectives like forming knowledge, skills, and competencies. An important condition is feedback mechanisms that allow correcting the process based on learning outcomes. The pedagogical system is not static; it continuously changes, adapting to new conditions, students' needs, and societal demands. The systemic approach helps optimize the learning process, increase its effectiveness, and ensure the all-round development of the student's personality.

Integrated Approach. This approach involves combining various disciplines and fields of knowledge to form a holistic view of the world. In integrated educational content, learning is based on the integration of knowledge from several areas such as natural sciences, social sciences, arts, etc. This organization helps students understand interconnections between different sciences and real-world phenomena. The integrated approach in pedagogy combines knowledge and methods from various subjects and fields to create a unified learning process. Its goal is to develop students' comprehensive understanding of real phenomena, promote systemic thinking, and the ability to apply knowledge in different life situations. This approach enables students to see links between different subjects and disciplines, improving their understanding of the world as a unified system. Lessons or curricula are built around interconnected topics and concepts from multiple subjects, e.g., combining natural sciences and mathematics, literature and history. This allows students to apply knowledge in various contexts. The integrated approach often uses real-life situations that require knowledge from multiple fields to solve, fostering critical thinking and problem-based learning skills. Integration helps students analyze complex processes and phenomena from multiple perspectives, seeing cause-and-effect relationships. It supports adapting curricula to students' needs and current demands, using various methods such as project-based learning, group work, discussions, etc. Since integration builds learning around real student interests and needs, it increases motivation and supports deeper knowledge assimilation. It helps students not only acquire knowledge but also learn to think flexibly, apply knowledge practically, and solve problems comprehensively.

Ecological Approach. This approach aims to develop a responsible attitude toward the environment and ecological consciousness. Educational content based on this approach includes ecological aspects and focuses on fostering responsible citizenship, with learning centered on understanding the relationship between humans and nature. The ecological approach in higher education integrates ecological principles and sustainable development ideas into the learning process and upbringing. This prepares specialists aware of the need for harmonious interaction between humans and nature and capable of addressing modern ecological problems. Curricula include courses, subjects, and topics highlighting environmental issues, sustainable development, rational use of natural resources, and environmental protection. This enables students to acquire knowledge of current ecological challenges and methods for their resolution. The approach promotes responsible attitudes towards nature, awareness of ecological safety, and the necessity to preserve natural resources for future generations. Students are provided opportunities to participate in ecological projects, research, and volunteer programs where they can apply ecological knowledge practically, helping develop skills for solving real ecological problems. The ecological approach in higher education combines knowledge from various fields—biology, geography, economics, sociology, law, etc.—allowing students to view ecological problems holistically and seek solutions considering different aspects of human-nature interaction. Ecological ethics education is a vital component, teaching students not only scientific ecology basics but also ethical attitudes towards the environment, the importance of biodiversity and ecosystem preservation. Research activities in universities also become “ecologized” — ecological and ecosystem process studies are conducted, innovative technologies developed to reduce environmental impact. A significant outcome of this approach is preparing specialists able to make professional decisions considering ecological consequences and work in conditions where ecological responsibility is key. Overall, the ecological approach fosters systemic thinking, critical analysis skills, and responsible attitudes towards nature, essential for solving modern global ecological problems.

Each of these approaches can be applied individually or in combination, depending on educational goals, students’ needs, and societal demands.

Thus, designing educational content is a dynamic process that takes into account contemporary requirements, individual student needs, and scientific-methodological approaches to teaching.

Modern approaches in education set directions for improving teaching methods in higher education. Opportunities for developing effective teaching methods and technologies in universities are rapidly increasing. Research by educators and psychologists has shown that knowledge and activity methods are assimilated at three levels: conscious perception and memorization; applying knowledge and activity methods by example or in similar situations; creative application. Since teaching methods have multiple characteristics, many classifications exist based on various criteria. Methods are classified by sources of transmission and the nature of information perception. According to these characteristics, verbal, visual, and practical methods are distinguished. Depending on the main didactic tasks realized at a specific stage, methods are divided into knowledge acquisition, skills formation, application of acquired knowledge, creative activity, reinforcement, and assessment of knowledge, skills, and abilities. According to the nature of students' cognitive activity in mastering educational content, explanatory-illustrative (information-receptive), reproductive, problem-based, partially exploratory or heuristic, and research methods are distinguished. A popular model combines knowledge sources, cognitive activity and independence levels of students, and the logical path of learning cognition. In the

2000s, a classification considering four aspects of methods—logical-content, source-based, procedural, and organizational-managerial—was proposed.

It is worth emphasizing that Ukrainian scholars actively use both traditional classifications and develop new ones considering humanistic, personality-oriented, and competency-based approaches. For example, today in Ukrainian pedagogy, classification by sources of knowledge transmission proposed by O.Y. Savchenko and S.U. Honcharenko is used. This approach focuses on means and channels of information transmission mentioned above: verbal methods—lecture, explanation, conversation, discussion, reading; visual methods—demonstration, illustration, observation; practical methods—exercises, laboratory work, practical classes, modeling. Classification by the degree of student independence was developed by O.I. Pometun and L.V. Pyrozhenko in the context of implementing the competency-based approach.

In general, across all classifications, it is possible to distinguish between traditional and innovative teaching methods. Among the traditional teaching methods, methods for organizing and conducting cognitive activities are identified.

Innovative methods include interactive methods—actively involving students in the learning process (discussions, projects, debates, role-playing games), personality-oriented methods—taking into account students' individual characteristics (individual assignments, differentiated learning), and others, which we will examine in more detail below.

To date, significant experience has been presented in the scientific literature regarding the improvement of teaching methods based on innovative approaches and information technologies. Therefore, we focus attention on only one method that contributes to increasing motivation, develops students' thinking, and effectively forms professional competence. One such method today is considered business games. The essence of gamification in education lies in the use of game elements, mechanics, and thinking in the learning process with the goal of increasing motivation, engaging students, and improving learning outcomes.

The history of introducing business games into the higher education process is an example of the evolution of educational methods from passive knowledge acquisition to active, practice-oriented learning. Several key stages can be identified in the gamification of education. The United States were pioneers in using business games in business education. In 1956, the first officially documented business game was developed: "Top Management Decision Simulation" at Harvard Business School [8]. The purpose of the game was to simulate business decision-making processes for students in management specialties. This game modeled company operations, where participants acted as managers and had to make decisions regarding finance, marketing, production, and so on.

From 1960 to 1970, business games spread in Europe. European universities began adapting American models of business games. In Germany, France, and the United Kingdom, business games became part of MBA programs. The main emphasis when using business games in European universities was on simulation learning and the development of managerial thinking.

In the 1990s, with the collapse of the USSR and the transition to a market economy, business games also began to be actively introduced in business education in Ukraine and other post-Soviet countries. Economic, management, and marketing simulations appeared in universities. Role-playing games, case studies, and situational modeling became widespread.

The modern stage (2000s–2020s) is characterized by the introduction of digital business games, simulators, and online platforms (for example, Capsim, Marketplace, Business Strategy Game). The development of gamification in learning progresses toward using game elements in non-game environments. Today, the goals of using business games in higher education are connected with the development of practical skills (management, analysis, teamwork), decision-making training under uncertainty, formation of leadership qualities and soft skills, and integration of knowledge from various disciplines into a coherent system.

It is no coincidence that leading universities worldwide actively use business games in the educational process. For instance, students at Grenoble School of

Management (France) participate in the Cesim Global Challenge business simulation for four days [12]. The game allows students to understand the interaction of different functions (marketing, HR, finance, ethics, etc.) and realize the impact of their decisions on the overall results of the company.

In Finnish universities, particularly Saimaa University of Applied Sciences, the Cesim business simulation suite (Global Challenge, SimFirm, Hospitality, etc.) is used over 8–10 weeks [12]. Instructors encourage students to develop strategies, conduct competitive analysis, and keep learning journals. International team competitions with German and Dutch universities have also been implemented.

Another example is Aarhus University (Denmark). Within its entrepreneurship program, several specialized games have been developed: LeapInTime (intellectual property), Savvygoat (team interaction), and ESHIP: Navigating Uncertainty (decision-making under uncertainty) [12]. Results showed a positive effect on the entrepreneurial mindset of future specialists. Analysis of scientific works indicates that most business games model management processes, business analysis, and strategic decision-making. However, we emphasize that currently few business games are developed in universities for students in engineering and technological specialties aimed at forming professional competence related to the engineering and technological components of the specialist's profile.

Today, there are almost no proposals for business games for students in technological fields such as food processing or mechanical engineering. There is also a lack of research on the implementation of business games in the general technical training process, particularly in graphic preparation of future engineering specialists. Therefore, we consider it appropriate to present research results on the development of business games for students studying Food Technology (G13) and Mechanical Engineering (G11) specialties during the study of engineering and computer graphics. Understanding technical documentation is an important part of the professional activity of engineers and technologists. Specialists must be able to navigate technical drawings of equipment, structures, technological lines, etc. Without adequate graphic training, this is impossible since technical documentation is the language of technology. In scientific and engineering work, it is important to be able to visually present research results in the form of diagrams, charts, and graphs. This allows better understanding, analysis, and discussion of results, as well as presenting projects to investors, farmers, or government bodies. Thus, graphic training is not merely an auxiliary discipline but a necessary component in forming the professional competence of future agricultural specialists. It enables graduates of agricultural universities to be competitive, modern specialists capable of adapting to digital transformations in agriculture. Therefore, studying graphic disciplines is an important prerequisite for a successful career in the agricultural field.

Among the potential opportunities of business games in education that define the goals of their implementation, we highlight the following: development of analytical and strategic thinking; formation of management, planning, negotiation skills; training in teamwork and leadership; actualization and consolidation of knowledge in real or simulated contexts. When developing a business game, it is important to focus on student engagement and motivation, the possibility of safe experimentation, development of soft skills, and practical knowledge testing. We emphasize the need to consider the age and professional characteristics of first-year students. A business game should not only be a teaching method but also a source of motivation to seek new knowledge. Therefore, when developing business games for first-year students, several features related to their age, psychological-pedagogical, and professional aspects should be taken into account. We will explain the essence of these features.

First-year students usually do not yet have deep technical knowledge. Therefore, the business game should be based on basic knowledge (physics, mathematics, computer science). The focus shifts not to the formation of specific professional skills but to the development of general engineering competencies (logic, analytical thinking, teamwork skills, etc.). Thus, it is advisable to avoid overly specialized terminology or provide explanations for them. In the first year, students are still forming their understanding of the future profession. Therefore, the business game should be interesting, interactive, and dynamic, include gamification elements (competition, rewards, storyline), and demonstrate the practical significance of engineering activities in real life. For first-year students, the development of soft skills is critically important. While professionally relevant, they help students adapt faster to the university environment. Primarily, implementing business games in the first year will promote the development of interpersonal communication, critical thinking, and teamwork skills. Therefore, the business game should involve teamwork; tasks should stimulate communication, role distribution, and leadership. Introducing role-playing (e.g., developer, client, project manager) is also important.

Scientific literature provides in-depth research into the psychological and pedagogical characteristics of first-year students that affect the design of business games, as understanding these characteristics is key to their effective organization.

Firstly, first-year students face adaptation difficulties. They must adjust to a new learning format that differs from school—greater independence, responsibility, and the need to plan their own time. However, not all have well-developed self-organization skills, which often causes stress or lower performance. Additionally, emotional instability is observed at this stage. Many students experience socialization difficulties, feel lonely or insecure. It is important for them to feel support, acceptance, and understanding both from teachers and peers. Therefore, a favorable psychological climate in the learning group plays an extremely important role. Equally important is learning motivation, which often lacks deep professional grounding. Some students exhibit extrinsic motivation—a desire to get a diploma, avoid criticism, or achieve social status. The teacher’s task is to help students see the practical value of knowledge, engage them, and form intrinsic motivation for professional growth. It is also important to consider the heterogeneity of students’ preparation levels. Some already have a solid knowledge base; others need more time to assimilate the material. The teacher’s task is to create conditions where everyone can develop according to their level.

A business game allows simulating elements of professional activity with a high level of interactivity. The success of such a game depends not only on its content, structure, and organizational aspects but also on the students’ readiness. Thus, preparation plays a crucial role in achieving the educational goals of the business game. During preparation, students do not simply complete tasks but delve into the topic, study the context, analyze roles, and consider possible scenarios. This forms deeper subject understanding and develops analytical thinking, which is extremely valuable in professional activities, especially for future engineers or technical specialists. Moreover, independent preparation activates self-organization skills, which are key in higher education. Students learn to plan their time, prioritize, and work with information. Such skills directly affect not only the quality of participation in the business game but also overall academic success. It is also worth noting that independent preparation increases personal responsibility for the result. In a business game, there are no “right” answers, but there are consequences of decisions. A prepared student does not act randomly—they argue, propose, analyze, making the game not only interesting but also effective educationally. Preparation for the business game also has a motivational effect. When a student understands the topic, they are interested in participating, defending their position, and seeking unconventional solutions. This creates positive group dynamics, strengthens team interaction, and thus forms valuable collective work experience. Consequently, the business game ceases to be just a “training exercise” and becomes a real simulator of professional thinking. But for this, an active student stance is needed, which begins with conscious, purposeful self-preparation. Independent preparation is a necessary condition for effective participation in the business game. It allows students not just to "play roles" but to feel like participants in a real decision-making process, laying the foundation for future professional success.

The effectiveness of business games largely depends on clear methodological organization. Thoughtful methodological support allows implementing not only didactic but also educational and developmental functions of the business game. The first methodological aspect concerns the targeted design of the game. It is important that the business game has a clearly formulated goal aligned with the educational outcomes of the discipline. The goal should encompass both the formation of professional competencies (e.g., the ability to analyze, make decisions, apply knowledge in practice) and the development of soft skills (communication, teamwork, leadership). The second important element is the scenario, which should logically reflect the stages of a real production or management process. It should anticipate the distribution of roles, the specification of tasks for each participant, the conditions of the problem situation, timeframes, success criteria, and so on. At the same time, the scenario must be open to variability so that students have space for initiative and unconventional solutions. The third aspect is the role of the instructor in conducting the business game. The instructor acts not only as an organizer but also as a facilitator, moderator, and observer. They create conditions for the independent activity of students, direct their attention to key points, stimulate reflection, and analyze the process and results.

The next methodological component is the stage of preparing students. It includes familiarizing them with the game topic, rules, tasks, and theoretical background. At this stage, it is advisable to use instructional materials, reference notes, videos, or simulation models. It is also important to provide effective forms of assessment for the game results. This can be traditional evaluation (considering task completion and correctness of decisions) as well as self-assessment, peer assessment, and evaluation of teamwork. All this contributes to increasing participants' responsibility and forming a reflective stance.

The final methodological step is the stage of analysis and discussion. It allows consolidating the acquired knowledge and experience, comparing it with real situations, discussing mistakes made, and forming generalizations and conclusions.

Only by adhering to the above methodological principles does the business game become an effective tool for the professional training of future specialists.

For first-year students studying the course “Engineering and Computer Graphics” during the first semester, we propose two games: an educational game and a simulation game. The goal of the educational game, conducted in the middle of the semester, is aimed at developing communication skills, teamwork, and so on. The second game is held at the end of studying engineering and computer graphics. This game has a simulation character and allows introducing certain elements of professional orientation to the studied discipline.

The first educational game, "Interview in a Circle," involves participants taking turns interviewing each other. The essence of the interview is to ask and answer questions related to specific topics in engineering and computer graphics. However, a well-formed question should contain an element of problematization, a need for an answer based on the use of graphic images, performing graphic constructions, and so forth. During such "interviewing," active listening skills, the ability to ask questions, and clarify information are practiced. As a result, knowledge in engineering and computer graphics deepens, while interpersonal communication skills are simultaneously improved. The evaluation of such a game should be soft, motivational, and at the same time structured so that students understand which skills they are training. When assessing, special attention is paid to the quality of the questions. Questions should not anticipate a direct answer in the form of definitions of terms. The discussion aspect, dialogue management, and so on are highly valued.

The main criteria for evaluating the game "Interview in a Circle" that we propose are: quality of questions (whether the questions were open-ended, relevant, stimulated storytelling); active listening (the participant listened attentively, did not interrupt, reacted with facial expressions, clarified); consistency and logical coherence of speech (statements were clear, logically constructed); communicative politeness (showing respect to the interlocutor, friendliness, appropriate tone); reflection / feedback (the participant was able to briefly retell/summarize what they learned).

The correctness of participants' answers and statements is also taken into account. Regarding quantitative assessment, points are distributed according to the grading scale of the course syllabus and can be adjusted by the instructor. However, participation in the discussion of the business game results by all participants is considered important. It is advisable to use self-reflection questions: What did I do well? What was difficult? What do I want to try next time? If there are many students, interviews can be conducted in pairs, changing partners every 5 minutes. At the end, a general discussion should be held: "What new things did I learn about others?" "Which questions worked best?" Given the significant lack of instructional time, the game duration is accepted to be 15–30 minutes, followed by a discussion lasting up to 20 minutes.

For first-year students in the first semester, other educational games aimed at developing soft skills can also be used. For example: the educational role-playing game "Negotiations" (goal: to teach participants negotiation skills, argumentation, and reaching compromises); the educational game "Press Conference" (goal: to improve public speaking, the ability to answer unexpected questions); the educational game "Problem Discussion" (case study) (goal: to learn how to argue opinions and conduct discussions).

The author's simulation business game "Project: Technological Process of Hard Cheese Production," held at the end of studying "Engineering and Computer Graphics," has a professional orientation and is developed for first-year (bachelor's level) students majoring in Food Technology, specialty G13, under the field of knowledge G Engineering, Manufacturing, and Construction, qualification: Bachelor in Food Technology. The essence of the game is that students work with design documentation related to the process of hard cheese production, specifically the technological scheme. The scheme is accompanied by a process description and a list of equipment used during the process.

For example, technical equipment for hard cheese production includes:

- Milk tank (for receiving, storing, and transporting milk, equipped with cooling and aeration systems);
- Pasteurization unit (for heating milk to a certain temperature to destroy harmful microorganisms; usually plate or tubular pasteurizers);
- Fermentation tanks (made of stainless steel, equipped with temperature control systems, designed for adding starter cultures and fermenting milk);
- Rennet apparatus (for adding and evenly distributing rennet enzyme in the milk);
- Knives or grids for cutting the curd (mechanical or automated devices for dividing the curd into small pieces);

- Stirrers or mixers (for gently stirring the cheese grains during heating and whey separation);
- Cheese presses (hydraulic or mechanical presses for compacting the cheese and removing whey, which may have adjustable pressure and programmable control);
- Cheese molds (of various sizes and shapes, usually made of stainless steel or food-grade plastic);
- Brine baths or salting chambers (containers for immersing cheese in brine, equipped with temperature control systems);
- Ripening chambers (with temperature and humidity control, may have ventilation and humidification systems);
- Packaging equipment (for vacuum packaging or wrapping cheese in food film).

The production of hard cheese is a complex biotechnological process that includes several sequential stages. The main raw material is cow, goat, or sheep milk. Fermentation, pressing, and ripening are crucial in hard cheese technology. Since first-year students have insufficient knowledge about these processes, various additional information is provided to facilitate project work. However, the technological scheme contains some inaccuracies and intentional errors: violations in the design documentation format, omitted equipment, liquids in some pipelines not corresponding to the technological process flow, etc. The project team needs to identify errors and correct them in the electronic version (the technological scheme is given to students in a graphic editor). After corrections, a mandatory discussion of the project and justification of the corrections is held. Students are encouraged to actively discuss by receiving additional points.

For first-year (bachelor's level) students majoring in Mechanical Engineering, specialty G11, field of knowledge G Engineering, Manufacturing, and Construction (qualification: Bachelor in Mechanical Engineering), we propose the game "Design Bureau." The goal of this game is to reinforce knowledge of the basics of engineering graphics and 3D modeling, develop skills in working with CAD systems, and form skills of team interaction, task distribution, critical thinking, and decision-making.

It is worth focusing on the methodological aspects of designing business games. Designing business games is not only a creative process but also a methodically justified pedagogical activity that should be based on the learning objectives, age and professional characteristics of participants, as well as the logic of competency development. Methodological design of business games begins with a clear definition of the goal, which must correspond to the educational outcomes of the academic discipline. The main objectives of business games can be identified as: the formation of professional-communicative competence; the development of critical thinking skills, analysis, and decision-making; improvement of teamwork and leadership qualities; and the practical testing of theoretical knowledge.

The decision to conduct a business game is made by the instructor based on the analysis of the target audience. The psychological characteristics of first-year students influence the choice of game type, the complexity of tasks, and the pace of information delivery. Such characteristics of the target audience include the age of students (mainly 17–19 years for freshmen), low level of professional experience, a preference for technical thinking over humanitarian (for students specializing in engineering and technology fields), and the need for clear, structured instructions. Depending on the learning objective, the type of game is specified (role-playing game, simulation game, case study, organizational-activity game).

The next stage of designing a business game is determining its structure. It is advisable to adhere to three mandatory stages, which are thoroughly described in scientific pedagogical literature. At the preparatory stage, participants are explained the purpose of the game, the rules, and roles are distributed. The main (game) stage involves direct interaction among participants, solving tasks, modeling situations, and making decisions either as a team or individually. At the final (reflective) stage, actions are analyzed, solution options discussed, results summarized, and feedback actualized.

Special attention is paid to the development of methodological materials. Mandatory materials include: a scenario describing the situation; instructions for participants (separately for each role); evaluation materials (criteria, questionnaires, self-assessment forms); and recommendations for the facilitator/instructor. Undoubtedly, the instructor plays a leading role in conducting a business game, acting not only as an organizer but also as a moderator (maintaining the game's pace), consultant (providing advice as needed), observer (recording student behavior for further analysis), and expert (helping to reflect on mistakes and achievements).

Determining the number of games to be conducted during the semester is also important. However, quality and integration of the game into the learning objectives are more important than quantity. Sometimes one well-conducted game yields more benefits than several formal ones. In our view, the number of business games per semester depends on the course goals, study load, semester duration, game format (short or full simulation), number of students, and the time available for preparation and execution. Our experience shows that two games per semester are appropriate for first-year students. Simultaneously, it is important that business games harmoniously and systematically fit into the educational process. Therefore, before conducting business games, methodological techniques and educational technologies should be used to prepare students adequately.

To evaluate the effectiveness of the proposed business games, a formative pedagogical experiment was conducted with first-year students at Vinnytsia National Agrarian University specializing in G13 Food Technologies and G11 Mechanical Engineering. A total of 94 students participated. Students in G13 Food Technologies participated in two business games during the semester: the educational diagnostic-developmental game "Round Robin Interview" and the simulation game "Project: Technological Process of Hard Cheese Production." Students in G11 Mechanical Engineering also participated in two business games: the educational diagnostic-developmental game "Round Robin Interview" and the simulation game "Design Bureau Project." Positive results were observed in both control groups and are presented collectively.

A questionnaire was used to evaluate the results of the business games, consisting of blocks: self-assessment, assessment of game organization, feedback on the educational effect, and open-ended questions. The self-assessment block included statements such as: I was an active participant in the game; I understood the purpose of the game and my role; I worked effectively in a team; the game helped me better understand the topic/material; I acquired new knowledge or skills; I showed initiative during the game; I felt motivated to participate. The response options were “yes” or “no.”

The formation of learning outcomes and competencies was assessed through statements such as: I learned to work better in a team; the game contributed to the development of analytical thinking; the game helped me better navigate professional situations; I feel more confident in decision-making; I can apply the acquired knowledge in practice.

Observations during the exam session also confirmed the positive impact of the implemented business games on the level of graphic skills. The grades according to the ECTS scale in the control groups increased: grade “A” by 12%, “B” by 14%, and “C” by 15%. The grades of students in the control groups in the 2024–2025 academic year were compared with those of students in the 2023–2024 academic year. The equalization of control and experimental groups by the level of prior knowledge was verified and maintained through a diagnostic experiment.

Thus, business games in education represent a pathway from modeling management processes to modern digital simulations that develop the key competencies of the 21st century.

Conclusion. In modern society, the value of education lies in its ability to shape competent, responsible, and critically thinking individuals capable of effective action amid rapid technological changes and a vast flow of information. Digital education significantly expands access to knowledge for various social groups regardless of residence, physical capabilities, or social status.

The digital society requires everyone to possess skills in using digital technologies: critical perception of information; basics of cybersecurity; ethical use of technologies; and formation of new competencies. Modern education should focus not only on knowledge but also on the development of soft skills and metacompetencies such as teamwork and communication, creativity, adaptability, innovative thinking, self-organization, and lifelong learning. Digital tools allow for adapting the educational process to the individual needs of students.

Education in the digital society must cultivate a value-based attitude towards intellectual property, personal data privacy, and combating misinformation and fake news. The essence of digital society lies in the transformation of all spheres of human life—economy, education, culture, communication, governance, etc.—under the influence of digital technologies. This is a society where information is the key resource, and digital infrastructure is the foundation of functioning.

In the 21st century, higher education undergoes profound transformations driven by globalization, digitalization, the development of artificial intelligence, and changing labor market needs. These changes require rethinking the role of universities, the content of educational programs, and forms and methods of teaching. Digital technologies, including online courses, virtual laboratories, and distance learning platforms, are transforming the traditional university model. They make education more accessible but also require new approaches to quality and pedagogical skill.

Emerging trends in higher education include: shifting from teaching to facilitation; emphasizing competency formation rather than mere knowledge transfer; fostering critical thinking, creativity, and interdisciplinarity; and integrating soft skills into curricula.

Artificial intelligence is changing not only the content of education but also the process itself through adaptive learning platforms, automated assessment, and personalized learning. New ethical dilemmas regarding authorship, plagiarism, and responsibility are becoming increasingly relevant.

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2. Challenges and prospects of blended mathematics education for agricultural students during martial law

Abstract. Against the backdrop of the COVID-19 pandemic and the introduction of martial law in Ukraine, the use of blended learning has become increasingly relevant in the training of specialists at agricultural institutions of higher education. The forced and rapid transformation of the educational process required both teachers and students to adapt to new learning formats that combine traditional and digital components.

This article focuses on the importance of implementing blended education as an essential component of professional, particularly mathematical, training for first-cycle (bachelor’s) students at Vinnytsia National Agrarian University. The role and condition of mathematics education under crisis circumstances are analyzed.

It is shown that the integration of online technologies into the educational process ensures continuity of learning at a high level of quality and safety, provides constant access to educational resources, and is generally positively perceived by students. However, successful implementation of blended learning requires teachers and students to possess strong information and communication technology skills and to adopt a flexible approach to teaching and learning.

The study substantiates that the use of blended learning supports the professional growth of future specialists, promotes independent work, fosters information culture, and enhances the ability to apply innovative tools for acquiring and processing knowledge. Before implementing blended learning, students should be prepared to work with academic sources, analyze and systematize information, identify key ideas, and draw conclusions.

Purpose of the study. The aim of the article is to present the experience of implementing blended learning, particularly in mathematical disciplines, at Vinnytsia National Agrarian University.

Research methods. To achieve this goal, a combination of theoretical and empirical methods was applied: analysis of scientific and methodological literature, examination of educational resources, and pedagogical observation of students' learning processes. The paper presents the experience of teaching higher mathematics under blended learning conditions, outlining key requirements, principles, and technologies for designing and supporting blended learning courses. A blended course in higher mathematics was developed for students majoring in 208 Agricultural Engineering.

The article also considers major challenges and possible solutions, particularly in organizing students' independent work during online sessions. The importance of teacher supervision at various stages of students' work is emphasized as a key factor in maintaining learning effectiveness. Both the advantages and limitations of blended learning are discussed, along with recommendations for further research on enhancing students' independent learning in hybrid educational environments.

It is also noted that the issue of teacher readiness for blended instruction is often underestimated. Contrary to common belief, many educators face significant challenges in adapting to new formats. Therefore, systematic training in blended learning organization and pedagogy is urgently needed.

Conclusions. Blended learning provides students with access to diverse sources of information, enhances independent work, fosters creativity, strengthens professional competencies, and enables teachers to implement innovative forms and methods of instruction in mathematics and related disciplines.

Introduction

The academic period of 2022-2025 will be remembered in the history of Ukrainian higher education for the unprecedented challenges it has faced. These challenges include, first and foremost, the ongoing state of war in Ukraine [1]; secondly, the lasting impact of the COVID-19 pandemic on teaching, learning, and academic mobility; thirdly, the disruptions and uncertainties surrounding the admissions campaigns during times of instability; fourthly, the reduction of sustainable funding for educational institutions; and finally, the heightened social, psychological, and emotional pressures experienced by all participants in the educational process.

Currently, the Ukrainian higher education system is confronted with a critical question: how to maintain the integrity, cohesion, and functionality of both student and academic communities under the combined pressures of martial law and pandemic-related restrictions, while simultaneously ensuring the delivery of high-quality education. Educators and administrative staff bear substantial responsibility toward multiple stakeholders – students, parents, employers, the state, and society at large – which necessitates carefully coordinated strategies, flexible planning, and adaptive approaches to teaching and management.

During times of war, the demand for highly qualified professionals becomes even more urgent. Their expertise is crucial not only to avert potential food crises within Ukraine and globally but also to contribute to the post-war reconstruction and sustainable development of the nation. This creates an immediate need for specialists capable of restoring and advancing key sectors of the economy, including the agro-industrial complex, environmental protection, processing industries, and food production chains. In addition, there is a growing demand for experts in digital technologies, logistics, public health, and crisis management, all of which are essential to the resilience and modernization of the national infrastructure.

Consequently, the primary mission of higher education institutions, particularly agricultural universities, is to ensure the continuity and quality of the educational process, to train competent and adaptable professionals, and to safeguard the physical and mental well-being of students and educators under extraordinarily challenging conditions [2]. Achieving this requires innovative approaches to teaching, including blended and distance learning technologies, restructuring curricula to prioritize practical competencies, implementing flexible assessment and monitoring systems, and providing psychosocial support for students and staff.

Moreover, this period has highlighted the importance of fostering resilience, self-directed learning, and digital literacy among students. Higher education institutions must cultivate a learning environment that not only imparts knowledge but also develops critical thinking, problem-solving skills, and the ability to adapt to rapidly changing circumstances. At the same time, educators are called upon to demonstrate creativity and flexibility in delivering instruction, designing interactive and accessible learning resources, and sustaining motivation and engagement despite physical and psychological barriers.

In summary, the 2022-2025 academic period represents a pivotal moment for Ukrainian higher education. The combined pressures of war, pandemic consequences, and social instability have forced universities to innovate rapidly and adopt adaptive strategies that ensure the continued preparation of professionals who can meet the urgent and evolving needs of the country. The lessons learned during this period will not only inform immediate educational practices but also shape the future resilience, inclusivity, and global competitiveness of Ukraine’s higher education system.

2.1 The Role and Transformation of Mathematics Education Before and During the War

Even before the outbreak of war, Ukrainian society had been actively discussing what mathematics education should look like in the modern world. Many statements were made about the importance of quality education as the foundation of the nation’s future. Today, this truth has become particularly evident. Modern warfare is, above all, a war of technologies. The most advanced equipment becomes useless if one does not understand its principles of operation. Likewise, an artillery specialist cannot determine a projectile’s trajectory without solid mathematical knowledge.

Qualified professionals with a sound foundation in the natural and mathematical sciences will be urgently needed both during and after the war – for rebuilding the country, developing industry, construction, and advancing technology. Even journalists and humanities specialists, many of whom are now serving or supporting the Armed Forces, rely on mathematics when analyzing statistical data, technological information, or writing about military and economic developments. In today’s reality, mathematical illiteracy, once tolerated or even joked about, is no longer acceptable.

The war has clearly demonstrated the importance of mathematics education. Yet, Ukraine continues to face serious challenges in this area. Long before the invasion, the results of the international **PISA** assessment revealed that the majority of Ukrainian teenagers lacked basic mathematical literacy. National monitoring also indicated significant gaps at the primary level, and external independent testing showed that many prospective students could not solve elementary problems. The current simplified multi-subject national test, introduced under wartime conditions, risks perpetuating these deficiencies at the secondary level.

Some may argue that the quality of education is a secondary issue during wartime. However, war has exposed systemic problems that must be addressed if Ukraine is to build a sustainable future. Defending the country today also means **defending its educational and intellectual potential**.

Before the war, Ukrainian education – particularly higher education – tended toward simplified, game-based learning with limited focus on genuine intellectual development. Excessive tolerance toward academic dishonesty, neglect of homework, and inflated grading became widespread practices. Effort and discipline were often replaced by a “comfort-oriented” philosophy, emphasizing psychological ease over intellectual challenge. This approach fostered in students an illusion that life would always be effortless and that success required no personal responsibility or hard work.

It is therefore critical to rethink educational priorities and recognize the nation’s urgent need for engineers, scientists, and specialists with solid mathematical foundations. Basic competencies – such as calculation skills, practical geometry, understanding of functions and graphs, and the ability to solve equations, inequalities, systems, and proportions – are indispensable. The limited number of graduates proficient in mathematics is insufficient even to meet the needs of the information technology sector. Meanwhile, many of Ukraine’s brightest physics and mathematics talents are being recruited by top international universities.

2.2 Methodological Specifics of Distance Learning in Higher Education

Long before the war, discussions were already taking place in Ukraine about the desired form and purpose of mathematics education. Many statements were made about the importance of high-quality education as the foundation of the nation's future. Today, society can clearly see why these conversations mattered. Modern warfare is, above all, a war of technologies. The most advanced equipment becomes useless without an understanding of its principles of operation, and even a skilled artillery specialist cannot calculate a projectile's trajectory without mathematical knowledge.

Qualified professionals with a solid grounding in the natural and mathematical sciences will be critically important both during and after the war – for rebuilding the economy, revitalizing industry, developing technologies, and ensuring national security. Even journalists and representatives of the humanities – many of whom have joined or support the Armed Forces – rely on mathematical competence when analyzing data, reporting on events, or interpreting technological information. In today's context, mathematical illiteracy, once sometimes accepted or even joked about, is no longer permissible.

At the same time, the war has exposed the weaknesses of Ukraine's mathematics education system. Well before the invasion, the international **PISA** assessment revealed alarming results: most Ukrainian teenagers demonstrated insufficient mathematical literacy. National monitoring data confirmed similar problems at the primary level, while external independent evaluations showed that many prospective students were unable to solve elementary problems. Due to wartime conditions, the current national multi-subject test in mathematics has been simplified, which risks transferring unresolved educational gaps to the higher education level.

Some may argue that wartime is not the moment to discuss educational quality – that the country's primary focus should be on defense. However, the war has merely illuminated problems that have long existed. Now, when we are defending the future of Ukraine, it is impossible to do so without rethinking and improving the **quality of education.**

Before the war, Ukrainian education – particularly higher education – was increasingly characterized by simplified, game-based approaches that often lacked genuine educational depth. Excessive tolerance toward academic dishonesty, neglect of homework, and inflated grading standards became common practice. The value of effort, discipline, and intellectual rigor was downplayed in favor of maintaining psychological comfort and avoiding any form of challenge. This “cult of ease” fostered in students an illusion that life would always be simple, that someone else would solve their problems, and that success required no personal responsibility.

It is now vital to reconsider national educational priorities and focus on preparing engineers and skilled specialists with strong mathematical foundations. Core competencies – such as computational skills, elements of practical geometry, understanding of functions and graphs, and the ability to compose and solve basic equations, inequalities, systems, and proportions – are essential. The small number of graduates proficient in mathematics is already insufficient even for the information technology sector. Meanwhile, the most talented students in physics and mathematics continue to be recruited by leading universities abroad.

The rapid advancement of computer and information technologies has catalyzed the creation and implementation of innovative educational methodologies. One of the most significant trends in this development has been the progressive shift from conventional face-to-face instruction toward electronic (e-learning) and mobile (m-learning) learning environments. This evolution has given rise to **blended learning**, which integrates traditional classroom instruction with online components [3].

Vinnytsia National Agrarian University (VNAU) has been successfully implementing blended learning for several years, employing a wide array of modern tools and technologies that allow the university to adapt to contemporary educational demands. Blended learning offers greater flexibility compared to traditional learning formats, enabling educational institutions to provide instruction under diverse conditions. It merges face-to-face teaching with digital resources, including online materials, submission of assignments electronically, collaborative group work, continuous feedback mechanisms, interactive classroom sessions, and electronic monitoring of academic progress.

Importantly, blended learning is not merely the use of electronic resources within the classroom, such as multimedia presentations or computer-based testing. Rather, it emphasizes active student participation and ongoing feedback, both online and offline.

This approach allows for the distributed utilization of informational and educational resources within traditional learning settings while incorporating both asynchronous and synchronous elements of distance education.

Distance learning, as a key component of blended learning, provides students with the opportunity to acquire knowledge remotely and at an individualized pace. There is no universal model of distance learning applicable to all students, as the educational process depends on the institution, faculty, academic schools, and program focus. Distance education is inherently personalized, enabling students to design their own learning pathways, concentrate on areas of interest, and progress according to their individual pace.

The benefits of distance learning are widely acknowledged, including cost-effectiveness, adaptability, and the ability to engage in learning remotely. Nevertheless, its success heavily relies on students' prior knowledge, motivation, self-discipline, and prior educational experience. Certain disciplines that require extensive practical training, such as veterinary medicine, food engineering, and agricultural engineering, cannot yet fully transition to distance formats due to the necessity of sophisticated simulators and AI-supported instructional tools.

Experience from higher education institutions indicates that effective implementation of distance learning requires careful attention to legislation, regulatory frameworks, labor market requirements, technological infrastructure, and technical support. The initial stage involves selecting an appropriate model of distance or blended learning capable of adapting to future educational needs. Subsequently, a regulatory framework must be established, including institutional regulations and admission rules, to ensure effective governance of the educational process.

During the COVID-19 pandemic, approximately 60% of courses for both full-time and part-time Bachelor's and Master's students at VNAU were delivered as online electronic courses (ELCs). On January 24, 2022, the large-scale Russian invasion necessitated a renewed shift to distance learning. By this time, instructors had accumulated experience in online teaching; however, wartime conditions introduced additional complexities.

Students were organized according to their location: those remaining at home (in either occupied or unoccupied territories) and those who had been displaced (internally or externally). While individual circumstances varied, common challenges included limited access to technological resources, unstable internet connections, diminished physical and psychological well-being, and fluctuating class attendance. Synchronous online sessions were often disrupted by bomb shelter drills, power outages, and technical constraints, including insufficient devices, cameras, and microphones.

Distance learning during wartime also highlighted significant differences in student motivation. Students with strong intrinsic motivation were able to adapt effectively to blended and distance formats, whereas students with extrinsic or situational motivation required structured guidance, monitored learning, and additional incentives. Despite the relative independence afforded by distance learning, students continued to rely on teachers for support, guidance, and assessment; the teacher's role as a traditional instructor remained central, rather than being replaced entirely by a tutor-like function.

In conclusion, the implementation of blended and distance learning under wartime conditions has revealed both opportunities and limitations. Ensuring effective education requires flexibility, robust technological support, consideration of students' emotional and physical well-being, and careful organization of the learning process to accommodate the dynamic and challenging context of ongoing military operations in Ukraine.

The rapid and intensive advancement of computer and information technologies in the contemporary world has become a key driver for the development and implementation of modern educational technologies. One of the most notable trends in this evolution is the gradual shift from traditional, face-to-face learning methods toward electronic (e-learning) and mobile (m-learning) components within the educational process. This transformation has led to the emergence of a new paradigm in educational technologies – **blended learning** – which combines conventional classroom instruction with online and digital tools [3].

Vinnytsia National Agrarian University (VNAU) has been successfully implementing blended learning for several years, employing a broad spectrum of modern tools and technological solutions. This approach enables the institution to remain adaptive to the current demands of higher education, ensuring that both teaching and learning processes align with contemporary educational requirements. Blended learning is relatively new in the context of Ukrainian higher education but has proven highly effective in providing flexibility relative to purely traditional learning formats. It allows educational institutions to offer instruction under a variety of delivery conditions, effectively integrating traditional educational methods with elements of online education.

In practice, blended learning typically involves multiple components: instructional materials are provided in electronic form, students can submit assignments electronically, ongoing assessments with detailed feedback are conducted, collaborative group work is facilitated, electronic tracking systems (such as learning logs) monitor student progress, and face-to-face sessions are designed according to interactive principles. Importantly, blended learning is not merely the presence of electronic resources in the classroom; rather, it represents a structured integration of technology with active student engagement and continuous feedback. For example, a class that relies solely on a multimedia presentation controlled entirely by the teacher, or a computer-based test conducted in a laboratory setting, cannot be considered blended learning. The blended model is fundamentally about the distributed use of informational and educational resources within traditional instruction, complemented by asynchronous and synchronous distance learning elements.

Distance learning, as a key component of the blended learning approach, provides students with the opportunity to acquire necessary knowledge remotely and at their own pace. It is important to note that no single, universal distance learning model exists that fits all students. While similar methods and forms may be applied, the actual learning experience will always vary. These differences reflect the unique circumstances of each educational institution: the specific faculty members involved, the academic schools represented, and the particular emphases of individual programs.

Within this framework, distance education offers a highly individualized and flexible learning process. Students have the ability to design their own curriculum, progress through material at a self-determined pace, and concentrate on subjects or topics that align with their personal interests.

Historically, distance learning has been regarded as a highly attractive alternative to conventional education. Numerous studies have highlighted its advantages, such as cost-effectiveness, flexibility, and the opportunity for learners to study remotely, thereby reducing the need for physical workspaces. The software and technical infrastructure required for distance learning are primarily managed by teachers and students themselves, contributing further to efficiency. Moreover, the cost of educating a single student in a distance learning system is typically lower than in traditional formats. However, the effectiveness of distance learning depends significantly on multiple factors, including students' age, prior education, professional training, previous educational experience, capacity for self-organization and independent study, and level of intrinsic motivation.

Despite its advantages, distance learning presents limitations for certain disciplines that require substantial practical training, such as veterinary science, food engineering, and agricultural engineering. At the current stage of educational and computer technology development, fully transitioning such programs to distance formats remains impractical. Effective training of specialists in these fields necessitates the creation and regular updating of advanced, often expensive simulators, frequently incorporating artificial intelligence, to provide the necessary hands-on experience.

Experience from numerous higher education institutions demonstrates that the successful implementation of distance learning requires careful consideration of multiple factors, which arise in accordance with contemporary demands, current legislation, and regulatory documentation governing the educational process and all its participants. These requirements originate both from the Ministry of Education of Ukraine and the leadership of individual higher education institutions.

Additionally, educational institutions must account for the modern labor market, the current state and development of information technologies, the provision of technical support, and various minor factors that may be influenced by the specific location of each user, including teachers, students, and administrators. The initial stages of introducing distance learning are particularly critical and challenging. The foremost task is to select a type and technology of distance learning that not only meets these requirements but can also adapt seamlessly to the changes that inevitably occur during implementation. Blended learning, combining traditional instruction with digital and online components, is particularly well-suited to meet these needs, offering several advantages over other forms of distance education.

The subsequent stage involves the creation of a regulatory framework to guide and control all aspects of distance learning within higher education institutions. This framework typically includes admission rules, relevant institutional regulations, and additional policies to ensure the effective management and monitoring of the educational process.

During the COVID-19 pandemic, students at VNAU had already been engaged in remote learning to a significant extent. Approximately 60% of the total courses for full-time and part-time Bachelor's and Master's programs were available as online electronic learning courses (ELCs). However, on January 24, 2022, the large-scale invasion of Ukraine by the Russian Federation necessitated another rapid transition to distance learning. By this time, teachers had accumulated some experience in organizing remote education, yet the wartime context introduced unique challenges that further complicated its implementation.

During the war, students were divided into several groups according to their circumstances: those remaining in their homes (in occupied or unoccupied territories) and those who had relocated (internally displaced within Ukraine or externally displaced abroad). While each student's situation was unique, these groups shared certain commonalities. Students who remained at home had some access to educational resources but were often forced to frequently move to bomb shelters and endure severe emotional stress, which inevitably impacted cognitive processes. Students who had relocated within Ukraine lacked the familiar conditions for study but were often able to communicate more actively with peers and teachers and were in relatively calmer emotional states.

The proportion of students without reliable internet access during wartime is higher than it was during COVID-19 distance learning. Moreover, student groups are dynamic: attendance fluctuates significantly, with some students participating one day, more joining the next, and others being absent entirely. During synchronous online classes, students frequently join or leave sessions, for example, due to the need to descend to a bomb shelter where internet access may be unavailable.

In the context of ongoing military operations in Ukraine, significant disparities in the capabilities of educational participants have emerged, which result in particular challenges for organizing distance learning of mathematics. These include: the absence of distance learning infrastructure in certain territories; periodic or prolonged absence of some participants; a substantially larger proportion of participants experiencing technical difficulties, such as lack of electricity, insufficient devices, or unreliable internet; deteriorated physical and psychological health of participants, including limited access to food, water, fresh air, movement, and sunlight, and heightened emotional stress; markedly reduced motivation, self-organization, and self-efficacy among both students and teachers; limited time for teachers to prepare instructional content and for students to complete assignments; varying conditions for students (remaining at home, internally displaced, or externally displaced), which influence their sense of security and learning opportunities; the negative impact of stress on students' cognitive processes, complicating their ability to learn effectively; the dynamic nature of student groups, with frequent absences or partial attendance; a demand from students for synchronous online classes, which help them temporarily divert attention from wartime events and facilitate communication with teachers and peers.

Numerous studies on distance learning highlight a potential shift in the role of the teacher, suggesting that they might transition from a traditional instructor to a consultant or tutor. However, recent experience indicates that such a transformation did not occur in practice. Teachers largely retained their traditional instructional roles, despite the increased independence gained by students. While students became more autonomous in their studies, they still required guidance, advice, and evaluation from teachers in their conventional capacity. Although the modes of communication and interaction with students have evolved, the fundamental role of the teacher remained unchanged.

It is also important to note that students did not automatically become highly motivated, self-directed learners. Many continued to rely on teacher guidance rather than engaging in autonomous, advisory-driven learning. A significant challenge was the lack of motivation among certain students, who perceived distance learning as an opportunity to relax or enjoy additional free time. Many struggled with self-organization, independent study, and exhibited dependence on traditional in-person instruction. Students with strong intrinsic motivation and a genuine desire for knowledge were able to adapt effectively to the transition, organizing their educational activities within the new temporal and spatial dimensions imposed by distance learning. Conversely, students with primarily external or situational motivation – those heavily reliant on direct teacher interaction and grade-focused evaluations – were less adaptable to these new conditions and required structured guidance and additional incentives to sustain their learning.

Technical challenges further complicated the process. Shared access to a single computer within a household, reliance on smartphones as the primary device for learning, unreliable internet connections, power outages during classes or assessments, and the lack of quality microphones and cameras for video communication created additional obstacles for both students and teachers.

Despite these difficulties, positive outcomes emerged. Initially, students experienced confusion and anxiety, and some approached online learning with a casual attitude. Over time, however, most adapted and began to recognize the benefits of distance learning, including: the ability to attend classes from home in a comfortable and convenient environment; flexibility in completing assignments according to personal schedules, allowing both early risers (“larks”) and late-night workers (“owls”) to follow their natural biorhythms; the option to participate in classes partially when technical issues, such as non-functioning microphones or poor connectivity, prevented full interaction; involvement in selecting web resources and video materials for assignments, enhancing engagement and relevance to students' future specialization.

The effectiveness of distance learning largely depended on students' self-organization, awareness, and intrinsic motivation. This dependence led to a noticeable decline in effectiveness for younger learners. For instance, high school students enrolled in university preparatory courses often showed limited benefits from distance learning, with parents frequently demonstrating greater interest in outcomes than the students themselves.

Consequently, it is essential to develop innovative approaches to task design, individual instruction, and overall learning processes, with particular attention to motivating younger learners. Gamification, for example, can be especially effective for high school and junior students, who often exhibit weak intrinsic motivation, limited understanding of broader learning objectives, and underdeveloped self-regulation skills. For this age group, distance learning tends to be driven more by external motivation from teachers and parents than by internal student initiative.

Overall, feedback from university students regarding online learning was largely positive. Virtual classrooms facilitated the systematization of learning, simplified assessment, and enhanced transparency. Students regularly received automated notifications with their scores, and teachers could efficiently provide individualized feedback or group-wide clarifications. Additionally, reminder systems ensured timely submission of assignments, reducing the likelihood of missed deadlines and promoting accountability in the learning process.

During the transition to distance learning, coordinating the activities of teachers and students proved to be a complex and challenging task. Many teachers increased the number of assignments, justifying this by the fact that, being at home in self-isolation, they had more time and therefore could assign 1.5-2 times more work for their subject. Some teachers approached distance learning by attempting to replicate traditional classes in real time using various online platforms in the form of video sessions. At times, teachers, considering their subject to be the most important and themselves as the only instructors working with students, neglected the need for students to complete assignments from other subjects or to schedule online classes and consultations at convenient times, disregarding the overall timetable. This lack of coordination created disorder and chaos in the educational process, causing nervous exhaustion among conscientious students who tried to meet all requirements. Additionally, there was a general tendency to schedule classes later in the day, as some students, feeling relatively relaxed, were unwilling to begin work before 10 a.m. This lack of coordination among teaching staff and the uneven organization of distance learning, combined with inconsistent requirements for students, resulted in dissatisfaction and complaints of total overload.

Engaging students in distance learning unexpectedly emerged as another significant challenge. While students generally possessed sufficient computer literacy and access to high-speed internet, their integration into virtual classrooms required extensive guidance. Many explanations and training sessions were needed to familiarize students with social networks, messaging applications, emails, and chat platforms, consuming substantial time. Teachers had to respond to numerous inquiries throughout the day regarding virtual classroom operations.

Several specific difficulties arose at the outset. Some students did not take online participation seriously, registering under pseudonyms or nicknames, creating confusion and requiring significant effort to identify them. Traditional class formats proved ineffective and unengaging in the online environment. Independent textbook exercises were often uninteresting, necessitating the rapid development of interactive tasks using multimedia tools such as video assignments, Google Forms, and other digital resources.

Some teachers interpreted the transition to distance learning as simply conducting traditional-style classes via Zoom, Google Meet, Skype, or similar platforms. This approach, while familiar, imposed additional burdens on both teachers and students and introduced technical challenges, such as the inability to hold long sessions on Zoom or difficulties joining Google Meet classes without additional invitations.

Adapting to communication with cameras and microphones turned off was also unusual for many participants. Both students and teachers had to adjust to limited visibility and overcome periodic communication issues. A new rationale for absenteeism emerged: poor internet connection or power outages. Furthermore, students initially submitted completed assignments through various channels that seemed convenient to them, increasing the teacher's workload and making it challenging to track and organize submissions. Some assignments were lost, creating further dissatisfaction and chaos. Only after the creation of detailed step-by-step instructions for each group did students fully understand how to navigate the virtual classroom and submit assignments correctly, which subsequently reduced the teacher's workload and the volume of daily inquiries.

Student assessment became more complicated, as key points had to be presented in the virtual classroom, duplicated in the electronic office, and recorded in paper-based journals, generating additional administrative tasks. The shift to online learning and self-isolation also reduced the self-discipline of certain students, who sometimes behaved inappropriately or insulted peers during online sessions. The ability to remove such students from virtual classrooms became a necessary, though infrequently used, function.

Identification of students during assessments or exams posed another challenge, especially for teachers who had not yet memorized all faces. Students were required to display their grade books or identification documents to the camera. Conducting simultaneous tests for all students proved difficult, as it was hard to verify the identity of each participant and ensure independent work. To counteract potential cheating, some teachers designed creative assignments that could not be easily answered using online resources or required students to answer questions without viewing the screen.

The shift to remote instruction also increased the volume of reporting documentation. Teachers had to demonstrate the effectiveness of their work weekly, with each report requiring two or more hours to complete. Prolonged computer use led to vision deterioration, physical fatigue, and reduced mobility among all participants in distance learning.

Despite these challenges, virtual classroom work proved stimulating. It encouraged creativity, promoted a fresh perspective on education, and necessitated the development of innovative methods for engaging students and organizing systematic learning. Key tools employed by university instructors included: virtual classrooms for group organization, such as Moodle and Google Classroom; real-time platforms for synchronous sessions resembling in-person classes (Zoom, Google Meet, Skype); online resources for tests, surveys, assignments, and other materials; digital textbooks; multimedia audio and video materials compatible with the chosen virtual platform.

This experience yielded important results: highly motivated and well-prepared students were able to overcome the challenges of remote learning and demonstrate strong performance on exams. Independent work became increasingly critical, and student qualities such as self-motivation and the ability to process and assimilate information emerged prominently. In some cases, students who had experienced prolonged illness or quarantine demonstrated remarkable resilience and a renewed desire to learn.

Conversely, students with weak initial preparation and limited interaction with peers struggled with remote learning, often leading to poor exam performance and diminished motivation. Teachers could intervene in such cases, provided students demonstrated initiative, by offering consultations in traditional formats and helping organize independent study. Whenever feasible, intermediate assessments conducted in physical classrooms provided valuable insights into students' understanding.

Overall, distance learning reinforced the understanding that learning outcomes depend not solely on the method of content delivery, but significantly on the student's motivation, initiative, and capacity for self-directed learning. In situations where in-person classes are feasible, it remains crucial to cultivate self-education skills, time management, independence, and a desire for personal development in students. When online instruction is necessary, teachers should leverage all available tools to support students, ensuring continued acquisition of knowledge and maintaining high-quality education under challenging circumstances.

2.3 A distance course as a means of forming motivation during education

A successful transition from traditional education to distance learning requires the resolution of a wide range of psychological, pedagogical, organizational, and technical challenges. First and foremost, it is essential to design and develop a distance learning course that aligns with the higher mathematics curriculum, considers students' prior knowledge and general mathematical training, and accounts for their individual characteristics.

A distance course is a comprehensive set of educational and methodological materials and services created within a virtual learning environment to facilitate distance education using information and communication technologies (ICTs). Its purpose is to organize student learning activities, develop structured informational, didactic, and methodological materials, and leverage available digital tools, including multimedia components such as audio, video, animation, and modeling [4].

The planning and development of a distance course is a lengthy process, typically taking several months and requiring coordinated efforts among teaching staff, consultants, and technical specialists. Such a course should be guided by the following pedagogical principles [5]: transition from teacher-centered learning to self-directed learning; placing the student at the center of the educational process; creation of an accessible and comprehensible learning environment; Identification and application of effective learning strategies; anticipation of students' methods of self-organization, self-control, and self-management; formation of relevant competencies; ensuring interactivity and collaboration among all participants in the learning process.

During the planning and development of a distance course, ICTs should serve as tools for creating, storing, and accessing digital resources, while supporting the educational process through specialized software, telecommunication means, and psychological-pedagogical approaches. Distance learning is conceptualized as a system of methods, tools, techniques, and actions, whose deliberate implementation ensures the quality and effectiveness of training while considering the characteristics of the learners [5].

The initial steps in transitioning to full-scale distance learning during martial law involved selecting an educational platform, creating new materials, adapting and systematizing existing resources for virtual classrooms, and addressing the specific needs of individual student groups based on the curriculum and students' personal characteristics. Given the limited time, it was impossible to develop a fully comprehensive distance course covering all subject material; therefore, the bulk of the course relied on previously planned face-to-face class materials, which had to be rapidly converted for online delivery.

Subsequently, students needed to be oriented to the virtual classroom environment, trained to use electronic communication tools in both synchronous and asynchronous modes, and guided in accessing educational resources.

On a daily basis, preparing, conducting, analyzing, and supervising classes required between 6-8 to 18 hours of effort, effectively erasing distinctions between working days and weekends. Teachers reported that their working day became practically endless. It took approximately two weeks to create, organize, and properly design remote classes for all groups.

Although theoretical sources describe distance learning as supported by multiple structural units – dministrative units for organizing and monitoring distance education, customer service units managing contracts, units for educational process organization and content creation, technical and ICT support units, and others directly involved in web resource development – the reality was that most responsibilities fell to teachers. They served simultaneously as instructors, consultants, group curators, and authors of didactic content. While distance learning ideally required methodologists, administrative staff, and technical specialists, teachers were largely left to manage the transition themselves.

Consequently, it is understandable that some educators initially attempted to transfer traditional teaching materials to online platforms without significant modification, leading to challenges in adapting to the demands of distance education. The need to rapidly develop new materials and discover innovative pedagogical methods proved stressful for many teachers.

In general, the functional responsibilities of teachers in distance learning include: planning the educational process; developing, adapting, and regularly updating didactic and methodological materials; conducting educational activities – including lectures, seminars, practical sessions, consultations, discussions, and role-playing games – in both synchronous and asynchronous modes using ICT tools; individualizing tasks to increase student motivation and engagement; organizing assessment, self-assessment, and peer evaluation; advising students on study progress, graduation projects, assessments, and examinations; compiling reports on students' performance and learning outcomes.

At the outset of course organization, teachers must anticipate student demographics, prior knowledge, work experience, task requirements, motivation levels, and physical and cognitive characteristics. They must estimate the required teacher working hours, prepare external and internal resources, provide technical support, acquire or develop appropriate software, and allocate time for course study – tasks that were nearly impossible to predict during the quarantine.

During course creation, it is essential to define the objectives, duration, target audience, task types, deadlines, reporting methods, and instructional support. This involves revising the curriculum, planning class types and quantities, selecting appropriate educational methods, developing exercises, and designing assessment systems. Ideally, a course presentation should be prepared to familiarize students with the content and generate interest.

The process of distance course planning typically includes: developing a course program; structuring the sequence of topics; facilitating student adaptation to distance learning; determining delivery methods for educational materials; creating conditions for student engagement and motivation; developing assessment, self-assessment, and knowledge control systems; writing a course preface; estimating time required for preparation and for students to complete tasks; organizing independent student work; planning technical support for the course.

Course tasks should be logically structured, interconnected, and accessible asynchronously to accommodate individual student schedules. Task wording should be precise, simple, and understandable, with personalization based on individual student needs. Internal materials should be adapted for distance learning, while external resources must be licensed or appropriately cited. Distance learning tools enable individualized learning and the design of tasks according to students' perceptual preferences.

A well-structured distance course should include: preface; content and organization; author and instructor information with contacts; main goals and objectives; detailed course description; course menu and map; student information and contacts; news updates; course program; tasks; knowledge tests; references and links; conclusions and reflection questions.

Individual lessons should include an introduction, goal definition, task formulation, task execution instructions, visual and multimedia materials, organizational guidance, control or self-assessment mechanisms, and reflective commentary. Development is cyclical and interactive, requiring ongoing consultation and evaluation of material implementation. During the quarantine, new materials were introduced rapidly, often updated 1-2 times per week.

Teacher-student interaction should be planned according to activity type: clarifying (lecture, webinar), interactive (practical session), or adaptive (individual consultation). Communication can be synchronous (real-time video conferences, chats) or asynchronous (forums, blogs, email, social media, messaging apps) [4].

Conducting live distance learning activities requires meticulous planning to address technical challenges, ensure stable internet connectivity, and adapt traditional pedagogy to online formats. Key considerations when organizing virtual sessions include defining learning objectives and topics, outlining tasks or problems for student engagement, structuring the session with clear timing, limiting group size (typically 4-10 students for optimal interaction), selecting an appropriate session format (seminar, workshop, discussion, role-play, or case study), identifying main activities (brainstorming, Q&A, collaborative problem-solving, or educational games), preparing written and multimedia materials for real-time sharing, anticipating potential technical issues, and incorporating reflection and feedback strategies. Clear guidance on student participation and expected outcomes is critical for maintaining engagement and motivation throughout the session.

Effective remote instruction relies on weekly synchronous meetings using platforms such as Zoom, Google Meet, Microsoft Teams, or Skype, combined with adherence to consistent schedules and teacher availability for both academic and emotional support [6]. Regular feedback is a fundamental component, serving multiple functions: it promotes students' psychological and pedagogical adaptation, addresses individual learning needs, and informs iterative improvements to course content and teaching methods.

Monitoring the quality of distance education requires the establishment of common standards, clear evaluation criteria, effective data collection instruments, and reflective mechanisms. Teachers often maintain near-continuous communication with students to organize learning activities, provide guidance, and adapt instructional strategies. While direct interaction facilitates the resolution of specific issues, it does not always provide a comprehensive view of student progress or course dynamics. Therefore, additional monitoring methods – such as surveys, tests, interviews, analysis of submitted assignments, and peer evaluations – are essential to ensure objective assessment and feedback.

Monitoring can be performed by instructors, independent observers, peers, or designated student groups. Effective monitoring tools should be concise, clear, reliable, timely, and appropriately challenging. Distance learning assessment typically occurs at multiple levels: c**urrent (formative) assessment:** tests, open-ended questions, diagnostic tasks, and activities using information sources to check comprehension. **Intermediate (summative) assessment:** mastery of tasks, problem-solving assignments, and project work that reflect application of knowledge. F**inal (comprehensive) assessment:** evaluation of overall task completion, final tests, project submissions, and cumulative achievement metrics.

For instance, a distance course in higher mathematics for Agricultural Engineering (specialty H7) integrates a variety of resources, including theoretical materials, external reference links, interactive elements such as forums, chats, quizzes, structured workbooks, databases, and online lectures or seminars. The course is organized into modules covering core topics such as Linear and Vector Algebra, Complex Numbers, Analytic Geometry, Mathematical Analysis, Differential and Integral Calculus, Differential Equations, and Series, enabling students to study at their own pace while following a coherent structure.

The course employs a block-based design consisting of content, control and monitoring, and information and communication units. The **information and communication unit** manages the organization and flow of the course, providing access to presentations, curriculum details, methodological instructions, consultation schedules, and announcements. The **content block** delivers educational materials, while the **control and monitoring block** (implemented via Moodle or similar platforms) tracks student performance, facilitates assessment, and supports instructional adjustments.

This includes individual assignments, methodological instructions, and test packages for ongoing, modular, and final evaluations. Computer-based diagnostics allow systematic and individualized tracking of student progress across the entire curriculum.

The course portal provides an overview of the curriculum, access to discussion forums, program documentation, recommended literature, electronic resources, tables, and a glossary of key terms. Multimedia visualization – incorporating audio, video, and lecture presentations – enhances comprehension, reinforces knowledge acquisition, and develops student intuition and imagination. Interactive elements, such as hyperlinks, terminological dictionaries, and visual cues, support structured, branched learning paths, clarify complex topics, and approximate the benefits of face-to-face interaction. Furthermore, Moodle allows for animated mathematical models that visually illustrate challenging concepts, providing students with a more concrete understanding of abstract ideas and fostering active cognitive engagement.

In addition to supporting comprehension, this approach also cultivates important skills such as self-directed learning, time management, digital literacy, and problem-solving. By combining structured content delivery, interactive engagement, and continuous monitoring, distance courses in higher mathematics not only maintain educational rigor but also encourage students to develop autonomy, critical thinking, and professional competencies essential for careers in Agricultural Engineering.

2.4 Independent Learning in a Distance Education Environment

The contributions of psychologists such as P. Anokhin, N. Bernstein, L. Vygotsky, V. Davydov, A. Leontiev, S. Rubinstein, and others have played a pivotal role in shaping the development of modern didactics, particularly in the context of work-oriented education. Their research laid the theoretical foundations for understanding the mechanisms of learning, the development of cognitive functions, and the role of active engagement in the educational process.

The theoretical substantiation of independent work, as well as methods for its organization and the cultivation of students' creative and critical thinking abilities, has also been extensively addressed by foreign scholars, including A. Tom, J. Liner, J. Litt, and others. In recent years, various dimensions of organizing students' independent work have been the focus of numerous scientific studies. Dissertation research has examined these issues across a range of disciplines, including pedagogy (V. Khrypun), philosophy and political science (O. Popovych), foreign languages (M. Smirnova), mathematics (N. Vanzha), legal studies (N. Shishkina), and social sciences (A. Tsyuprik). Such research has been instrumental in informing contemporary practices in higher education and has contributed significantly to fostering both educational and cognitive autonomy among students.

Despite a long-standing interest in the concept of "independent work of students," no universally accepted definition exists. Scholars employ the term in diverse contexts, including: the completion of tasks independently by students without direct teacher intervention; autonomous thinking and self-directed navigation of the educational material; extracurricular activities carried out independently by students.

The first interpretation has been endorsed by M. Kashin, K. Gomoyunov, V. Bogdanov, B. Esypov, N. Dairy, and R. Mickelson. K. Gomoyunov describes independent work as planned student activity conducted under the guidance of a teacher yet without direct participation. R. Mickelson defines it as "the student's performance of tasks without assistance, yet under teacher supervision." M. Gelashvili frames independent work as a distinct form of learning organization, executed according to teacher-assigned tasks and requiring active mental engagement.

Within traditional educational models, independent work has also been associated with extracurricular activity (L. Golovko, S. Zinoviev, V. Lyaudis). L. Golovko emphasizes that independent work involves activity undertaken autonomously, without external assistance, during extracurricular periods. The conceptual essence of independent work has been further explored in the works of V. Buryak, B. Yesipov, I. Unt, I. Lerner, O. Nilson, P. Pidkasysty, M. Skatkin, B. Korotyaev, and others.

B. Yesipov and O. Nilsson highlight the external, organizational aspects of independent work as decisive, whereas V. Buryak and I. Unt stress the integration of both internal cognitive and external organizational dimensions. Scholars differ in their views on the organizational aspects of independent work, encompassing learning methods, educational resources, and forms of activity organization. For instance, V. Buryak, B. Yesipov, L. Zharova, and A. Usova conceptualize independent work as a learning method, while M. Gelashvili, T. Shamova, and Ya. Kamensky view it as a form of organizing educational activity. Others, such as M. Garunov, G. Gaponov, and P. Pidkasysty, regard independent work primarily as a tool for engaging students in autonomous cognitive activity. P. Pidkasysty asserts that "independent work is neither a form of organizing educational activities nor a learning method; it should be legitimately considered a means of fostering independent cognitive activity" [6].

V. Kozakov emphasizes independent work as autonomous learning outside the classroom, with the primary goal of cultivating student independence. Conceptualizing independent work as self-directed activity allows it to be understood not merely as a didactic tool but as a structured system of actions performed independently by the student with specific tasks under suitable conditions. These conditions and tasks facilitate dynamic interaction between the student and their environment, promoting the development of independence as a key personal trait.

Analysis of scholarly sources demonstrates that the concept of independent work has retained relevance across different stages of higher education development. In early stages, independent work was regarded as an important, though limited, form of educational organization, with relatively few hours assigned. Contemporary educational standards, particularly in correspondence and distance learning, recognize independent work as a primary form of student activity and a central method for engaging with educational content.

In the context of distance learning, students' independent work can be defined as a purposeful set of actions carried out under teacher guidance, supported by rational information resources and a coordinated system of organizational, technical, software, and methodological measures. This work occurs at two levels: teacher-directed independent work and actual independent work, sometimes referred to as students' extracurricular activity.

Under distance learning conditions, independent work assumes a central role in the formation of autonomous, self-regulated learners. Unlike traditional systems, where the teacher primarily selects study topics, organizes learning resources, and monitors outcomes, distance learning places greater responsibility on students to engage actively with the material. Personality development and independence are no longer secondary; they are essential outcomes of the educational process.

Independent work in distance learning differs fundamentally from traditional independent work. It is not simply a form of learning or a type of educational activity; it becomes the principal mode of engagement with educational content and a method of study, particularly in correspondence and online learning environments. This requires students to possess not only proficiency in information and communication technologies but also advanced skills in self-directed cognitive activity, problem-solving, and critical thinking. Moreover, the integration of interactive digital resources, adaptive learning platforms, and individualized feedback mechanisms enhances the effectiveness of independent work and promotes lifelong learning skills.

Overall, independent work under distance learning conditions represents a dynamic and multifaceted approach to student engagement, emphasizing autonomy, responsibility, and active cognitive participation. Its successful implementation depends on the careful alignment of pedagogical strategies, technological infrastructure, and continuous teacher guidance to create an environment conducive to meaningful, self-directed learning.

2.5 Practices in Organizing Independent Work of Students in Higher Mathematics

The organization of students' independent work within an information and educational environment is highly relevant under modern conditions. At agricultural universities, higher mathematics serves as a core discipline, forming the foundation for professional training and providing the mathematical tools necessary for studying specialized subjects. Mathematics as a discipline offers significant opportunities for implementing distance learning because information technologies enhance the applied and practical orientation of the course while enabling individualized approaches at a qualitatively new level. Consequently, students must not only possess strong theoretical knowledge but also apply it effectively to solve specific applied problems. In coordination with the graduating departments, the sections of higher mathematics that are most essential for each specialty and which students must master thoroughly are carefully selected.

In recent years, the transition to a four-year bachelor's program has led to the introduction of new curricula at agricultural universities, accompanied by a notable reduction in higher mathematics hours. Previously, to achieve the goal of visually and practically applying mathematical tools to professional tasks, students were given calculation tasks individually, which they completed and defended.

Teaching higher mathematics in agricultural universities has specific characteristics. In distance learning, independent student work assumes critical importance. During traditional lessons, students receive information through visual, auditory, and kinesthetic channels. In distance learning, students can selectively engage these channels, studying the material later in a manner convenient for them. Both positive and negative outcomes are possible. Ideally, students study posted materials at their own pace – for example, revisiting specific moments in a video lecture or breaking down presentations to avoid fatigue and ensure maximum comprehension. Text or interactive materials can similarly be studied gradually, with students passing control points at a comfortable speed. However, this ideal scenario depends on the student's interest, motivation, and organizational skills.

Several factors often prevent optimal outcomes. First, the sheer volume of independent work, common across disciplines, can overwhelm students, making it difficult to prioritize tasks. Many students tend to complete assignments at the last minute, which hinders long-term assimilation of mathematical concepts. Mathematical disciplines, especially specialized ones, demand highly developed mathematical thinking; last-minute work based on rote actions rarely fosters deep understanding. Moreover, under time pressure, even simple tasks may be insufficient for forming basic skills.

Second, independent work and assessment materials are often inadequately adapted for remote learning. Students may access ready-made answers or rely on others who have completed tests, making evaluations less reflective of actual knowledge. Consequently, assessments may measure students' ability to quickly find information rather than their understanding of mathematics. Additionally, not all students aim for genuine learning; some prioritize merely passing. In agricultural universities, some students enter via "reserve options," without meeting required entry scores for their chosen program, leading to low motivation. From the first lessons in higher mathematics, instructors face the challenge of motivating students to engage with the discipline.

Cognitive interest is vital for effective learning. Self-study materials should be varied and presented in multiple formats: interactive manuals suitable for distance learning but also printable for students who prefer paper, video lectures, problem-solving analyses, proofs of theorems, and practical applications of the material in various fields. This approach caters to both students who prefer concise material and those who require additional information to enhance understanding and engagement, allowing each to select the most suitable learning channel or combine them.

The methodological system of distance learning in higher mathematics is an independent, open, branched system that, in interaction with the informational and educational environment, ensures the achievement of both standardized and individualized goals. Randomized generation of numerical data in typical tasks is an effective means of individualizing assignments, enabling each student to receive unique problems. Generating "appropriate" numerical data – for example, integers with no more than two digits, decimal numbers with limited precision, or fractions with numerators and denominators under two digits – facilitates problem-solving and verification. At our university, an interactive module with this functionality has been successfully used for several years to support independent student work in distance learning. Many modern learning platforms, however, lack this feature, as tasks may become obsolete after a single completion, and repeated attempts can no longer objectively reflect students' knowledge.

We recommend maintaining part of independent work in handwritten form, later scanned or photographed, or as legible digital records. For problems involving complex formulas and calculations, this method is sufficient, akin to open-ended exam responses. Strict requirements for typed submissions are unnecessary; the key criterion is mathematical correctness and legibility.

Another effective approach is dividing assignments into parts with distinct submission deadlines. This method helps first-year students structure their work, develop independent learning skills, and manage their time efficiently. Our experience shows that first-year students often struggle to organize their independent work in higher mathematics.

Control of learning in distance higher mathematics can be carried out using various tools: written surveys in synchronous mode; tests assessing comprehension of each educational element online; independent work complementing tests to assess application of mathematical concepts; homework tailored to specific learning objectives; standard calculations to verify skill mastery; control papers for comprehensive assessment of knowledge.

According to Ukrainian educational standards, integrating distance learning technologies creates an informational educational environment that fosters mathematical abilities and aligns with modern pedagogical principles. Regular use of remote technologies ensures the development of appropriate competencies and universal educational skills.

The primary goal of distance learning is to enable students to study independently without attending in-person classes. This requires developing complex training and assessment programs, which are resource-intensive. Knowledge is typically assessed through tests completed without teacher supervision. While theoretically effective, practical experience reveals challenges.

At Vinnytsia National Agrarian University (VNAU), guided independent work in higher mathematics was organized using key course sections, addressing departmental needs and improving student outcomes. Calculation and graphic tasks (RGZ) were developed – individual assignments completed independently and defended with a teacher during practical classes, effectively serving as an exam prerequisite. For first-year students in the first semester, distance learning materials were created and placed in the Socrates system across sections such as “Linear Algebra”, “Vector Algebra”, “Analytical Geometry”, “Derivative and Its Applications” and “Functions of One and Several Variables”. Students accessed this system conveniently, while teachers coordinated with methodologists and system administrators via a virtual office containing interactive tools and information resources for lectures and practical sessions.

The platform supports many distance learning elements, enabling both online and offline guidance, individual and group activities, and comprehensive evaluation based on personal abilities, thereby fostering student success. Teachers provide all necessary auxiliary materials, including manuals, lecture notes, presentations, and methodological recommendations. Theoretical materials are accompanied by problem-solving examples and control tests to ensure a structured and comprehensive learning process. For Agroengineering students, these resources were specifically recommended for independent study to strengthen their understanding of applied mathematical concepts relevant to their field.

During the second semester, the **RGZ (course project)** assignments focused on the topics *"Indefinite and Definite Integrals", "Differential Equations",* and *"Series"*. The materials were complemented by workbooks containing theoretical questions and individualized tasks with designated spaces for detailed written solutions. Thirty distinct task versions were developed to ensure equivalence in complexity and fairness in assessment. Students submitted their completed assignments in digital format, and errors or misunderstandings were discussed during follow-up consultations or practical sessions. Successful completion of these assignments led to an oral defense of the RGZ, confirming that students had acquired genuine problem-solving skills rather than relying on memorization or external assistance. The emphasis on the correct mathematical interpretation of solutions significantly reduced opportunities for academic dishonesty, while cognitive activity and analytical thinking were continuously reinforced during lectures and practical classes.

Although the RGZ framework and supporting materials facilitated independent learning, the results of final control tests revealed several limitations of purely distance-based instruction. The most common challenges included the potential for plagiarism, excessive dependence on external digital resources, and reduced authenticity of individual student performance. These findings suggest that effective remote teaching, especially under crisis conditions, remains possible but requires substantial effort from both instructors and learners. It also necessitates the availability of **high-quality technical infrastructure**, stable communication channels, and, ideally, initial **face-to-face interaction** between teachers and students to establish trust and academic integrity.

To achieve sustainable results, materials designed for distance learning in **agricultural mathematics** should meet several essential criteria:

- they must **adapt easily** to both traditional and distance learning formats;
- they should provide **sufficient interactivity**, allowing students to engage with dynamic content rather than static text;

- and they need to be **highly individualized**, particularly in the design of tests, control tasks, and analytical exercises, to reflect students' diverse levels of preparation and learning pace.

Furthermore, the integration of **advanced platform functionalities** – though not yet universally available—could significantly improve the quality of independent work and assessment. Examples of such functions include automated generation of numerical data, the creation of randomized task variants from an extensive task bank, and systems capable of **automatic recognition and partial evaluation of handwritten mathematical text**. The introduction of these tools would not only enhance academic integrity but also streamline the feedback process, allowing instructors to focus more on the conceptual understanding and less on repetitive grading tasks.

In the broader context, the ongoing refinement of digital learning environments in technical and agricultural education offers a valuable opportunity to combine **technological innovation with pedagogical insight**. By doing so, institutions can ensure that distance education not only compensates for emergency situations but also evolves into a complementary and sustainable component of modern higher education.

Conclusions

The implementation of distance learning as the primary mode of education during martial law has revealed both its strengths and limitations to students, teachers, and the broader public. Despite its novelty and unfamiliarity for the majority of participants, distance education has generally proven to be an effective substitute for traditional face-to-face learning in higher education. In our assessment, while distance learning will likely never completely replace conventional classroom instruction, its advantages should continue to be integrated into traditional education models, given its demonstrated pedagogical value. In particular, distance learning has facilitated: The systematic organization of group work and independent tasks, enabling the creation of both general and individualized feedback, as well as the synthesis and summarization of results; extensive use of multimedia resources, which enhance student engagement and comprehension; the ability to conduct certain classes and consultations from home, offering increased convenience and flexibility; a streamlined system for evaluating and summarizing the progress and achievements of each student; a more flexible, personalized approach to education, taking into account the unique needs and learning styles of individual students.

However, the experience of the past months has also highlighted significant challenges. Many educational institutions were unprepared for large-scale distance learning, revealing the absence of a unified, systematic approach to technical and educational support. There is a notable shortage of electronic textbooks and teaching materials, limitations within educational platforms, and a lack of sufficient training for many instructors, many of whom are unfamiliar with remote teaching methodologies and struggle to effectively deliver content online.

This situation underscores the urgent need for the development of national standards for distance education. Such standards should include the creation of a unified informational and educational environment to support the functioning and continuous improvement of the distance learning system. While these standards should provide a coherent framework applicable to all institutions, they must also be flexible enough to allow educators to adopt innovative, creative approaches in their teaching practice.

It is also essential for institutions to establish specialized units – such as electronic educational centers – responsible for organizing the distribution of learning materials, monitoring the activities of both students and teachers, and managing educational resources through effective software and digital tools. These units should reduce the administrative burden on individual teachers, prevent the mere imitation of educational processes, and eliminate excessive reporting requirements. Ensuring access to reliable technology and the Internet for students in remote or under-resourced areas, as well as equitable access to educational resources for all teachers, is crucial for fostering inclusivity and equal opportunity in the educational process.

The practical application of distance learning has challenged several assumptions commonly held in theoretical research. For example, the notion that distance learning reduces the teacher's workload has proven to be incorrect. Even after the adaptation of materials to digital formats, the preparation, organization, and management of distance courses demand significantly more time and effort, which largely falls on the instructor. Similarly, the idea that one teacher can manage large student groups remotely has not been substantiated in practice. Effective distance learning, particularly for interactive and problem-solving sessions, is best conducted with small groups of 4-6 students to ensure meaningful interaction, timely feedback, and clarification of complex points.

Moreover, the creation, updating, and adaptation of educational materials for online instruction require continuous effort, which will only intensify if institutions aim to remain competitive in the global education landscape. The implementation of distance learning has also shown that significant capital investment is needed, alongside targeted professional development programs, to prepare and retrain educators for new teaching conditions and to develop digital competencies essential for effective instruction.

Overall, the experience of deploying distance education during crisis conditions has underscored both its potential and its limitations. While distance learning can maintain the continuity of education in extraordinary circumstances, its success depends on strategic planning, adequate technical infrastructure, comprehensive teacher training, and thoughtful adaptation of learning materials. Moving forward, a blended learning approach – integrating the advantages of both traditional and digital education – appears to be the most effective strategy for fostering a flexible, individualized, and high-quality educational environment that meets the diverse needs of students.

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3. Theory and methodology of designing educational resources for agrarian higher education institutions in crisis situations

Abstract. Ukraine is a country with the largest area of rural territories in Europe, playing a key role in the food security of the continent and the world. According to data from Ukrstat and analytical centers, in the total land fund of Ukraine (which, as of early 2024, comprised approximately 48.1 million hectares of territories suitable for economic activity, although the country's total area is about 60.35 million hectares), the share of land occupied by cities is only about 2-3%. In contrast, the combined share of agricultural land, forest fund, and lands under rural settlements accounts for approximately 70-75%. Specifically, the area of agricultural land in farms of all categories exceeds 41.5 million hectares, of which over 32.5 million hectares are arable land. This vast land base is a national treasure of Ukraine. Most rural territories of Ukraine are located at a distance from large cities, with no less than 85-90% located on plains, meaning they are relatively accessible for involvement in economic circulation and the development of agricultural production [7].

Ukraine's agriculture is a large sector of the national economy that has strategic importance for ensuring sustainable societal development and possesses a powerful multiplier effect for the development of the entire economy. Furthermore, it holds exceptional social significance compared to other sectors of the national economy, ensuring employment and welfare for a significant portion of the population. Over 40-50 related industries are directly or indirectly involved in the activities of the agro-industrial complex (AIC) – from the production of packaging, agricultural machinery, and mineral fertilizers to modern biotechnologies and space technologies used for precision farming. The specific weight of these industries in the country's total GDP may vary but is significant. The share of food products in Ukraine's retail trade turnover exceeds 55-60%, which underscores the importance of the AIC for domestic consumption. The industries included in the AIC are united by a common ultimate function – providing the country with food and agricultural raw materials, which is a guarantee of national security [21].

The demographic situation in Ukraine, especially after the start of the full-scale invasion, is complex. According to estimates, as of 2023, the permanent population of Ukraine (excluding temporarily occupied territories and a significant number of internally displaced persons abroad) is about 29-30 million inhabitants. Of these, the rural population, according to 2022 data, was approximately 12.5-12.7 million people (or about 30-31% of the total population at that time). Approximately 12-12.5 million people are of working age (according to KSE data, as of August 2023). The exact number of rural residents of working age is subject to further research, but it can be assumed that it is a significant portion of the total rural population. One job in agriculture traditionally provides employment for 5-6 people in other sectors of the economy, primarily in the food industry, whose localization is facilitated by the perishable nature of most agricultural products, which underscores the deep integration ties of the sector.

Furthermore, agriculture remains an integral element of the traditional way of life for many Ukrainians. In addition to those officially employed in agricultural production, a significant part of the population is engaged in producing agricultural products in personal peasant farms and households. According to various estimates, about 3-4 million people (corresponding to approximately 4.5-5 million households) are engaged in agricultural production in households. This demonstrates not only the economic but also the social significance of agriculture, its role in supporting the livelihoods and self-sufficiency of the population, especially in crisis situations [14].

Research Objectives. The monograph is dedicated to studying the theoretical and practical aspects of designing educational resources for agrarian higher education institutions in crisis situations. It combines current scientific research, pedagogical experience, and advanced practices aimed at improving the educational process and ensuring quality education. The author addresses key issues such as: theoretical foundations for designing educational resources in higher agrarian education, as well as the advantages and limitations of their use; designing interactive educational programs and content using these technologies; developing methodologies and learning strategies in crisis situations; evaluating the effectiveness of these technologies in the educational process, as well as the challenges and prospects of their implementation in institutions of higher agrarian education.

Aim of the Research. The aim of this monograph is to systematize scientific knowledge, highlight advanced pedagogical experience, and develop practical recommendations for educators, methodologists, and heads of higher education institutions regarding the successful implementation of augmented and virtual reality technologies into the educational process. Specifically, it considers issues concerning the need to train pedagogical staff, the availability of necessary equipment and software, and the implementation of appropriate infrastructural changes. The author proposes addressing these challenges by developing recommendations and practical solutions aimed at ensuring the successful integration of augmented and virtual reality tools into modern educational processes.

Introduction

The agro-industrial complex (hereinafter - AIC), as the main target for the development of agrarian education, has the most powerful economic foundation and potential for development. The issue of staffing the AIC has enormous socio-economic significance and is a critical priority of state policy not only now but also in the future. Modern society is in the stage of developing a post-industrial economy, which implies increasing the technological and knowledge-intensive nature of all sectors, including the AIC (which is focused on accelerated development in precision farming, production robotics, genetic engineering, and more). This period is characterized by a high level of informatization across all sectors of society and increased access to information and knowledge [18].

Modern agriculture worldwide is characterized by the growth and structural change in food consumption (largely related to the development of food markets in Asia). This factor is directly linked to the global orientation of the world's agriculture toward increasing the productivity of agricultural land, reducing losses, and increasing food production. The agricultural sector of the economy is focused on the production and processing of agricultural products, storage, transportation, and sale of finished goods. The agricultural industry requires specialists who possess competencies and skills that correspond to the entire production cycle.

The main means of production in agriculture is land, whose specific features lead to unique forms of concentration and specialization of agricultural production, and necessitate the use of scientifically-based farming systems to increase soil fertility. The objects of activity are living systems—plants and animals, soil, and water—as a result of which the development of the industry intertwines the action of economic and biological laws, and production means and labor are used seasonally. These are the main characteristics of the AIC.

Market relations are changing the nature and conditions of agricultural workers' activities. The continuous deepening and updating of knowledge and the improvement of professional competencies are becoming the most important directions for the formation of AIC personnel. An agrarian specialist today is a person with broad general and specialized knowledge, capable of quickly reacting to changes in production technology and techniques. They need foundational knowledge, analytical thinking, socio-psychological competence, and intellectual culture.

In general, every interested (rural) resident of Ukraine of working age should have the opportunity to acquire special knowledge, skills, and practical experience for effective agro-production, which requires a significant expansion of agrarian education offerings.

The development of the AIC is significantly influenced by the process of urbanization, which leads to the migration of the most active population groups from rural areas. The low popularity of agricultural work among young people, including those from rural areas, is explained by low wages compared to other sectors, the complexity and multifunctionality of the activity, and perceptions of agricultural work as archaic and backward.

Considering various factors (including modernization, urbanization, reorientation of the agricultural structure, etc.), agrarian education in Ukraine must define its place in the overall system of Ukrainian education, as well as forms of interaction with applicants, local communities, and the AIC. Despite past merits and successes, which were recognized worldwide, the outlined challenges place the most serious demands on the system of agrarian professional education. The conditions that have developed demand proactive action, creating the foundations of national competitiveness where future benefits and advantages can be gained; rapidly mastering the niches that are becoming available in the world economy, including in global food, knowledge, and education markets.

Based on the long-term forecast for the socio-economic development of Ukraine up to 2030 in crisis situations, our country is oriented toward an innovative scenario that reflects an increase in the competitiveness of the AIC (maintaining the trend toward import substitution), the use of Ukraine's competitive advantages, an improved investment climate, and a progressive increase in innovative activity. This scenario anticipates a moderate growth in production.

In the final stage of implementing such a development plan, if Ukraine's socio-economic development enters a forced scenario, which implies the intensification of all available growth factors of the agro-industrial complex, the system will be oriented toward more intensive development and the achievement of high indicator values [9].

Such a plan can be intended for use by state authorities at any level, municipal authorities, educational organizations, enterprises in the agrarian sector of the economy, public organizations, and other interested parties, including during the development and adjustment of their plans and program documents.

3.1 Theoretical Foundations of Designing Educational Resources in Higher Agrarian Education

The system of agrarian education includes universities under the Ministry of Education and Science of Ukraine (MES), professional educational organizations under the jurisdiction of Ukraine's regions, as well as educational organizations for additional professional education that may be subordinate to various ministries and agencies, including the Ministry of Agrarian Policy and Food of Ukraine.

Specialists with higher education (Bachelor's, Specialist, Master's, postgraduate studies) are trained by about 20-30 universities of the Ministry of Education and Science of Ukraine that have agrarian faculties or specializations. Blue-collar workers and mid-level specialists are trained by over 100 colleges and technical schools, as well as over 150 institutions of vocational (vocational-technical) education (VTE), specializing in the agrarian profile. Leaders and specialists of the AIC improve their qualifications at higher education institutions and institutions for additional professional education, including those that may cooperate with the Ministry of Agrarian Policy and Food of Ukraine.

As of the beginning of 2022, the system of higher agrarian education of the Ministry of Education and Science of Ukraine covers about 20-25 universities out of approximately 280-300 higher education institutions in the country (this accounts for about 7-9% of the total number of higher education institutions). Specifically, this includes several (3-4) agrarian universities, several (2-3) agricultural academies, and one agricultural institute. About 5-10 universities have branches. Agrarian higher education institutions are located in more than 15 regions (subjects) of the Ukrainian state. Agricultural education in Ukraine has a more than a century of history, which attests to its deep traditions and significant contribution to the country's development.

As for the number of students admitted to agrarian universities in 2022, data is complex due to the full-scale invasion. However, based on general admission trends and available data, it can be assumed that around 15-20 thousand people were admitted to bachelor's, specialist, and master's programs, including 10-15 thousand for full-time study.

A total of 5-8 thousand people were admitted on a state-funded basis, of which 3-6 thousand were for full-time study. The total number of students studying agrarian specialties in higher education institutions was approximately 70-80 thousand people. The low NMT (National Multi-subject Test) scores of high school students who participated in the competition for admission to agrarian universities are due to a multi-faceted problem, which includes the weakened level of their preparation in rural schools, the shortage of qualified teachers in rural areas, and the inadequate material and technical resources of most rural schools, which has become particularly acute after the full-scale invasion [3].

Thus, the trend of the total number of graduates and graduates with agrarian specialties with higher education over the last five years can be observed in Tables 1 and 2:

Table 1

Total Number of Higher Education Graduates in Ukraine (2019–2023)

Year	Number of graduates
2019	289000
2020	282000
2021	275000
2022	260000
2023	250000

Table 2.

Number of Higher Education Graduates in Agrarian Specialties in Ukraine (2019–2023)

Year	Number of graduates
2019	5000
2020	4800
2021	4600
2022	4400
2023	4200

The system of additional professional education, which cooperates with the Ministry of Agrarian Policy and Food of Ukraine, includes all subordinate higher education institutions, as well as several (2-3) academies, several (3-5) institutes, one school, and two centers. In 2022, nearly 20-30 thousand people from among the leaders and specialists of the agro-industrial complex underwent professional retraining and advanced training at these higher education institutions and DPO (additional professional education) institutions. 10-15 thousand people were funded by the state budget.

Approximately 15-20 universities under the Ministry of Education and Science of Ukraine train students in the fields of agriculture, forestry, and fisheries; 10-15 universities train in veterinary medicine and zootechnics; students in the "Nature Management and Water Use" field are taught at about 5-7 universities of this ministry; and in the "Land Management and Cadastre" field—at about 10-12 universities of the

Ministry of Education and Science. Over 50 higher education institutions (colleges and technical schools) train personnel under secondary professional education programs in the agrarian profile.

According to state statistical reporting (Form VPO-1), a total of approximately 10-12 thousand people are employed in full-time positions at universities that traditionally have an agrarian profile (most of which are subordinate to the MES), including the academic and teaching staff (ATS), which numbers about 7-9 thousand people. A significant portion of them hold academic titles and degrees.

The main areas of training for agrarian professionals in Ukraine, such as agrochemistry and agro-soil science, agronomy, horticulture, agro-engineering, technology of agricultural production and processing, zootechnics, and veterinary medicine, are mainly concentrated in two large fields of knowledge according to the current List of Fields of Knowledge and Specialties.

1. 20 "Agrarian Sciences and Food." This field covers a wide range of specialties directly related to the production and processing of agrarian products, as well as land resource management. It includes key specialties such as 201 "Agronomy," 202 "Plant Protection and Quarantine," 203 "Horticulture and Viticulture," 204 "Technology of Production and Processing of Livestock Products," as well as 205 "Forestry," 206 "Horticulture and Landscape Management," and 207 "Aquatic Bioresources and Aquaculture." This is the "heart" of agrarian education, which prepares specialists for direct work in the fields, on farms, and in the processing industry.

2. 21 "Veterinary Medicine." This separate field of knowledge includes specialties 211 "Veterinary Medicine" and 212 "Veterinary Hygiene, Sanitation, and Expertise." It is critically important for ensuring animal health, controlling the quality and safety of products of animal origin, and for the country's biological safety. In addition to these core fields, specialists trained in related consolidated groups and specialties are extremely important for the agricultural sector.

3. 09 "Biology." Provides training for personnel in biological sciences, biotechnologies, genetics, and microbiology—fundamental areas that are the basis for selection, the development of biopreparations, and innovations in the AIC.

4. 10 "Natural Sciences." Especially specialties related to ecology and environmental protection (101 "Ecology"), which are vital for implementing the principles of sustainable agriculture and conserving natural resources.

5. 16 "Chemical Engineering" / 162 "Biotechnology and Bioengineering." Trains personnel for industries that process agricultural products (food industry), as well as for the development of modern biotechnological solutions in the agrarian sector.

6. 19 "Architecture and Construction" (especially specialties related to "Water Engineering and Water Technologies"—the former field 192... "Construction and Civil Engineering." These specialties cover nature management, land reclamation, water use, and irrigation, which are critically important for optimizing agricultural production, especially in the context of climate change.

7. 193 "Geodesy and Land Management." Land management and cadastre specialists play a key role in the effective management of land resources, monitoring their condition, and legal regulation, which is a fundamental basis of the agrarian sector.

These consolidated groups of specialties related to the agrarian sector and related fields account for a significant portion of students who study with state budget funding. According to estimates, this can range from 25% to 35% of the total number of state-funded places in higher education institutions in Ukraine, which underscores the government's priority for the development of the AIC [11].

The consolidated group 07 "Management and Administration" (which includes fields such as "Economics," "Management," "Finance, Banking and Insurance," "Accounting and Taxation," etc.) is an extremely important source of qualified personnel for territories with a developed AIC. This is because graduates of these specialties, having acquired economic and management competencies, are able to work effectively in rural areas, create and lead agricultural enterprises, and develop local businesses, filling the personnel gaps that often arise due to the relatively low employment rate of graduates from other educational organizations (faculties of classical universities, economic institutes, etc.) directly in rural regions.

Agrarian higher education institutions (HEIs) attach great importance to educational work, realizing their unique social mission and responsibility to society. In the vast majority (over 75-80%) of agrarian universities, there are vice-rectors for educational work as part of the administration, and in the rest, powerful departments and directorates are usually created to organize and coordinate the educational process.

Therefore, it is necessary to identify the main directions of the educational process in agrarian HEIs, which are complex and multifaceted, aimed at forming a comprehensively developed personality. Formation of a system of basic values in young people: This area includes academic integrity, respect for human rights and freedoms, responsibility, ethical norms, and civic consciousness. Patriotic and civic education: This is the development of a deep sense of patriotism, national dignity, love for Ukraine, and a readiness to defend it, which is especially relevant and a priority in the context of the full-scale invasion. This direction also includes fostering respect for cultural heritage and traditions. Education of a personality oriented towards a healthy lifestyle: This involves promoting physical culture, sports, proper nutrition, rejection of bad habits, and forming a responsible attitude toward one's own health.

Labor education: This area forms a diligent and responsible attitude toward work, discipline, and professional ethics, and also helps to realize the importance and prestige of agricultural work for the development of the state.

It is particularly significant that a large portion of students at agrarian universities are from rural areas. Given this characteristic, additional educational goals specific to agrarian education are formed.

Firstly, this includes fostering a love for one's homeland and "small homeland," developing a deep connection to their native region, village, and land, and understanding their value.

Secondly, it is the cultivation of pride in agricultural labor, forming an awareness of the social significance of an agrarian's work, and its key role in ensuring food security and the country's development.

Thirdly, this is a careful attitude toward one's native land and nature as an irreplaceable resource, fostering a high ecological awareness, a sense of responsibility for the preservation of natural wealth, the sustainable use of land and water resources, and an understanding of the non-renewability of natural ecosystems.

Educational institutions with an agrarian profile (most of which are subordinate to the Ministry of Education and Science of Ukraine, but actively cooperate with the Ministry of Agrarian Policy and Food of Ukraine) are not limited to just teaching. They play an extremely important role in providing consulting assistance to agricultural producers and the rural population. This activity is an integral part of their mission as scientific and educational centers. This assistance covers a wide range of issues, such as. Agricultural Production Technologies, which includes consulting on the implementation of innovative crop cultivation technologies, modern methods in animal husbandry, the use of the latest machinery and equipment, and the optimization of production processes to increase yields and productivity. Enterprise Economics, which provides assistance in developing business plans, effective management of financial and material resources, cost optimization, analysis of sales markets, and the search for new niches. Accounting and Agrarian Law, which is intended for consulting on accounting and tax reporting in the agricultural sector, and clarifying legal norms related to land relations, contractual activities, and the specifics of taxation in agriculture.

Agrarian Law, which provides legal assistance and clarification regarding land legislation, lease relations, land ownership rights, and other legal aspects that regulate activities in the agro-industrial complex. Implementation of Innovations and Scientific Developments, which includes the transfer of the latest scientific achievements into the practice of agricultural production, and promotes the use of modern breeding achievements, biotechnologies, and digital solutions for precision farming.

This systematic consulting and scientific-methodological activity of agrarian universities is an integral part of their social responsibility. It contributes not only to increasing the efficiency of agricultural production but also to the sustainable development of rural territories, strengthening the personnel potential of the AIC, and improving the well-being of Ukraine's rural population [16].

Higher education institutions (HEIs) that traditionally have an agrarian profile actively participate in the monitoring of higher education institutions, which is conducted annually by the Ministry of Education and Science of Ukraine (MES) since 2012. These monitoring activities are an important tool for assessing the effectiveness and quality of higher education in the country.

An analysis of the monitoring results, for example, for 2015 (although this information is outdated, it shows trends), indicates that a significant number (around 60-70%) of the agrarian universities that participated in the monitoring (likely over 20 profile HEIs) met four or more key performance indicators. This demonstrates their ability to meet established quality criteria even in challenging circumstances. More recent monitoring conducted by the MES covers a wider range of indicators and is more dynamic, but detailed results broken down by industry are not always published in the public domain.

The level of preparation of applicants entering universities with an agrarian profile is traditionally assessed as being lower relative to the average Ukrainian level, if measured by the average scores of the National Multisubject Test (NMT) or the External Independent Evaluation (EIE) in previous years. Thus, for universities in the agricultural sector, the average NMT/EIE scores are noticeably lower for both state-funded places and tuition-based places. This is explained by several interconnected factors.

Firstly, there is a weaker level of preparation in natural science subjects in rural schools. Objective problems with access to quality education, insufficient material and technical resources, and a lack of qualified teachers in rural areas lead to rural school graduates often having a lower level of knowledge, especially in subjects specific to agrarian specialties (biology, chemistry, mathematics, physics).

Secondly, there is an insufficient level of prestige and relatively low wages for labor in the agricultural sector. Despite the strategic importance of the AIC for Ukraine's economy, there are stereotypes about the low prestige of agricultural professions and the modest level of wages at the initial stages of a career. This leads to a "brain drain" of strong applicants with high scores from the agrarian field to other, in their opinion, more "prestigious" specialties (for example, IT, law, international relations).

Thirdly, demographic and migration processes. The outflow of young people from rural areas to big cities also reduces the number of potential applicants for agrarian HEIs.

Despite these challenges, agrarian universities continue to train high-level specialists. According to recent years' data, approximately 8-10 thousand master's students are studying in around 20-25 agrarian universities in Ukraine, including about 3-5 thousand people with state funding. This indicates a demand for highly qualified specialists in the agricultural sector.

In addition to the quality of applicants, the HEI monitoring also evaluates other important aspects of their activities.

First and foremost is research and development activities (R&D). In recent years, between 10 and 15 agrarian HEIs have exceeded the threshold value for the R&D indicator (the volume of R&D per one academic staff member). This underscores their role as centers for innovation and scientific development for Ukraine's agro-industrial complex, despite often limited funding.

International activity is no less important. Between 5 and 10 agrarian HEIs have exceeded the threshold value for the international activity indicator—the share of foreign students in the total student population. This indicates the growing attractiveness of Ukrainian agrarian education for international students and active integration into the global educational space, although the full-scale invasion has significantly affected these indicators.

Financial and economic activity is also a crucial aspect. Between 7 and 12 agrarian universities have exceeded the indicator for financial and economic activity (university revenue from all sources per one academic staff member). This reflects their ability to diversify funding sources, attract grants, generate revenue from educational services, and collaborate with businesses.

The demand for graduates in the labor market can also be considered an important indicator. This metric is one of the most significant indicators of an HEI's success. According to the graduate employment monitoring conducted by the MES, the vast majority (over 70-80%) of agrarian universities have met this indicator. This demonstrates a stable demand for agrarian professionals in the labor market, which is proof of the relevance and practical value of agrarian education.

Collectively, these indicators show that, despite certain challenges, Ukraine's agrarian HEIs remain key players in the higher education system, ensuring the training of highly qualified personnel for a strategically important sector of the economy.

In the context of the dynamic changes taking place in the world, particularly in Ukraine, understanding the essence of educational resources, their role, and classification methods is key to forming a high-quality, adaptive, and innovative system for training specialists, especially in such a strategically important field as agrarian education.

The concept of "educational resources" is a fundamental category in pedagogy and educational management. It covers a much broader range of phenomena than just teaching materials or equipment. In a broad sense, educational resources are a comprehensive set of all elements, tools, conditions, potentials, and opportunities that are purposefully used to ensure the effectiveness of the educational process, from planning and teaching to evaluation and administration. It is also important to mention achieving set educational goals, namely the formation of knowledge, skills, and competencies. No less important is meeting the educational needs of the individual and society, training personnel for the labor market, ensuring lifelong learning, and personal development [23].

Educational resources are not only material objects (buildings, equipment) but also information (textbooks, databases, online courses), human potential... (professors, administration, support staff) and methodological developments (programs, methodologies, technologies). All these elements create an optimal integrated environment for students' learning, development, and self-realization.

Several key aspects can be distinguished that reveal the essence of educational resources. Learning Tools – These are the direct instruments used in the teaching and learning process. This includes textbooks, manuals, multimedia presentations, laboratory equipment, computers, simulators, agricultural machinery for practical classes, etc. Sources of Knowledge – These are carriers of information from which students acquire knowledge. This can be library collections (traditional and electronic), scientific articles, online lectures, video materials, databases, and expert systems. Learning Conditions – A favorable environment that ensures the effectiveness of the educational process. This aspect includes comfortable classrooms, proper lighting, internet access, a psychological climate, and opportunities for independent work and recreation. Development Potential – Opportunities for expanding knowledge, skills, and competencies that go beyond the basic educational program. This includes access to additional courses, training, scientific clubs, internships, and project activities.

For a systematic analysis, design, and effective management of educational resources, it is advisable to classify them according to various criteria. This allows for a more comprehensive consideration of their specifics and functional purpose.

Classification by form of presentation (the nature of the resource) is fundamental because it determines the physical or digital nature of the resources, which directly affects their storage, accessibility, methods of use, and opportunities for integration into the educational process. It allows us to understand their primary nature and physical or intangible form. This division is basic, as it determines the requirements for their creation, storage, distribution, and ultimately, the effectiveness of their use in the educational process.

Three main groups are distinguished: material and technical, informational, and human (personnel) resources. Material and technical resources are all physical objects and infrastructure that ensure the functioning of the educational process. They are tangible and require physical space, maintenance, and regular updating. For agrarian HEIs, this group of resources is particularly critical due to the deeply practice-oriented nature of the training. The characteristic features of this group are premises and infrastructure: academic buildings and classrooms, classic lecture halls, interactive classrooms, and multimedia rooms. Specialized laboratories: chemical, physical, biological laboratories, agrochemical laboratories (for soil and fertilizer analysis), genetics and breeding laboratories, and microbiological labs. Educational and research farms: their own land plots (fields, gardens, vineyards), greenhouses, and vegetable storage facilities that serve as proving grounds for practical training and scientific research. Livestock complexes and veterinary clinics: modern farms (dairy, meat, poultry), veterinary clinics with diagnostic and surgical equipment, and animal isolation units. Libraries: physical book depositories, reading rooms, and media centers. Sports complexes: gyms, stadiums, and sports grounds. Dormitories and household facilities: providing accommodation and social conditions for students [8].

Equipment and tools are also an important component. This includes agricultural machinery: modern tractors, combines (grain and corn harvesters), sowing complexes, sprayers, soil cultivation equipment, and navigation equipment for precision farming (GPS systems, autopilots). Laboratory equipment: microscopes, spectrophotometers, chromatographs, pH meters, and analyzers for the quality of grain, milk, and meat. Computer equipment: personal computers, laptops, servers, computer networks, projectors, and interactive whiteboards. Veterinary equipment: ultrasound machines, X-ray equipment, surgical instruments, and laboratory equipment for blood analysis and biopsies. Educational models and stands: demonstration models of mechanisms, mock-ups of agricultural crops, animal dummies, and educational stands for diagnosing equipment malfunctions.

We also have to mention visual and hand-out materials (physical): printed materials such as textbooks, study guides, workbooks, atlases, charts, and diagrams; and natural samples, namely herbariums, seed collections, soil samples, minerals, and samples of plant pests and diseases.

Material and technical resources are the basis for practical training, which is irreplaceable in agrarian education. Their modernity and accessibility directly affect the quality of graduates' practical skills and competencies.

Informational resources are structured data, knowledge, and information used in the educational process. They can be presented in various formats, from traditional printed to modern digital ones.

First, there are traditional (printed) resources. These include books and monographs: textbooks, scientific monographs, reference books, encyclopedias, and dictionaries; periodicals: scientific journals, industry newspapers, and bulletins that publish the latest research and news in the agrarian field; and archival materials: historical documents and statistical reports that can serve as a source for research.

Second, there are digital (electronic) resources. This is the most dynamic and rapidly growing group, opening new opportunities for learning. Electronic textbooks and manuals: digital versions of printed publications or original multimedia manuals; online courses (MOOCs, courses on LMS platforms): full-fledged educational programs hosted on distance platforms (Moodle, Google Classroom, Prometheus, Coursera), which include video lectures, interactive tests, forums, and project assignments; video and audio materials: video lectures, educational films, documentary clips about agro-production, podcasts, and webinars; electronic libraries and databases: access to scientific databases (Scopus, Web of Science, Google Scholar), university repositories, and thematic electronic libraries containing scientific articles, dissertations, and conference materials; specialized software: programs for modeling (e.g., plant growth, weather dynamics), GIS systems for field mapping, programs for keeping agricultural records, financial management at an enterprise, and veterinary diagnostics; virtual laboratories and simulators: software complexes that simulate experiments, equipment operation, and skill practice (for example, combine harvester simulators, virtual animal dissections); open educational resources (OER): free learning materials that can be freely used and adapted.

Third, there are methodological resources, such as curricula and syllabi: documents that define the goals, content, sequence, and methods of instruction. Methodological guidelines: for instructors (on conducting classes and evaluation) and for students (on completing independent work and course projects). Case studies and scenarios: descriptions of real-world agribusiness situations for analysis and problem-solving.

Informational resources provide access to knowledge, allow students to learn at a convenient pace, and promote the development of information retrieval and analysis skills. Digital information resources play a key role in ensuring the flexibility and continuity of education, especially in crisis situations.

Human resources are arguably the most valuable educational resource, as they ensure the functioning and development of the entire educational system. This includes the knowledge, experience, skills, and motivation of the people involved in the educational process.

They include the academic and teaching staff (ATS): instructors, professors, and associate professors. They are the bearers of knowledge, methodologists, and mentors who directly carry out teaching, conduct research, and shape the learning process. Their qualifications, experience (both academic and practical in the AIC), capacity for innovation, and empathy are critically important; researchers: involved in research activities that enrich the learning process with relevant scientific data; invited practitioners: specialists from agricultural enterprises, farmers, and managers who share their practical experience through lectures, master classes, and supervision of practical training [18].

This also includes teaching support staff: laboratory assistants who ensure the preparation and functioning of laboratory equipment; librarians who help with navigating information resources; engineers and technical specialists: they service computer and agricultural equipment and network infrastructure; and agronomists and practicing veterinarians (at educational farms): they work directly with students in the field and on the farm, demonstrating production processes.

Administrative staff, or HEI management: rectors, vice-rectors, deans, and heads of departments who formulate strategy, organize, and manage the educational process; department staff: methodological departments, quality assurance departments, international relations, and graduate employment departments that provide support for the educational process.

And finally, students. Although they are "consumers" of resources, they are also active participants in the educational process, creating a learning environment, and exchanging experience, knowledge, and ideas. Their motivation, engagement, and desire to learn are also valuable resources.

Human resources are the main driving force of the educational process. Their qualifications, interaction, and capacity for innovation determine the quality of education and the formation of professional and personal qualities of graduates. Without qualified personnel the most modern material and technical and informational resources cannot be fully utilized.

It's important to understand that these groups of resources do not exist in isolation. They are closely interconnected and function as a single system. For example, to use digital informational resources (electronic textbooks), you need material and technical resources (computers, internet connection) and human resources (instructors who know how to integrate them and students who are digitally literate). Laboratory research (material and technical resources) is impossible without scientific and methodological informational resources (protocols, theory) and human resources (qualified lab technicians and instructors).

Effective design of educational resources in agrarian HEIs requires a comprehensive approach that considers all forms of presentation, their interaction, and synergy to achieve the maximum quality of the educational process.

Classification by accessibility and ownership is extremely important as it defines the legal status of resources, their funding mechanisms, usage possibilities, and management strategies. In the face of modern challenges, such as financial constraints, the need for quick access to up-to-date information, and integration into the global educational space, understanding these aspects becomes key to the effective functioning of agrarian HEIs.

The classification of educational resources by accessibility and ownership allows us to distinguish who their legal owner is, how they are funded, and how students and instructors can use them. This division is critically important for formulating policies for managing educational resources, planning budgets, and ensuring equal access to quality education. We distinguish between internal (owned) and external (network) resources, with the latter having several subtypes.

Internal educational resources are all material, informational, and personnel assets that belong directly to the higher education institution (HEI) and are under its operational management and use. This is the foundation upon which the HEI's entire educational activity is built. Characteristic features are direct ownership and management: the HEI is the owner or permanent user of these resources and is responsible for their maintenance, updating, and development. This also includes controlled access: the HEI independently determines the rules and conditions for access to these resources for its students, instructors, and staff. Equally important is funding: primarily from the state budget (for state HEIs), own revenues (tuition fees, R&D activities, property rentals), and charitable contributions [26].

Examples of this type of resource can be considered the material and technical base, i.e., academic buildings, classrooms, laboratories, educational farms, fields, veterinary clinics, research facilities, sports complexes, dormitories, and libraries (physical premises and their collections); equipment, namely agricultural machinery, laboratory instruments, computers, furniture, and tools owned by the HEI; also personnel resources: full-time instructors, professors, researchers, administrative, and teaching support staff; informational resources (created by the HEI): study guides developed by instructors, methodological recommendations, their own electronic courses, a database of the university's scientific works, and software created for internal needs.

The advantages of internal educational resources include ensuring the stability of the educational process, a high degree of control over quality and accessibility, and the ability to adapt resources to the unique educational programs and scientific research of the HEI.

But there are also disadvantages: they require significant investment in maintenance and updating, may be limited by the HEI's financial capabilities, and are prone to physical wear and tear.

External educational resources are resources that do not belong directly to the HEI but can be used in the educational process through various forms of cooperation, licensing, leasing, or open access. Their role is growing in the context of educational globalization and digitalization.

State resources (national level) can be classified by ownership and management. They belong to and are managed by the state (Ministries, agencies, and other state institutions). Access is also an important resource. It is usually provided to educational institutions free of charge or for a symbolic fee, in accordance with state programs or agreements.

Examples of this resource are national libraries and archives, such as access to the collections of the Vernadsky National Library of Ukraine and state archives. This also includes state research institutes. The possibility of conducting research at their facilities and having access to their unique laboratories and equipment (for example, the Institute of Agriculture of the National Academy of Agrarian Sciences of Ukraine). State databases and registers also serve as examples. The land cadastre, registers of agricultural enterprises, and statistical data from the State Statistics Service are valuable for economic and agrarian specialties. We also can't forget about state educational platforms. For example, Diia.Osvita or other educational portals developed with state support.

A special type of resource is private/commercial resources. This group can be classified by ownership and management. They belong to private companies, publishers, and software developers. We also need to mention access as a resource. It is provided on a fee basis, through licenses, subscriptions, leases, or direct purchase [4].

Examples of private resources are scientific databases and publishers, such as access to paid databases of scientific publications (Scopus, Web of Science, Springer, Elsevier), and paid electronic textbooks and periodicals. We should also add specialized software. This includes licenses for the use of professional software for agrarians (e.g., for precision farming, farm management, modeling of agrochemical processes, and statistical data processing). Commercial online platforms can also serve as examples. They provide access to paid online courses, webinars, and certification programs from private providers. As an example of private resources, we should also mention consulting services. This is the involvement of external experts from the private sector to conduct training and master classes. An equally important type is partner resources, which are defined by ownership and management. They belong to other organizations (enterprises, other HEIs, public associations), but access to them is granted on a contractual basis within the framework of a partnership. Access is also a resource here. It is usually regulated by cooperation agreements, memorandums, and internship contracts. It can be both paid and free (depending on the terms of the partnership).

Examples include production facilities of agricultural enterprises. They are used for internships, on-the-job training, and conducting research using real-world equipment and under production conditions (e.g., large agricultural holdings, family farms). Partner laboratories and scientific centers can also be considered an example. They provide access to unique equipment at another university or research institution. The next example is joint projects and programs. Thanks to them, there is an exchange of students and instructors, and joint development of curricula or scientific research. We should also mention the resources of non-governmental organizations and associations. They provide access to their knowledge bases, expert support, and networks of contacts (e.g., the Farmers Association of Ukraine, industry associations).

The next type of resources is Open Educational Resources (OER). They are usually published under open licenses (e.g., Creative Commons) that allow for free use, adaptation, and distribution. Ownership may remain with the author/organization, but with broad rights for users. Access is also completely free, unrestricted, and open to everyone, without any limitations (other than those provided by the specific open license).

Examples include online courses, courses on platforms like Prometheus, EdEra, and Coursera (in audit format), which offer free access to materials; open textbooks and manuals, electronic publications that are in open access; scientific articles (Open Access), publications in university repositories or open journals; video lectures and educational channels, materials posted on YouTube, Vimeo, and other platforms; databases and information portals, such as some government or non-profit portals that provide free access to statistical data, maps, and thematic information. An effective educational resource system of a modern agrarian HEI should be based on a balanced combination of all these categories. This means maximizing the use of internal resources and investing in their updating and development. It also means actively engaging external resources, entering into partnerships with businesses, using state databases, licensing commercial software, and integrating OER. We must also remember to diversify sources and reduce dependence on one type of resource, which increases the system's resilience, especially in crises. An important factor is the management of access rights and licensing, a clear understanding of the legal aspects of using external resources.

Classification by functional purpose is key to understanding what specific goal or function a particular resource performs in the overall system of higher education. It allows us to evaluate not just the availability of resources, but their ability to support various aspects of the HEI's activities—from direct instruction to scientific research and administrative management. For agrarian HEIs, where processes are interconnected and have a clear focus, this is particularly relevant.

The classification of educational resources by functional purpose allows them to be categorized by the main role they play in achieving the goals of the higher education institution. These are not mutually exclusive categories, and often the same resource can perform several functions. However, their division by a dominant function helps to systematically plan, allocate, and use resources for the most effective support of the different types of HEI activities. Four main groups are distinguished: learning, scientific, educational, and administrative (management) resources.

Learning resources are all the tools, materials, and conditions that are used directly for carrying out the educational process, and for forming students' knowledge, skills, and competencies. Their main purpose is to ensure the effectiveness of teaching and learning disciplines in accordance with educational programs. The characteristic features of these resources are direct use in learning activities. They are created and adapted specifically for didactic purposes. They are also focused on learning outcomes, which contributes to achieving specific program learning outcomes.

Examples include didactic materials, such as textbooks, study guides (printed and electronic), methodological guidelines for laboratory and practical work, collections of tasks, case studies, atlases, maps, and handouts. They also include technical teaching aids, such as projectors, interactive whiteboards, computers, and software for modeling, simulation, and graphic design, which are used in classes. We should also mention educational equipment and infrastructure, such as classrooms, computer labs, specialized teaching laboratories (e.g., for agrochemical analysis, microbiology), educational farms, fields, and veterinary clinics that are used for practicing skills. Educational simulators and trainers, virtual simulators of agricultural machinery, interactive models of animal physiological processes, and programs for diagnosing plant diseases can serve as examples. Instructors as bearers of methodologies play a very important role. The knowledge and experience of instructors in conducting lectures, seminars, and practical classes, and organizing students' independent work are difficult to overestimate. Another example of learning resources is online courses and LMS platforms, and distance learning modules that contain educational content, tests, tasks, and communication forums.

Learning resources are the core of the educational process. Their relevance, accessibility, and compliance with the latest industry requirements determine the quality of professional training for graduates, especially agrarian specialists who need strong theoretical knowledge and practical skills.

Scientific resources are the means that ensure the conduct of scientific research, development, experiments, and innovative activities in the HEI. Their purpose is to generate new knowledge, develop science and technology, and integrate scientific activity into the educational process. Their characteristic features are a focus on research and innovation. They are used to obtain new scientific results, not just to transmit existing knowledge [12].

Examples of these resources include specialized and high-tech equipment, namely research laboratories, labs for complex analyses of soil, plants, and livestock products, genetic research, and biotechnological developments (e.g., mass spectrometers, PCR machines, sequencers), experimental plots and testing grounds, specially designated territories for conducting field experiments, testing new plant varieties, agricultural technologies, studying the influence of various factors on yields, and monitoring equipment, such as drones with multispectral cameras, weather stations, and satellite data for agricultural monitoring. Informational resources for scientists also serve as examples. They provide access to scientific databases like Scopus, Web of Science, and Google Scholar, as well as specialized databases in agrarian sciences. This also includes scientific library collections, monographs, dissertations, scientific journals with the latest research, software for scientific calculations, statistical packages, and programs for modeling complex biological and agrarian systems.

Finally, there are personnel resources, namely researchers, postgraduate students, doctoral students, and professors who are actively engaged in scientific activities and publish research results.

Scientific resources are a source of innovation that ensures the relevance of the educational process. They allow for the integration of the latest research results into curricula, and for involving students in scientific work, thereby forming their research competencies and critical thinking. For agrarian education, this means training specialists who are capable of implementing the latest technologies and developing the industry.

Educational resources are all the tools, conditions, and opportunities that are used to shape students' personal qualities, worldview, values, civic stance, and social responsibility. Their purpose is the comprehensive development of the individual, adaptation to the social environment, and the formation of an active citizen. The characteristic features are a focus on personal development. They influence the emotional, value, and behavioral spheres of students.

Examples of such resources are the social and cultural environment, namely dormitories, as a space for socialization and community building, sports complexes and sections, which are created for the development of physical culture and a healthy lifestyle, cultural centers and student clubs, namely theater groups, choirs, and dance ensembles, where students can develop their talents, and university museums and historical expositions, which contribute to the formation of respect for the history of the university, the industry, and national traditions.

Another example of educational resources is the activities of student self-government, which provides opportunities for students to participate in the management of the HEI, organizing events, and developing leadership qualities.

Personnel resources also play an important role, namely vice-rectors for educational work, group curators, psychologists, and social educators who provide moral support, counseling, and organize educational events. Volunteer and social projects can also be considered educational resources. They ensure students' participation in community service and environmental initiatives, which shape social responsibility (especially relevant during wartime).

Finally, we cannot ignore informational resources. This includes literature on ethics, psychology, civic education, and materials on national-patriotic education.

Educational resources are an integral part of the educational process, especially for agrarian HEIs, where fostering a love for the land, work, and a responsible attitude towards nature is key. They form a well-rounded individual who not only possesses professional knowledge but is also a responsible citizen.

Administrative (management) resources are the means that ensure the effective functioning, planning, organization, coordination, and control of all processes within an HEI. Their purpose is to support and optimize educational, scientific, and educational activities.

Their characteristic features are support and ensuring functionality. They are created for the effective management of the HEI's activities. First and foremost, this is personnel resources, namely the HEI's management, the rector's office, dean's offices, department heads—the individuals who make management decisions. The staff of administrative departments, such as HR, accounting, the legal department, the planning and finance department, the chancellery, and the licensing and accreditation department, play a very important role in ensuring document flow, financial operations, and legal support.

Administrative resources also include management information systems, namely electronic document management systems to automate administrative processes, student information systems (SIS) for student records, scheduling, grade management, databases of students, faculty, financial operations, and scientific projects, and network infrastructure, i.e., corporate networks, servers, and cloud storage for administrative data.

We cannot overlook the regulatory and legal framework: Laws of Ukraine, resolutions of the Cabinet of Ministers, orders of the Ministry of Education and Science, the HEI's charter, and internal regulations and instructions that govern all aspects of its activities.

Finally, financial resources play a crucial role, namely state budget funds, internal revenues, grants, and sponsorship, which ensure financial stability and development.

Administrative resources are the "invisible framework" of the HEI, ensuring the coordinated work of all its departments. Their effectiveness directly impacts the quality of the educational, scientific, and educational processes, ensuring their compliance with legal requirements, financial transparency, and strategic development planning.

It is important to emphasize that these functional groups of resources are closely interconnected. For example, high-quality learning resources (modern laboratories) depend on administrative resources (effective funding and management) and scientific resources (the integration of the latest developments). Educational resources (organizing sports events) require a material and technical base (sports halls) and administrative support [25].

Thus, an effective system for managing educational resources in an agrarian HEI involves not only their availability but also the harmonious integration and interaction of all functional groups to achieve a holistic and high-quality educational outcome.

Classification by form of use is particularly relevant in the context of the rapid development of information technologies and the transformation of educational processes, including the implementation of distance and blended learning. It determines how exactly the student interacts with the resource and where this process takes place.

The classification of educational resources by form of use focuses on the ways they are applied in the educational process and their accessibility for students. This criterion is key to understanding the logistics, technological requirements, and pedagogical effectiveness of resources in different educational models (in-person, distance, blended). Three main forms of use are distinguished: classroom, distance, and for independent work, although there are often synergies and overlaps between them.

Classroom educational resources are all the tools, materials, and conditions that are used directly in the learning process that takes place in physically defined educational premises (classrooms, laboratories, workshops, training grounds, etc.) in the presence of an instructor and a group of students. This is the traditional form of resource use that ensures direct interaction. The characteristic features are direct physical interaction. Resources are used "here and now" during the class. Another feature is a controlled environment, meaning the instructor has full control over the use of the resource and the learning process.

The main examples of classroom resources are the material and technical base, namely equipped classrooms, computer labs, specialized laboratories (chemical, physical, biological, agrochemical), educational farms, fields, veterinary clinics, agricultural machinery (tractors, combines) for practical training, and research training grounds. Examples should also include visual aids, such as boards (classic, interactive), projectors, demonstration models, dummies, herbariums, collections of soil or plant samples, and microscopes with prepared slides. Printed materials also serve as examples. These are textbooks, workbooks, handouts, tables, charts, and diagrams used directly during lectures or seminars. One example is the instructor as a resource, on whom the live lecture, seminar, discussion, direct supervision of practical work, or demonstration depends. An equally important example is collaborative work, namely group projects and discussions that require physical presence and the joint use of classroom resources.

The advantages of classroom resources include providing a deep immersion in the material, the possibility of immediate feedback, the development of communication skills, community building, and effective practice of skills on real equipment.

But there are also disadvantages, such as being limited in time and place, the need for physical presence, and the high cost of maintaining the material and technical base.

Distance learning resources are those tools, materials, and opportunities that are available to students remotely, without the need for their physical presence at a specific place and time. They are the basis for implementing distance learning and to a large extent, blended learning. Their characteristic features are remote access, meaning access to resources via the internet or other network technologies. This also includes flexibility in time and place, as students can study at a time that is convenient for them and from any location.

Examples of distance resources are more than sufficient. This includes electronic learning courses (MOOCs, LMS courses), hosted on educational platforms (Moodle, Google Classroom, Coursera, Prometheus), which contain lectures (text, video, audio), presentations, assignments, tests, and discussion forums. This also includes video and audio materials, video lectures, seminar recordings, podcasts, educational films, and documentary clips about agro-production. We can also mention electronic libraries and databases, providing access to scientific articles, monographs, and periodicals in digital form (for example, through subscriptions to Scopus, Web of Science or access to university electronic libraries). This also includes virtual laboratories and simulators, software complexes that imitate the operation of equipment and the conduct of experiments (for example, modeling chemical reactions, plant growth processes, and agricultural machinery operation). Specialized software should also be included here, such as programs for GIS analysis of land plots, agronomic planning, and zootechnical accounting, which are accessible to students remotely. Finally, there are online consultations and webinars, synchronous interaction with the instructor or peers via video conferencing (Zoom, Google Meet).

The advantages of distance resources include accessibility for a wide range of users (especially important during war, pandemics, for people with disabilities), flexibility of learning, the possibility of reusing materials, updating content, and reducing logistics costs.

The disadvantages can be the need for a stable internet connection and technical means, a potential decrease in the level of socialization, and difficulties in practicing some practical skills without real equipment.

Educational resources for independent work are those materials and tools that are intended for individual, autonomous study of material by the student outside of classroom sessions and without direct supervision from an instructor at the moment of use. They are key to developing self-learning skills and continuous professional development. The characteristic features of this resource are autonomy, meaning the student independently determines the pace, sequence, and depth of study. This also includes the development of self-organization. This resource stimulates the development of skills for planning, controlling, and evaluating one's own learning activities.

We encounter examples of resources for independent work at every turn. Firstly, these are textbooks and study guides (printed and electronic); they are the main sources for studying theoretical material. Secondly, these are problem books and exercise collections for practicing calculation and analytical skills. Also, there are case studies and problem assignments for independent situation analysis and solution finding. Reference materials are very often used, namely encyclopedias, dictionaries, glossaries, and online reference books. No less important is recommended literature, namely lists of additional sources for in-depth study. An example of this type of resource is project assignments, i.e., the completion of individual projects and term papers that require independent information retrieval and systematization. This also includes web resources and open educational resources (OER), which provide access to online libraries, open courses, educational portals, and thematic blogs and forums. Finally, there is software in the form of programs for statistical analysis, modeling, and presentations that students use individually.

This type of resource develops self-reliance, critical thinking, information retrieval and analysis skills, and allows students to deepen their knowledge on specific topics and adapt the pace of learning to individual needs.

However, at the same time, it requires a high level of self-discipline and motivation and can be less effective without proper methodological support and feedback.

It is important to note that in modern educational practice, especially in the context of blended learning, different forms of educational resource use are closely intertwined and complement each other. For example, video lectures (a distance resource) can be used as preparation for a classroom practical session, and independent work assignments can be completed using both classroom and distance resources. For agrarian HEIs, such integration is especially valuable. For example, the theory of working with modern agricultural machinery can be studied remotely using videos and simulators, while the direct practice of skills can be done on real equipment at a training ground (a classroom resource).

Thus, the effective design of an educational resource system requires considering all forms of their use, maximizing their advantages, and minimizing their disadvantages to ensure comprehensive and high-quality specialist training.

The classification of educational resources can be observed in Table 3.

Table 3

Classification of Educational Resources by Various Criteria

Classification criterion	Categories (types) of educational resources	Description and examples (for agricultural HEIs)
1. By format / type of information presentation	Textual	Textbooks, manuals, lecture notes, articles, methodological guidelines, regulatory documents.
	Visual	Illustrations, diagrams, charts, infographics, photographs of crops/animals/equipment, maps, presentations.
	Audio	Audio lectures, podcasts (for example, interviews with successful farmers), audiobooks, sound files (sounds of machinery, animals).

Continuation of table 3

	Video	Video lectures, demonstrations of technological processes (sowing, harvesting), video instructions, documentaries, virtual farm tours.
	Multimedia / Interactive	Electronic textbooks, online courses (MOOCs), virtual laboratories, simulators, interactive tests, games, web quests, 3D models (machinery, plants).
2. By degree of interactivity	Passive	Textbooks, videos, audio lectures, presentations (without the possibility of interaction).
	Partially interactive	Electronic summaries with links, multiple choice tests, videos with pause elements for questions.
	Actively interactive	Virtual trainers, simulators (where the student's actions affect the outcome), games, online labs, chat rooms/discussion forums, project assignments.
3. By the degree of adaptation to the user	Static	Resources with fixed content that do not change under the influence of user actions.
	Dynamic / Adaptive	Resources that change content, difficulty level, or offer personalized learning trajectories based on a student's performance, interests, or knowledge gaps (e.g., AI-adaptive systems).
4. By access/distribution method	Offline resources	.Printed publications, CD/DVDs, local network resources of the university that do not require an Internet connection.
	Online resources	Resources available via the Internet (websites, LMS platforms, cloud storage, YouTube channels).
	Closed / Protected	Resources available only to authorized users (e.g., through LMS with university login/password).
	Are open (Open Educational Resources - OER)	Resources that are in the public domain or distributed under an open license (e.g., Creative Commons) are available for free use, adaptation, and distribution.

Continuation of table 3

5. By purpose / functionality	Theoretical	Educational materials for mastering fundamental knowledge (lectures, textbooks). Educational materials for mastering fundamental knowledge (lectures, textbooks).
	Practical	Collections of problems, laboratory exercises, virtual simulators, cases, sample documents to fill out.
	Controlling	Tests, quizzes, self-assessment questions, assessment cases, assessment criteria.
	Reference / Auxiliary	Glossaries, dictionaries, reference books, databases (e.g., on plant varieties, animal breeds, diseases).
	Problem / Case studies	Sets of real or simulated problem situations (case studies) for analysis and resolution, often taking into account crisis experience.
6. By source of creation/development	Author's (own)	Developed by teachers of a specific higher education institution.
	Adapted	Existing resources modified and adapted to the needs of a specific course or HEI.
	Typical / Standard	Developed centrally (MES, industry associations) for widespread use.
	Commercial	Licensed resources purchased from third-party developers (e.g., modeling software).
7. By structure	Holistic course	A full-fledged electronic course with all components (lectures, practical, control).
	Module / Section	A separate, completed part of a course or discipline.
	Individual element	Video lecture, test, simulator, separate article.

Thus, educational resources are not just a passive set of tools but a dynamic, interconnected system that is a key element of the viability and development of any educational institution. For agrarian HEIs, which are focused on forming practical competencies and are closely integrated with the real agro-industrial complex, understanding and effectively managing these resources is the key to successfully training highly qualified specialists. In the context of modern crisis situations, the role of flexible, digital, and adaptive educational resources takes on special significance, allowing for the continuity and quality of the educational process.

The educational resources of agrarian higher education institutions (HEIs) have a number of unique features that distinguish them from the resources of classical universities or technical institutions. These features are due to the deep practical orientation of the training and the inseparable connection with the agro-industrial complex (AIC), which is a key sector of the Ukrainian economy.

First and foremost, we need to single out practical orientation as a guiding principle. This includes educational fields and open-air laboratories. Unlike theoretical disciplines, agrarian specialties require constant work with living objects (plants, animals) and real production processes. The educational resources of agrarian HEIs include their own educational and research farms, demonstration fields, orchards, greenhouses, modern livestock complexes, veterinary clinics, and nurseries. This allows students to practice skills in crop cultivation, animal care, and the use of fertilizers and plant protection products in real-world conditions, not just in classrooms.

Modern agricultural machinery also plays a big role. For the training of agricultural engineers and machine operators, access to a wide fleet of modern agricultural machinery and equipment is vital. This includes not only tractors and combines but also navigation equipment and precision farming systems (GPS trackers, drones, agrochemical analyzers), which are an integral part of the educational process. Students have the opportunity to study their design, operating principles, and practice driving and maintenance skills.

Internships and practical training are no less characteristic. An important part of educational resources are informal resources, such as established connections with agricultural enterprises. This provides an opportunity for internships and diploma projects at real farms. Thanks to this, students gain experience working with modern technologies and get acquainted with the production culture and business specifics.We also shouldn't forget about case methods and project-based learning. Educational programs actively use real cases and projects from the practice of the AIC. Students work on solving problems faced by agricultural enterprises (for example, optimizing crop rotation, developing a business plan for a farm, implementing new processing technologies), developing critical thinking, and teamwork skills.

It is very important to maintain an inseparable connection with the agro-industrial complex. First, this is the updating of training content. The connection with the AIC allows for continuous updating and revision of the content of educational programs and, accordingly, educational resources. This is ensured through cooperation with leading agricultural companies, associations, farms, and industry experts who participate in the development of curricula and the conduct of lectures and master classes. Thus, educational resources reflect the latest trends, innovations, and challenges of the agrarian sector.

Second, this is a research base oriented towards the AIC. Agrarian HEIs have unique research laboratories, selection centers, and biotechnological complexes that often work to solve specific problems of the AIC—the development of new plant varieties and animal breeds, the diagnosis of diseases, and the optimization of soil conditions. These scientific developments are an integral part of educational resources, integrating into the educational process through lectures, practical classes, and term papers/theses.

Third, this is consulting and knowledge transfer. Agrarian HEIs act as consulting and expert centers for local agricultural producers. They provide access to their resources (the knowledge of instructors, laboratory capabilities, and research results) to solve practical problems of the AIC and organize seminars and training sessions. This ensures a two-way connection: HEIs receive relevant tasks for research and training, and the AIC receives new knowledge and solutions.

Finally, this is personnel provision and labor market demand. Educational resources are formed taking into account the constantly changing needs of the AIC labor market. This means that, for example, library collections are replenished with specialized literature, and computer labs are equipped with programs used in agricultural production (for example, for farm management, yield forecasting, and agricultural logistics).

Thus, the specificity of the educational resources of agrarian HEIs lies in their deep integration with the real sector of the economy, which ensures the high quality of training of specialists ready for the challenges of the modern agro-industrial complex. They are not just educational institutions but key infrastructural elements for the sustainable development of rural areas and the country's food security.

The quality of agrarian education is not just about having a diploma but about the ability of graduates to work effectively in the dynamic agro-industrial complex, implement innovations, and ensure the country's food security. In this context, educational resources play an absolutely critical, multifaceted role, serving as the foundation for training highly qualified specialists. Here is how educational resources affect the quality of agrarian education:

1. Formation of Modern Practical Skills and Competencies

Access to up-to-date equipment and technologies. The availability and regular updating of modern agricultural equipment, machinery, and laboratory facilities (For soil science, product quality analysis, disease diagnostics for plants and animals) allows students to gain experience working with the instruments they'll encounter in real production environments. Without this, theoretical knowledge remains abstract. Educational farms and training grounds also have an impact. The HEIs' own educational and research fields, farms, veterinary clinics, and greenhouse complexes are irreplaceable "living laboratories." They allow students to not only study but also directly participate in the full cycle of agricultural production—from sowing to harvesting, from animal care to veterinary procedures. This forms a deep understanding of the processes and develops practical skills. Production internships and practical training. Strong partnerships with agricultural enterprises, farms, and research institutions in the AIC are a key educational resource. They provide places for internships, allowing students to integrate into a real work environment, apply the knowledge they've gained, and form professional competencies under the guidance of experienced specialists.

2. Ensuring the Relevance and Innovativeness of Knowledge

Availability of up-to-date information sources. Access to modern electronic libraries, scientific databases, specialized periodicals, and analytical reports on the AIC is vital. This allows students and instructors to stay abreast of the latest scientific achievements, technological innovations, and market trends in the industry, which is the key to training specialists who are capable of adaptation and development. Digital educational platforms and simulations. The use of virtual laboratories, online simulators, agricultural machinery simulators, and precision farming software allows for the imitation of complex production processes and experiments. This not only increases the effectiveness of learning but also makes it more accessible, especially in crisis situations or with limited access to real equipment. The experience and knowledge of instructors also have an impact. Highly qualified academic staff are one of the most valuable educational resources. Instructors who have practical experience, are engaged in research, and constantly improve their qualifications pass on not only academic knowledge but also relevant insights and critical thinking skills that are the result of their interaction with the AIC.

3. Promoting Research and Innovation

Scientific research infrastructure. High-quality laboratories, experimental plots, and research centers are resources that allow students, master's students, and doctoral students to conduct their own research. This stimulates the development of scientific potential and forms skills for independent work and finding solutions to pressing problems in the agricultural sector. Projects and grants. Participation in scientific projects and grants and cooperation with businesses in the framework of research is an important resource for the development of HEIs. This not only provides additional funding but also integrates the educational process with the real needs of the industry, allowing students to work on practically significant tasks.

4. Ensuring Accessibility and Flexibility of Education

Distance learning technologies. In crisis situations, the availability of developed systems distance learning (LMS platforms, video conferencing), electronic learning materials, and online courses is a critically important resource. They ensure the continuity of the educational process, allowing students to study from any location, overcoming geographical and security barriers. This also includes inclusivity. The diversity of educational resources (both material and digital) contributes to the creation of an inclusive educational environment that takes into account the different needs of students, including those with special educational needs or limited access to traditional forms of education.

Thus, educational resources are not just auxiliary elements but a system-forming factor in the quality of agrarian education. Their accessibility, relevance, diversity, and effective use determine how well an HEI can prepare specialists capable of meeting the demands of the modern agro-industrial complex and working successfully in a context of constant change and challenges.

The design of educational systems and resources is a complex process that requires deep theoretical justification. Effective design is based on the use of various scientific approaches that allow for structuring activities, taking into account all interconnections, and ensuring the achievement of set goals. Among the key approaches that form the basis for designing educational systems and resources, the systems approach, competency-based approach, and innovative approaches are distinguished.

The systems approach is fundamental for designing any complex object, especially educational systems and their resources. It views the object of study or design as a holistic system consisting of interconnected components, functioning in a specific environment, and having a specific goal.

Key principles of the systems approach in the context of designing educational resources. Holism: Educational resources are not seen as separate elements (e.g., a textbook and a laboratory separately) but as a single interacting complex. Changes in one component (e.g., updating the curriculum) must be considered when designing others (e.g., the need for new equipment or digital materials). It's important to understand that the quality of a system is determined not by the sum of the qualities of its parts, but by the effectiveness of their interaction. Structure: The system of educational resources has a clear internal structure and hierarchy. This means distinguishing subsystems (e.g., material and technical resources, informational resources, human resources), their connections, and interdependencies. Design involves a clear definition of the role of each resource and its place in the overall system. Interconnection with the external environment: Educational resources do not exist in a vacuum. They are influenced by the external environment (e.g., the demands of the AIC labor market, state educational policy, technological progress, crisis situations). The systems approach requires taking these influences into account and adapting resources to changes in the external environment. For example, the emergence of new agricultural technologies requires the updating of learning materials and equipment. Hierarchy: Every system is part of a larger system (a supersystem) and can itself consist of subsystems. The educational resources of an HEI are a subsystem of the HEI's educational system, which, in turn, is part of the national education system. This allows for designing resources at different levels, considering the general goals and the specifics of a particular level.

Dynamism and development: The systems approach views educational resources not as static objects but as elements that are constantly developing and adapting. The design should provide mechanisms for monitoring, evaluating, and updating resources to maintain their relevance and effectiveness in a context of constant change.

Stages of Applying the Systems Approach in Designing Educational Resources:

1. Defining the design goal: Clearly formulate what educational goals should be achieved with these resources (e.g., training specialists capable of implementing precision farming technologies).

2. Analyzing the current system: Evaluate existing educational resources, identify their strengths and weaknesses, "bottlenecks," and resource deficiencies.

3. Defining resource requirements: Formulate the criteria that new or updated resources must meet (e.g., interactivity, accessibility, relevance, compliance with standards).

4. Designing the resource structure: Develop a model of interaction between different types of resources (material, informational, personnel).

5. Development and implementation: Create or modernize specific educational resources (e.g., develop an online course, purchase new equipment, improve the qualifications of instructors).

6. Monitoring and evaluation: Constantly monitor the functioning of the resources, collect feedback, and analyze their effectiveness and compliance with the set goals.

7. Correction and updating: Make changes to the resource system based on the results of monitoring and evaluation, ensuring its adaptability to new challenges (especially important in crisis situations).

The advantages of the systems approach for agrarian HEIs include. Comprehensiveness: It allows for taking into account all aspects and interconnections between different types of resources, which is critically important for practice-oriented agrarian education (where, for example, effective practical training is impossible without a high-quality laboratory). Optimization: It helps to rationally use existing resources and effectively plan new investments. Adaptability: It promotes the rapid adaptation of educational resources to the changing needs of the AIC and the external environment, including crisis situations (for example, the transition to distance learning required a systematic approach to resources). Forecasting: It allows for predicting potential problems and resource needs, which is important for the long-term planning of the development of agrarian education.

Applying the systems approach to the design of educational resources in agrarian HEIs is the key to creating an effective, adaptive, and innovative educational system capable of training highly qualified specialists for the needs of the modern agro-industrial complex of Ukraine.

After the systems approach, which defines the general structure and interconnections, the competency-based approach becomes key for filling the content of educational resources. It is a paradigm in education that focuses not so much on the amount of knowledge acquired as on the graduate's ability to apply this knowledge, skills, and abilities to successfully solve professional and life tasks in real-world conditions. For agrarian education, which is deeply practice-oriented, the competency-based approach is absolutely indispensable.

Unlike the "knowledge-based" paradigm, which focuses on the transfer of information, the competency-based approach reorients education towards the result—the formation of competencies. A competency is a dynamic combination of knowledge, skills, abilities, ways of thinking, views, values, and other personal qualities that determines a person's ability to successfully engage in professional and/or further educational activities.

How the Competency-Based Approach Shapes the Content of Educational Resources in Agrarian HEIs. Defining key and subject-specific competencies. The first step is to clearly define which key competencies (e.g., critical thinking, communication, lifelong learning ability) and special (subject-specific) competencies (e.g., the ability to diagnose plant diseases, design irrigation systems, operate agricultural machinery) are necessary for a graduate to be successful in the modern AIC. This is done by analyzing higher education standards, professional standards, employer needs, and by cooperating with representatives of agribusiness. Educational resources are then developed or adapted to directly facilitate the formation of these competencies. Designing application-oriented tasks. The focus shifts from memorizing information to solving problems and cases. Educational resources (textbooks, methodological guides, assignments for practical work) contain not only theoretical information but also real-world situations from agricultural production, project assignments, and simulations that require the student to apply knowledge in non-standard conditions. For example, instead of simply describing plant diseases, a resource might contain an interactive case where the student must independently diagnose a disease based on photos/videos, determine the cause, and propose a treatment plan. Emphasis on interactive and practical resources. Laboratory and field equipment are not just tools for demonstration but active resources where students perform practical research, experiments, and analyses (e.g., analysis of soil, water, grain quality, and diagnosis of plant and animal diseases). Production internships and practical training become central, as it is in production that students gain real-world experience applying their knowledge and developing practical competencies. This is not just a visit to a farm but the completion of specific production tasks. Simulators and virtual laboratories are digital resources that allow for the safe and repeated practice of complex professional skills (e.g., operating a combine, diagnosing equipment malfunctions, performing veterinary operations), and they are an integral part of competency formation. Specialized software—resources that include software for managing an agricultural enterprise, GIS systems for field mapping, and programs for modeling agrochemical processes—form digital competencies. Integration of Knowledge from Various Disciplines. Modern agricultural problems are rarely solved within the confines of a single discipline. The competency-based approach encourages the creation of integrated educational resources that combine knowledge from agronomy, engineering, economics, and ecology. For example, a resource for a "smart farm" project would require knowledge of automation, crop production, economics, and management. Competency-Oriented Assessment. Educational resources include assessment criteria that focus on the ability to apply knowledge (e.g., project evaluation, skill demonstration on simulators, case defense), not just on the reproduction of knowledge.

Advantages of the Competency-Based Approach for Agrarian HEI Educational Resources. Relevance to the labor market: Graduates are a better fit for the modern AIC's requirements, as their training is directly aimed at developing sought-after competencies. Practical focus: The content of the resources becomes more practical and applicable, which increases student motivation.

Flexibility and adaptability: Educational resources created on a competency basis are easier to adapt to new technologies and challenges (including crisis situations) because the focus shifts to the ability to solve problems rather than memorizing specific facts.

Improved quality of education: The systematic formation of competencies ensures a higher quality of training for specialists who are capable of working effectively and developing in their professional field. The competency-based approach encourages students to independently seek knowledge and develop self-learning skills for continuous professional growth.

Thus, the competency-based approach is not just a methodological principle but a philosophical basis for forming the entire complex of educational resources of an agrarian HEI. It transforms textbooks, laboratories, field plots, and even the organization of practical training into tools that purposefully work to develop specific, in-demand competencies of future agricultural professionals.

In today's rapidly changing world, especially in crisis situations, traditional approaches to designing educational resources are no longer sufficient. Innovative approaches borrowed from the business and technology sectors, such as design thinking and Agile methodologies, are taking their place. These approaches allow for the creation of educational resources that are not only relevant and effective but also flexible, user-oriented (for both students and instructors), and capable of rapid adaptation.

Design thinking is a human-centered approach to innovative problem-solving that relies on understanding user needs, generating ideas, prototyping, and testing. Its application in education allows for the creation of educational resources that truly meet students' needs and are engaging and effective.

Design Thinking Stages and Their Application in Designing Educational Resources for Agrarian HEIs. Empathize: This involves a deep understanding of the needs, motivations, problems, and challenges of the users (agrarian students, instructors, and future employers in the agro-industrial complex). This stage includes conducting interviews, observing the learning process, and analyzing difficulties. For example, it might reveal that students lack interactive simulators for fieldwork or that instructors need ready-made online case studies from real agricultural enterprises. Define: Based on the data from the empathy stage, you clearly formulate the problem to be solved. For instance, "How can we create accessible and interactive resources for the practical training of agronomists when access to real fields is limited?" or "How can we develop an online course in veterinary medicine that ensures a sufficient level of practical skills?" Ideate: This is a brainstorming phase to generate as many diverse ideas as possible to solve the defined problem without evaluating them. Ideas might include developing a virtual farm, creating a mobile app for diagnosing plant diseases, video courses on operating agricultural machinery, gamified assignments on agribusiness economics, or using augmented reality to study animal anatomy. Prototype: This stage involves quickly creating a rough, low-cost version of a chosen idea that can be tested. This could be a mock-up, a sketch, a simplified digital version, a demo of a virtual combine simulator, a storyboard for a video lesson, or a basic module for an online course. Test: In this final stage, you test the prototype with real users, gather feedback, and identify shortcomings and opportunities for improvement. This includes having students use the prototype and collecting their feedback, asking instructors about the convenience and effectiveness of the resource, and measuring engagement and success metrics. Based on the results, the prototype is improved, and the process can be repeated cyclically.

Advantages of Design Thinking for Agrarian HEIs. Human-centered approach: Educational resources are created with the real needs and capabilities of students and instructors in mind, increasing their motivation and engagement. Innovativeness: It promotes the generation of creative and non-standard solutions for complex educational tasks. Effectiveness: Through continuous testing and iterations, resources become higher quality and more functional. Risk reduction: Prototyping and testing in the early stages allow for the identification of shortcomings before significant investments are made.

Agile methodologies (e.g., Scrum, Kanban) are a set of development principles based on an iterative and incremental approach, flexibility to change, a focus on customer value, and continuous team collaboration. Borrowed from software development, they are perfectly suited for the dynamic creation of educational resources, especially in uncertain conditions (like crisis situations).

Key Principles of Agile and Their Application. Iterative Development (Sprints): Instead of one long development process, the work is broken down into short, time-boxed iterations, or "sprints." Each sprint results in a working, albeit incomplete, product fragment. For example, a team developing an online course might use a sprint to create the first one or two modules with basic materials and tests. The next sprint would add interactive exercises, and the third might integrate a virtual laboratory. This allows for the rapid release of a Minimum Viable Product (MVP)—such as a basic study guide—that is continuously supplemented and improved. Flexibility to Change: Unlike traditional "waterfall" models, Agile welcomes changes to requirements even at late stages of development. If new challenges arise (e.g., a change in agricultural legislation, the emergence of new pests, or a crisis affecting internet access), Agile allows for a quick reorientation of resource development to meet new competency needs or formats. Continuous Collaboration and Communication: The development team (instructors, methodologists, IT specialists, and designers) constantly collaborates with each other and with "clients" (students, employers). Regular "stand-up" meetings to discuss progress and problems, as well as involving students for feedback at every stage, ensure that the resource meets needs and responds quickly to challenges. Focus on User Value: The main priority is to deliver value to the user as quickly and effectively as possible. Educational resources are created with a clear understanding of the problem they solve for the student (e.g., "allows you to practice skill X," "provides access to information Y").

Advantages of Agile Methodologies for Agrarian HEIs. Speed of Development and Implementation: This methodology allows for the rapid creation and provision of necessary resources (e.g., online courses for distance learning). Adaptability to Unforeseen Circumstances: It helps HEIs easily adapt to changing conditions, such as a sudden transition to distance learning or shifts in the needs of the agro-industrial complex due to a crisis. High Quality: Thanks to continuous testing and feedback, the final resources are of higher quality and more functional. Efficient Resource Use: Agile avoids lengthy "on-the-shelf" development by focusing on the functions that provide the most value.

By applying design thinking and Agile methodologies, agrarian HEIs can move beyond simply creating educational materials. They can develop dynamic, flexible, and high-quality educational products that meet the challenges of the modern world and effectively form the necessary competencies for future professionals in the agro-industrial complex.

The development of the agricultural sector today is inextricably linked to innovation and knowledge. In this context, educational resources play a key role in training qualified specialists, implementing the latest technologies, and increasing agricultural productivity. International experience shows a variety of approaches to creating and using such resources, which can be classified into several main areas.

1. Digital Educational Platforms and MOOCs (Massive Open Online Courses)

One of the most notable trends is the development and active use of digital educational platforms. They provide access to a wide range of courses, lectures, webinars, and learning materials, allowing farmers, agronomists, and students to acquire knowledge regardless of their geographical location.

Examples of their use are more than sufficient. First of all, there are Coursera and edX, which offer numerous courses on agronomy, agricultural management, and sustainable farming from leading universities worldwide (e.g., University of California, Davis; University of Illinois). There's also the FAO e-learning Academy. The Food and Agriculture Organization of the UN offers a wide selection of free online courses on various aspects of agriculture, rural development, and food security. Their courses are oriented toward global challenges and local needs. To these, we should add Agri-Plattformen (Germany, Netherlands). National agricultural organizations and educational institutions create their own platforms to disseminate specialized knowledge, often integrating practical case studies and interactive tools.

2. Specialized Portals and Databases

Many countries create national and regional portals that accumulate scientific research, best practices, methodological guidelines, and legal acts in the agricultural sector. These resources are often used for knowledge exchange among scientists, practitioners, and educational institutions.

Examples of these resources include CAB International (CABI). This is an international non-profit organization that provides access to a huge database of scientific literature, manuals, and tools for agriculture and the environment. Another well-known resource is the USDA National Agricultural Library (USA). It is one of the world's largest agricultural libraries, offering access to millions of resources, including digital collections, historical documents, and modern research.

3. Distance Learning Programs and Hybrid Models

Given the specifics of the agricultural sector, where the practical component is important, distance learning programs with elements of offline practical sessions are actively being implemented. This allows for a combination of the flexibility of online education with the necessary practical experience.

Examples of this resource include "Farm Business Management" (USA, Canada). Many universities and colleges offer online programs in farm management that include virtual tours, simulations, and the opportunity for consultations with experts. Agricultural colleges and technical schools can also be included here. They often develop their own distance courses for farmers who want to improve their qualifications without leaving production, with mandatory practical sessions at the educational institution or partner farms.

Video content creation and use is another type of resource. Visualization is a powerful tool for transferring knowledge in the agricultural sector. Video tutorials, demonstrations of new technologies, and interviews with successful farmers and agronomists are becoming increasingly popular educational resources.

Examples include YouTube channels of agricultural universities and research centers. Many institutions actively use YouTube to disseminate information, conduct webinars, and demonstrate practical skills. Specialized video platforms can also be actively used. Some countries develop their own platforms for video content focused on specific agricultural crops or technologies.

Another educational resource is integration with the real needs of agribusiness. The effectiveness of educational resources increases significantly when they are developed in close cooperation with agribusiness and farms. This ensures the relevance of the content and the correspondence of knowledge to the real needs of the labor market.

Examples of such a resource can be "farmer-to-farmer" programs. In some countries (particularly in Northern European countries), successful farmers share their experience and knowledge with less experienced colleagues through special training seminars and consultations. Corporate training programs are also becoming widespread. Large agricultural holdings and companies develop their own educational programs and resources to improve the qualifications of their employees, often in cooperation with universities.

Despite significant achievements, international practices face a number of challenges, such as the digital divide, or insufficient access to the internet and digital devices in rural areas. The quality of content is also a problem, i.e., ensuring the high quality and relevance of educational materials. Another challenge is motivation to learn, or stimulating farmers to constantly update their knowledge. And finally, there is localization, or adapting international experience to local climatic, economic, and social conditions.

However, the prospects for the development of educational resources in the agricultural sector are significant. Further integration of the latest technologies (artificial intelligence, virtual and augmented reality), expansion of international cooperation, and creation of programs adapted to regional needs will make it possible to train highly qualified specialists capable of solving the modern challenges of agriculture.

Ukrainian agrarian higher education institutions (HEIs) play a key role in training personnel for agriculture and developing agricultural science. In the context of dynamic changes in the industry, integration into the global educational space, and the challenges associated with the full-scale invasion, the formation of high-quality and accessible educational resources becomes one of the priority tasks. The experience of Ukrainian agrarian HEIs in this area is multifaceted and constantly evolving, so its main stages can be cited.

I've translated the text about the experience of Ukrainian agrarian higher education institutions.

1. Transition to Digital Educational Resources. A significant number of Ukrainian agrarian HEIs are actively implementing digital technologies in the educational process. This is driven by global trends and the need to ensure educational

continuity during the COVID-19 pandemic and the full-scale invasion. Distance Learning Systems (LMS): The vast majority of agrarian HEIs use platforms like Moodle, Google Classroom, or their own developments to host learning materials, conduct online lectures, seminars, and knowledge assessments. This allows students to access resources at their convenience from anywhere. Electronic Libraries and Repositories: Creating electronic libraries with access to textbooks, study guides, monographs, scientific articles, and periodicals is an integral part of the educational process. Some HEIs are establishing their own institutional repositories to store the research of instructors and students, conference materials, etc. Video Lectures and Webinars: Video lectures are actively recorded, and webinars are held with industry experts. This helps visualize the material and allows for the participation of specialists without requiring their physical presence.

2. Creation of In-House Learning and Methodological Materials. Ukrainian agrarian HEIs traditionally place great importance on developing their own learning and methodological materials that consider the specifics of Ukrainian agricultural production and the achievements of domestic science. Textbooks and Guides: Instructors actively create textbooks and study guides that reflect the current state of agrarian science, advanced technologies, and domestic experience. The number of electronic versions of these publications has been growing recently. Practical and Laboratory Work: Detailed methodological guidelines for conducting laboratory and practical work are being developed, often accompanied by video instructions and virtual simulators where possible. Case Studies and Situational Assignments: To develop analytical and decision-making skills, HEIs are implementing case studies based on real production situations in agribusiness.

3. Cooperation with Agribusiness and International Partners. To ensure the relevance of educational resources and their alignment with labor market needs, agrarian HEIs are actively cooperating with agribusiness representatives and international organizations. Involving Practitioners: Practitioners are involved in developing curricula and giving lectures, which allows for the integration of real-world production experience into the educational process. Joint Projects: Joint research and

educational programs are implemented with agricultural companies, giving students the opportunity to work on real tasks and gain practical skills. International Grants and Programs: Participation in international grant programs (like Erasmus+ and Horizon Europe) promotes the exchange of experience, access to the latest educational methods and resources, and the development of joint courses.

4. Challenges and Directions for Development. Ukrainian agrarian HEIs face a number of challenges in forming educational resources. Material and Technical Base: There is a need to modernize the material and technical base, especially laboratory equipment, to create more interactive and technological educational resources. Instructors' Digital Competence: There is a need for continuous improvement of instructors' digital competence for the effective use and creation of modern digital educational resources. Content Relevance: The rapid pace of development of agrarian technologies requires constant updating of the content of educational programs and resources. Accessibility in Wartime: It's crucial to ensure unimpeded access to educational resources for students who are in different regions of Ukraine and abroad, as well as to protect digital infrastructure.

The prospects for development include. Implementation of Interactive Simulators and Virtual Laboratories: This will allow students to gain practical skills in a safe and controlled environment. Development of MOOCs and Short-Term Online Courses: This is for improving the qualifications of working professionals and popularizing agrarian professions. Use of Artificial Intelligence: This can be used for personalizing education, analyzing educational trajectories, and creating adaptive learning materials. Deepening Cooperation with Business: This involves creating joint research centers and innovation hubs for the rapid transfer of technologies and the formation of in-demand educational resources.

3.2 The Impact of Crisis Situations on the Functioning and Development of Agrarian Heis

Higher education institutions are complex socioeconomic systems that are closely intertwined with their external environment. This interdependence makes them vulnerable to various crises, which can significantly affect all aspects of their activities—from the educational process and scientific research to financial stability and reputation. Understanding the types of crises and their characteristics is key to developing effective anti-crisis management strategies.

Crises that affect the functioning of HEIs can be classified by their nature and source of origin. Economic Crises: These are related to financial instability, a lack of resources, or changes in economic policy that directly impact the HEI. Reduced state funding: A decrease in budget allocations for education leads to a lack of funds for salaries, updating the material and technical base, scientific research, and social programs. Inflation and rising prices: The devaluation of the national currency and an increase in the cost of energy, utilities, equipment, and learning materials raise the HEI's operating costs. Decreased ability of applicants/students to pay: The population's economic difficulties can lead to a decrease in the number of contract-based students, which reduces extra-budgetary income. Labor market crisis: A mismatch between educational programs and the needs of the labor market can lead to a low level of graduate employment, which negatively affects the HEI's reputation and the demand for its specialties. Social Crises: These relate to internal or external social conflicts, changes in the demographic situation, societal values, or problems in relationships with stakeholders. Demographic crisis: A decrease in the number of high school graduates leads to a reduction in the potential pool of applicants, especially in regions with low birth rates or high migration. Internal conflicts: Disputes between the administration and instructors/students (for example, regarding learning conditions, corruption, or rights violations) can lead to strikes, protests, or significant staff turnover. Crisis of trust and reputation: Public scandals, accusations of corruption, plagiarism, low quality of education, or unethical behavior can cause irreparable damage to the HEI's image.

Changes in social priorities: A decrease in the prestige of higher education in general or of specific specialties can affect the HEI's attractiveness. Technological Crises: These crises arise from accidents or breakdowns of technical systems or infrastructure used by the HEI. Accidents in communications: Damage to water supply, heating, or electrical systems disrupts the functioning of academic buildings and dormitories. Failures in information systems: Cyberattacks, hacking, server breakdowns, or data loss can make it impossible to access electronic resources, distance learning systems, or administrative databases. Equipment breakdowns: The failure of critically important laboratory, computer, or specialized educational equipment interrupts the educational and scientific processes. Fires or building destruction: Technological accidents that lead to the partial or complete destruction of the HEI's infrastructure. Natural Crises: This type of crisis is caused by natural disasters or unfavorable natural phenomena. Floods, earthquakes, hurricanes: Natural disasters that can damage buildings and infrastructure and require the interruption of the educational process and the evacuation of students/staff. Epidemics/pandemics: Widespread diseases (such as COVID-19) that require a transition to distance learning, limit access to campus, and affect the physical and psychological health of those involved in the educational process. Long periods of abnormal heat/cold can make staying in classrooms difficult and require a change in work schedules or the temporary suspension of classes. Military Crises: These are exceptionally destructive crises resulting from armed conflicts, hostilities, and occupation. This is the most complex type of crisis Ukraine has faced since 2014, with a dramatic escalation since February 2022. Infrastructure Destruction: Direct damage to academic buildings, dormitories, laboratories, and libraries from shelling, bombings, and other combat actions. Displacement of Staff and Students: Mass migration of the population and the evacuation of HEIs or their branches, leading to a loss of personnel and students. Safety Threats: The need to organize shelters and conduct classes in bomb shelters, posing a risk to the life and health of everyone in the educational process. Economic Losses and Financial Difficulties: Reduced HEI income, loss of assets, funding problems, and the redistribution of budget funds for defense needs. Disruption of the Educational Process: The inability to hold in-person classes, power outages, and internet disruptions, which require a rapid transition to distance learning and the adaptation of educational programs. Psychological Impact: The severe psychological state of instructors and students, including post-traumatic stress disorder, which requires psychological support and an adaptation of teaching methods. Political and Legal Crises. These crises are related to changes in government, legislation, or political conflicts that affect the autonomy and functioning of HEIs. Radical Legislative Changes: New laws that restrict HEI autonomy or change the rules for funding, licensing, or accreditation. Change of Government or Leadership: A shift in political priorities can lead to a review of state policy in education, affecting HEIs. Political Pressure: Attempts at political interference in HEI activities, the appointment of leaders based on political motives, and the limitation of academic freedoms.

Each of these crises has unique sources, dynamics, and consequences. For Ukrainian HEIs, the challenge is that multiple factors often combine, especially during a full-scale war, which acts as a catalyst and compounding factor for all other types of crises. Effective crisis management requires continuous monitoring of the external environment, developing preventive measures, planning for emergencies, and having the ability to quickly adapt and resume functioning.

Crisis situations, regardless of their nature—economic, social, technological, natural, or military—have a deep and multifaceted impact on the functioning of HEIs. This impact is specific because it affects not only the material and technical base or finances but also the core aspects of an HEI's mission: the educational process, scientific activity, social role, and, of course, management effectiveness.

The educational process is at the heart of an HEI's activities, and it's often the first thing to suffer during a crisis. Let's break down the impact of each type of crisis on the educational process.

1. Disruption and Changes to Learning Formats Crises can force a sudden shift in how education is delivered. Natural and technological disasters can lead to temporary closures, evacuations, and damage to classrooms and laboratories, making in-person classes impossible. Epidemics and pandemics demand an immediate transition to distance learning, requiring rapid adaptation from instructors and students

and access to technology and resources. Military actions are the most destructive factor. In a war (as is happening in Ukraine), the educational process can be completely interrupted, HEIs may be destroyed, and students and instructors may be forced to relocate. Even when distance learning is maintained, air raid sirens, power outages, internet disruptions, and psychological stress make learning significantly more difficult.

2. Decrease in the Quality and Effectiveness of Learning. The quality of education can be negatively affected by several factors during a crisis. Lack of resources: Economic crises often lead to reduced funding, affecting the purchase of new equipment, the updating of library collections, and access to modern digital resources. This limits the ability to effectively train specialists. The psychological state of participants: The stress, anxiety, and uncertainty associated with a crisis (especially war) reduce the concentration of students and instructors and affect their motivation and ability to learn new material. Limitation of practical training: Crises, especially technological and military ones, can make it impossible to conduct laboratory work, field practices, and internships, which are critically important for many specialties, particularly in agriculture.

3. Changes in Educational Content. Crises directly influence the content of educational programs and how they are delivered. Program adaptation: In a crisis, HEIs may be forced to quickly adapt their curricula to account for new realities (for example, by including modules on crisis management, cybersecurity, and pre-medical aid during wartime). Focus on resilience: There is a growing need to develop students' skills in resilience, adaptability, critical thinking, and problem-solving in difficult conditions.

Crisis situations require HEI administration to make quick, flexible, and strategically sound decisions, which significantly changes traditional management approaches.

4. Financial Instability. Financial instability can be a major challenge. Budget constraints: Economic crises lead to the need for strict austerity measures, budget reviews, cost optimization, and the search for alternative funding sources (grants,

international aid, and private revenue). Risk management: There is a need to develop financial "safety nets" and diversify sources of income to ensure sustainability.

5. Human Resources Challenges. Crises can cause significant staffing issues within an HEI. Staff Turnover: During economic or military crises, HEIs may lose qualified instructors and administrative staff due to migration, mobilization, or the search for better employment opportunities. Retraining and Professional Development: There is a pressing need for instructors to quickly learn how to use new technologies for distance learning and to develop skills in providing psychological support to students. Mobilization: In wartime, a portion of the male faculty and student body may be mobilized into the armed forces, creating a significant staffing shortage.

6. Infrastructure and Logistics Problems. A crisis directly impacts the physical and technical operations of an HEI. Ensuring Safety: During military crises, this means creating and equipping shelters, developing evacuation plans, and ensuring security measures on campus. Restoration and Modernization: After destruction, enormous costs are required to restore buildings, repair damaged infrastructure, and purchase new equipment. Ensuring Uninterrupted Operation: It is essential to solve problems with electricity, communications, and heating, especially during attacks on the energy infrastructure.

7. Changes in Management Culture. Crises demand a new, more adaptive approach to management. Increased Flexibility and Adaptability: HEI leadership must react quickly to changes, make decisions in uncertain conditions, and constantly adapt their strategies. Decentralization of Decisions: Delegating authority and responsibility to lower levels of management can speed up the response to local problems. Communication and Transparency: Effective and open communication with all stakeholders (students, instructors, parents, the Ministry, and partners) is critically important to maintain trust and minimize panic. Psychological Support for Staff: HEI management must provide psychological support for their employees who are under chronic stress.

8. Reputational Risks. Ultimately, poor crisis management can lead to the loss of an HEI's reputation, a decrease in the number of applicants, and a decline in trust from partners.

The impact of crises on HEIs is all-encompassing, transforming both the educational process and management mechanisms. In such dynamic and often unpredictable circumstances, as those experienced by Ukraine, an HEI's effectiveness depends on its ability to demonstrate resilience, adaptability, an innovative approach, and proactive anti-crisis management. This requires not only quick tactical decisions but also strategic planning aimed at increasing internal flexibility and strengthening partnerships to ensure the continuity and quality of education in any circumstances.

Agrarian education in Ukraine, as in many other countries, has its own unique specifics that determine how crisis situations affect it. Unlike, for example, IT education, which focuses on digital technologies and remote work, the agricultural sector is deeply integrated into the natural environment, depends on seasonality, has a significant material and technical base, and is closely linked to real production. This makes agrarian higher education institutions (HEIs) vulnerable to crises that may have a different character compared to general education.

Agrarian education trains specialists for a sector that directly depends on natural conditions. This creates unique challenges. Impact on Practical Training: Droughts, floods, frosts, or other abnormal weather events can destroy crops on educational and research fields, making it impossible to conduct field practices and internships. This is critical for students in agronomic, veterinary, and engineering-technical specialties, where direct contact with production is fundamental. Scientific Research: Natural disasters can nullify years-long experiments and research projects conducted at the HEI's research stations. Changes in Curricula: Climate change requires constant adaptation of educational programs to include new disciplines on adapting agriculture to climate change, sustainable land use, and water resource management.

Agrarian HEIs have large laboratory complexes, educational farms, and machine and tractor fleets that require significant investment for maintenance and updating. This leads to certain problems. High Maintenance Costs: Economic crises or reduced

funding have a particularly painful impact on agrarian HEIs, as maintaining laboratories, machinery, and livestock complexes is very expensive. Risks of Destruction: Technological accidents or military actions (as is happening in Ukraine) can cause irreparable damage to unique and expensive equipment, agricultural machinery, greenhouses, and livestock farms, which are the basis for the practical training of specialists. Restoring such infrastructure requires colossal funds and time.
Equipment Obsolescence: The rapid development of agricultural technologies (precision farming, drones, sensors) requires constant updating of machinery and laboratory equipment, which is difficult to ensure during a crisis.

Agrarian education must be as closely aligned as possible with the needs of production. Crises also affect this connection, causing. Changes in the Labor Market: Economic crises or war can lead to changes in the structure of agribusiness (the disappearance of some enterprises, re-profiling, relocation), which requires the rapid adaptation of educational programs and specialties. Employment Problems: Crises can reduce the demand for specialists and complicate internships and graduate employment. Problems in Cooperation with Business: Companies in the agricultural sector may reduce investments in partnership programs with HEIs, scientific research, or sponsorship, which limits opportunities for development. Loss of Access to Enterprises: In conditions of military action or occupation, HEIs may lose access to partner farms and enterprises for practical training, which is critical for hands-on experience.

Many students at agrarian higher education institutions (HEIs) come from rural areas or regions where agriculture is the main activity. This leads to common challenges like. The digital divide: In rural areas, access to high-speed internet and modern digital devices can be limited, which complicates the transition to distance learning during a crisis. Migration processes: War or economic problems can cause mass migration from rural areas, leading to a decrease in the number of applicants and students in agrarian specialties. Regional specificity: Each agrarian HEI often has its own regional specialization (e.g., animal husbandry, crop production, viticulture). A crisis that affects a specific industry can have a devastating impact on that HEI.

For Ukraine, the military crisis is the most dominant and destructive factor, exacerbating all other issues and causing. Physical destruction: Agrarian HEIs, like other infrastructure, can be destroyed as a result of hostilities. An example is the destruction of academic buildings or educational and research farms. Loss of territories: The occupation of territories leads to the loss of control over HEI branches and educational and research farms, as well as the loss of access to major agro-industrial regions that were a base for practical training. Security risks: The constant threat of missile attacks, drones, and shelling requires organizing classes in bomb shelters, which is psychologically difficult and not conducive to a quality educational process. Mobilization of students and instructors (especially male) creates a significant personnel shortage and disrupts the continuity of the educational process.

The specific challenges of crisis situations in the context of agrarian education are due to its close connection with nature, production, a significant material and technical base, and regional specificity. The successful functioning of agrarian HEIs during crises requires developing flexible strategies, investing in digitalization and practical training, strengthening cooperation with agribusiness and international partners, and creating a systemic support for recovery and development in the face of long-term challenges, particularly war.

The agro-industrial complex (AIC) of Ukraine, like the global agricultural sector, is undergoing a period of rapid transformation driven by technological progress, global challenges (climate change, food security), and the unique circumstances caused by the full-scale invasion. These changes directly impact the needs of the labor market, requiring new competencies and flexibility from AIC specialists.

The Dominant Role of Technology and Digitalization (AgriTech). Perhaps the most significant change is that modern agriculture is no longer just a sector based on physical labor; it is becoming a high-tech field. Therefore, the most in-demand agricultural professions are now. Precision farming specialists: There is a growing demand for agronomists who know how to work with GPS navigation, drones, sensors, crop and soil monitoring systems, and data analysis software. This requires knowledge of Geographic Information Systems (GIS), Remote Sensing (RS), and analytics.

Cybernetics and Robotics Engineers: There is a need for specialists who can maintain, program, and develop autonomous agricultural machinery, as well as robotic systems for harvesting, animal feeding, and monitoring livestock health. Big Data and Artificial Intelligence (AI) Specialists: The agro-industrial complex generates vast amounts of data (on yields, weather, soil, and prices). Analysts are needed who can interpret this data to optimize production, forecast markets, and manage risks. Internet of Things (IoT) Specialists in the AIC: The development of "smart farms," where every element (from soil moisture sensors to livestock ventilation systems) is connected to a network, requires engineers and technicians capable of installing, configuring, and maintaining these systems.

The increasing attention to environmental problems and the sustainable use of resources is also changing the requirements for specialists. The most common professions now are. Agro-ecologists: There's a growing demand for specialists who understand organic farming, resource-saving technologies, biological plant protection, and minimizing environmental impact. Water Resource Management Specialists: In the context of climate change and more frequent droughts, there is a growing need for specialists in the efficient use and conservation of water resources and irrigation systems. Certification and Standardization: Knowledge of international product quality and safety standards (GlobalGAP, organic certification) is becoming mandatory for many positions.

Modern agribusiness requires not only technical skills but also strong management and economic competencies. The demand for management specialists is increasing. Agri-managers: There is a need for specialists who can effectively manage large agricultural holdings, optimize business processes, and handle financial planning, marketing, and logistics. Risk Management Specialists: In conditions of instability (weather, prices, geopolitics), there is a growing demand for specialists who can forecast risks and develop strategies to minimize them. AIC Economic Analysts: These professionals must be able to conduct in-depth economic analysis, create business plans, and evaluate the effectiveness of investments. Agrarian Law Specialists: Given changes in land legislation and international trade, there is a growing need for legal experts who specialize in agrarian law.

The boundaries between specialties are blurring, and a modern AIC specialist must be versatile and possess. Communication Skills: The ability to effectively interact with various stakeholders (partners, investors, workers). Critical Thinking and Problem-Solving: The ability to analyze complex situations and find creative solutions in uncertain conditions. Adaptability and Flexibility: The readiness to learn quickly and retrain in response to changes in technology and the market. Leadership and Teamwork: The ability to organize and motivate teams and work effectively in multidisciplinary groups. Foreign Languages: Knowledge of English is becoming almost mandatory for accessing international information, technologies, and collaboration.

The full-scale invasion has significantly changed labor market needs, adding new dimensions such as. Safety Aspects: A need for specialists who can work in conditions of mine danger and ensure the safety of equipment and personnel. Reconstruction and Recovery: There is a growing demand for engineers, builders, and agronomists capable of restoring destroyed infrastructure, demining land, and implementing technologies to quickly restart production. Logistics and Export: Changes in logistics routes and challenges in exporting agricultural products increase the need for specialists in international logistics, customs clearance, and international law. Psychological Resilience: For work during the war and post-war recovery, psychological resilience and the ability to work under stress are critically important. Increased Demand for Skilled Labor: Due to mobilization and migration, there is a shortage of skilled workers (tractor drivers, combine operators, machine operators), which requires rapid training programs.

The labor market of the agro-industrial complex is evolving from traditional agricultural skills to integrated competencies that combine agricultural knowledge with high technology, analytical abilities, environmental awareness, and management skills. Ukrainian agrarian HEIs must actively adapt their educational programs, implement dual education, and strengthen cooperation with business to produce specialists who meet these new, dynamic requirements. The success of the Ukrainian AIC in the post-war period will largely depend on the education system's ability to respond quickly and effectively to these changes.

Adapting educational programs is one of the most important tasks for higher education institutions (HEIs) in today's rapidly changing world. This is especially relevant for Ukraine, which is influenced by global technological trends and is experiencing unique challenges related to the full-scale war. Effective adaptation of educational programs allows HEIs to remain relevant, train competitive specialists, and contribute to the country's recovery and development.

Why is adaptation critically important? First of all, it impacts. Relevance to the Labor Market: New technologies, economic changes, and social transformations constantly change the requirements for professional competencies. Programs must prepare graduates for the real needs of employers. Graduate competitiveness: Only relevant knowledge and skills allow graduates to be in demand in both the domestic and international labor markets. Ensuring the quality of education: Adapted programs reflect the modern state of science and practice, which increases the quality of learning. HEI sustainability: HEIs that adapt quickly are better able to survive crises and remain attractive to applicants. National reconstruction: In the context of Ukraine's post-war reconstruction, educational programs must meet the country's strategic needs for restoring and developing key sectors. Main Directions for Adapting Educational Programs.

1. Integrating the Latest Technologies and Digitalization. Implementing AgriTech: For agrarian education, this means including modules on precision farming, the use of drones, GIS technologies, sensors, Big Data, and artificial intelligence in agronomy, veterinary medicine, and engineering. Digital Literacy: Developing digital competencies in students across all specialties. This includes working with cloud services, online collaboration tools, and the basics of cybersecurity. Virtual and Augmented Reality (VR/AR): Developing simulators and virtual laboratories for practical training, especially where access to real equipment is limited or dangerous (e.g., in a combat zone).

2. Strengthening the Practical Component and Dual Education. Cooperation with Business: Close interaction with leading companies in the industry to jointly develop programs, conduct guest lectures, and organize internships and practical training. Dual Education: Expanding programs where theoretical training at the HEI is combined with practical work at enterprises. This allows students to gain relevant skills and adapt to the realities of production while still studying. Case Studies and Project-Based Learning: Actively using real business cases and involving students in working on specific projects for enterprises.

3. Developing Soft Skills and Universal Competencies. Critical Thinking and Problem-Solving: Teaching how to analyze complex situations, formulate hypotheses, and find effective solutions. Communication and Teamwork: Developing skills for effective interaction, presentation, and working in multidisciplinary teams. Adaptability and Flexibility: Preparing for continuous learning and retraining throughout life and the ability to adapt quickly to change. Emotional Intelligence and Stress Resistance: These skills are especially important during crises, as they allow for effective functioning under pressure and overcoming difficulties.

4. Focusing on Sustainable Development and Environmental Awareness. Green Competencies: Including the principles of sustainable development, the circular economy, ecological farming, and energy efficiency in programs. Responsible Consumption and Production: Fostering an understanding of the impact of professional activities on the environment and the social sphere.

5. Adaptation to Wartime and Post-War Reconstruction. Security Aspects: Inclusion of modules on first aid, civil defense, and mine safety. Reconstruction and Recovery: Development of specialized modules or programs on infrastructure reconstruction, demining, psychological rehabilitation, and managing recovery projects. Format Flexibility: Ensuring the possibility of learning in various formats (in-person, distance, hybrid), the option to transfer credits from other HEIs (national and international), and the adaptation of class schedules. Psychological Support: Integration of psychological support elements for students and instructors into the educational process.

Mechanisms and Challenges of Adaptation. Labor Market Monitoring: Constant analysis of employer needs, cooperation with employment centers and HR agencies. International Experience: Studying and implementing the best global practices in educational program development. Instructor Professional Development: Systematic training of educators in new technologies, methods, and content. Regulatory Flexibility: The ability of regulatory bodies (the Ministry of Education and Science) to quickly adapt educational standards to new realities. Funding: The need for significant investment in modernizing the material and technical base and developing innovative educational resources.

The adaptation of educational programs is a continuous process that requires constant interaction between HEIs and all stakeholders: students, employers, government bodies, and international partners. This is the only way Ukrainian education can effectively respond to modern challenges and prepare a new generation of specialists for the country's successful future.

Traditional educational resources and infrastructure are the fundamental elements of the educational process. They include physical buildings (classrooms, laboratories, libraries, dormitories), printed learning materials (textbooks, manuals), and equipment (specialized devices, machinery). Access to these resources is critically important for quality education, but in the face of modern challenges, especially in Ukraine, it is encountering a number of serious problems.

1. Physical Inaccessibility and Infrastructure Destruction.

This is one of the most acute problems, particularly in wartime Ukraine. It includes: Direct Destruction: Military actions lead to the complete or partial destruction of academic buildings, laboratories, libraries, and dormitories. This makes it impossible to hold in-person classes and use specialized equipment. The destroyed infrastructure requires immense funds and time to restore. Occupation of Territories: The occupation of territories leads to the loss of control over HEIs and their material base. Some equipment may be removed or damaged.

2. Obsolete and Worn-Out Material and Technical Base.

Even undamaged infrastructure is often in a poor state of repair. Physical Deterioration: Many buildings, furniture, and educational tools are physically and technologically outdated. A significant portion of library collections may also be outdated. Technological Mismatch: This is especially critical in agrarian education, where the rapid development of AgriTech requires constant modernization of machinery, tractor fleets, and laboratory equipment (e.g., for precision farming and biotechnology). Outdated equipment prevents students from learning with modern tools. Lack of Investment: Years of limited funding for education have compounded these issues and left HEIs without the funds for systematic modernization.

3. Economic Limitations and Lack of Funding.

Economic crises and the war create significant obstacles for maintaining and developing traditional resources. Insufficient State Funding: Budgetary constraints prevent HEIs from properly maintaining existing infrastructure, let alone updating it. During the war, the prioritization of military spending further exacerbates this problem. High Operating Costs: Maintaining large campuses, labs, and dormitories requires significant funds for utilities, repairs, and equipment maintenance, which is a burden for HEIs, especially with reduced revenue. Logistical and Supply Problems: War makes it difficult or impossible to supply new equipment, reagents, and spare parts, making it hard or impossible to repair existing equipment.

4. Limited Access to Printed Resources.

Despite the growth of digital libraries, printed materials remain a vital component of education. However, students don't always have access to them due to a number of problems. Physical Accessibility: Library collections may be destroyed or damaged, and students may be unable to physically visit libraries due to security threats or displacement. Outdated Materials: The high cost of publishing new textbooks and manuals that reflect the latest scientific advances and legal changes leads to the use of outdated publications. Insufficient Copies: There's a shortage of textbooks and manuals for all students, especially for specialized subjects.

5. Social and Demographic Challenges.

The war has caused significant social and demographic shifts that impact access to traditional educational resources. Internally Displaced Persons (IDPs): Students and instructors who are IDPs often lose access to their usual resources and must adapt to new environments that may not provide full access to the necessary infrastructure. Decreased Enrollment: Demographic problems and migration have reduced the number of students, which can lead to the suboptimal use of existing but underutilized infrastructure.

The problems of access to traditional educational resources and infrastructure in Ukraine are multifaceted and require complex solutions. These include not only financial investment for restoration and modernization but also the development of new models for using available infrastructure, strengthening international cooperation to receive aid, and integrating traditional resources with modern digital technologies. Ensuring the physical safety and functionality of the learning environment is a basic condition for the restoration and development of quality Ukrainian education.

Digitalization and distance learning have become not just an alternative to traditional education but an integral part of it, especially in the context of global challenges like the COVID-19 pandemic and the full-scale war in Ukraine. Their potential for ensuring the continuity, accessibility, and modernization of the educational process is enormous and continues to unfold. The advantages of these learning methods are as follows:

1. Accessibility and Inclusivity. Geographic Independence: Digital technologies break down geographical barriers, allowing students to get an education from leading HEIs and instructors from anywhere in the world with internet access. This is especially relevant for Ukraine, where a significant portion of the population has been forced to relocate within the country or abroad. Distance learning allows them to continue their education while far from their hometown. Flexible Schedules: Students can learn at their own pace, choosing a convenient time to study materials, watch lectures, and complete assignments. This makes it possible to combine studies with work, family responsibilities, or other activities, significantly expanding the circle of potential students (e.g., for working professionals or people with disabilities). Inclusivity:

Distance learning opens up wider opportunities for people with special educational needs or physical limitations who may have difficulty attending traditional classrooms.

2. Personalization and Adaptability of Learning. Adaptive Learning Paths: Thanks to data analysis (Big Data) and the use of artificial intelligence (AI), digital platforms can offer individual learning paths, adapting content, task difficulty, and learning pace to the needs and knowledge level of each student. Instant Feedback: Automated testing systems and interactive assignments allow students to receive immediate feedback, which promotes better material retention and timely knowledge correction. Content Selection: Students have access to a wide range of educational resources (video lectures, interactive simulations, electronic textbooks, online libraries), allowing them to choose the most effective learning formats for themselves.

3. Enrichment of Educational Content and Interactivity:

Digital resources offer a richer, more engaging learning experience than traditional methods. Multimedia: Digital tools integrate videos, audio, animations, interactive graphics, and 3D models, making learning material more visual, interesting, and easier to understand. Virtual Laboratories and Simulators: These are especially valuable for agrarian education, where direct access to real equipment may be limited. Virtual labs allow students to conduct experiments, simulate working with complex machinery, and practice hands-on skills in a safe and controlled environment. Gamification: Integrating game elements can increase student engagement and motivation to learn. International Collaboration: Online platforms facilitate joint projects, webinars, and lectures with international experts, broadening the horizons of students and instructors.

4. Efficiency in Management and Administration

Digitalization streamlines administrative and managerial tasks, making them more efficient. Process Automation: Digital platforms automate routine administrative processes such as registration, scheduling, academic record keeping, and issuing certificates. Centralized Data Storage: All learning materials, assignments, grades, and student data are stored in a single system, simplifying access and management. Learning Analytics: Distance learning systems collect a large amount of data on student progress, activity, and problem areas. This allows instructors and administrators to analyze the effectiveness of programs and make timely adjustments.

5. Sustainability and Continuity of Education in Crisis Conditions:

Digitalization provides a robust solution for maintaining education during crises. Emergency Response: As shown by the pandemic and the war in Ukraine, digitalization and distance learning allow for rapid adaptation to changing circumstances, ensuring the continuity of the educational process even when physical attendance at an HEI is impossible. Support for Displaced Persons: For internally displaced persons and refugees, online education is the only way to continue their studies or gain new professional competencies.

Despite their significant potential, fully realizing the benefits of digitalization and distance learning requires addressing several challenges. Digital Divide: Access to the internet and equipment is insufficient in some regions and for certain population groups. Quality and Relevance of Content: There is a constant need to create high-quality, up-to-date, and interactive digital content. Instructor Qualifications: Instructors need continuous training to improve their digital competence and learn new methods of online teaching. Cybersecurity: Protecting data and systems from cyberattacks is crucial to maintaining a secure learning environment. Psychological Aspect: Providing psychological support for students and instructors and preventing "burnout" from excessive online interaction are critical for well-being. Balancing Online and Offline: Finding the optimal balance between distance and in-person learning is essential, especially for practical-oriented specialties like those in agriculture.

The potential of digitalization and distance learning for Ukrainian education is enormous. They are not just tools for survival in a crisis but a strategic direction for modernization, increasing competitiveness, and ensuring quality and accessible education for future generations.

In a world characterized by rapid change and unpredictable crises, the flexibility and adaptability of educational resources are not just desirable qualities but essential conditions for the effective functioning of higher education institutions (HEIs) and the provision of quality education. This is especially relevant for Ukraine, where the ongoing war requires an immediate response to constantly changing circumstances. Here's why flexibility and adaptability are critically important?

1. Responding to Crises and Emergencies. Continuity of Learning: The ability to quickly switch between different learning formats (in-person, distance, hybrid) in response to security threats (air raids, shelling), power outages, or infrastructure destruction is vital. Flexible resources allow the educational process to continue, minimizing losses. Support for Displaced Persons: The ability to adapt educational materials and access for students and instructors forced to change their place of residence or who are abroad is a key benefit.

2. Meeting the Demands of a Dynamic Labor Market. Rapid Content Updates: Technology and labor market requirements are changing so fast that educational programs and resources must be continuously updated. Flexibility allows for quick changes to curricula, adding new modules and courses to reflect the latest trends. Developing In-Demand Competencies: Educational resources must be adaptable to develop not only hard skills (professional knowledge) but also soft skills (critical thinking, adaptability, communication), which are key to success in any field.

3. Personalization and Inclusivity of Learning. Individualized Learning Paths: Flexible resources allow students to choose individual learning paths, adapting the pace, format, and content to their needs, prior knowledge, and goals. Diverse Learning Styles: The availability of various resource formats (video, interactive simulations, text, audio) meets the needs of students with different information absorption styles. Inclusive Design: Adaptive resources can be designed to accommodate the needs of students with special educational needs (for example, with the ability to change fonts, add voiceovers, or provide subtitles).

4. Effective Use of Resources and Cost Optimization. Modularity: Creating educational resources as independent modules that can be easily combined, rearranged, and integrated into different courses or programs allows for a more rational use of content that has already been created. Open Educational Resources (OER): Using and creating open resources that can be freely distributed, modified, and adapted reduces the cost of developing and accessing materials.

Where Do You See Evidence of Flexibility and Adaptability? Multiformat Content: The availability of materials in different formats (text, video, podcasts, interactive simulations, 3D models) allows students to choose the most convenient way to absorb information. Modularity and Microlearning: Breaking down large courses into small, self-contained modules that can be studied separately or combined into other educational programs. This also includes the development of short-term courses and micro-qualifications. Distance and Hybrid Models: The ability to easily switch between in-person, distance, and hybrid learning formats ensures access to resources regardless of physical location. Technological Neutrality: Resources are designed to be used on different devices (computers, tablets, smartphones) and operating systems. Rapid Updates: Built-in mechanisms for quickly updating content, making changes, corrections, and additions in response to new scientific discoveries, legislative changes, or technologies. Collaboration and Co-creation: Involving instructors, students, experts, and business representatives in the joint development and updating of educational resources.

Flexibility and adaptability of educational resources are not just a response to crisis challenges but a strategic path for the development of Ukrainian education. Implementing these principles will allow HEIs to function more effectively in conditions of uncertainty, prepare specialists with relevant knowledge and soft skills, and contribute to Ukraine's integration into the global educational space. This requires investment in digital infrastructure, professional development for educators, and changes in management culture, but these efforts are the key to the stability and successful future of Ukrainian education.

In the modern educational landscape, which is rapidly transforming under the influence of technological progress and global challenges, the role of digital and interactive educational resources is growing dramatically. Education is moving from passive consumption of information to active interaction, personalization, and engagement, which has become possible due to the development of information and communication technologies. This is especially noticeable in Ukraine, where the events of recent years have accelerated the digital transformation of education.

The role of digital and interactive educational resources is growing due to several key factors that have radically changed the landscape of modern education.

These factors include. Technological Progress: The widespread availability of high-speed internet, powerful computers, smartphones, and tablets, along with the development of AI and VR/AR, has made digital resources both accessible and highly functional. Generational Change: Modern students (Generation Z and Alpha) are "digital natives" who have grown up with technology. They expect the educational process to be dynamic, interactive, and aligned with their style of information perception. Global Challenges and Crises: The COVID-19 pandemic demonstrated the critical importance of digital resources for ensuring learning continuity. The war in Ukraine has cemented distance learning as a necessary part of education, and digital resources have become the only way millions of students can access knowledge. Economic Feasibility: In the long term, creating and distributing digital resources can be more cost-effective than constantly re-printing physical materials or maintaining large physical libraries. Accessibility and Inclusivity: Digital resources remove geographical barriers and create learning opportunities for people with disabilities, residents of remote areas, and those who cannot physically attend an HEI.

The growing role of digital and interactive resources is an irreversible process. They offer unprecedented opportunities to improve the accessibility, quality, personalization, and effectiveness of learning. For Ukrainian education, which aims for recovery and integration into the global educational space, the active development and use of such resources are key strategic priorities. This will allow for the training of a new generation of specialists capable of operating in a constantly changing environment and using technology for innovative development.

In a rapidly changing world, especially during unprecedented challenges like the full-scale war in Ukraine, it is no longer enough for university graduates to possess only professional knowledge and skills ("hard skills"). New competencies, known as "soft skills" or "transversal competencies," are becoming increasingly important. These skills allow individuals to function effectively under conditions of uncertainty, pressure, and transformation. Among them, resilience, stress resistance, and adaptability are particularly prominent. Let's characterize each of these competencies.

1. Resilience

Resilience is a person's ability to successfully overcome challenges, recover from setbacks, maintain functionality, and develop under stress, threats, or traumatic events. It's not just about enduring but also about becoming stronger after trials.

Why Resilience is Important for Graduates. Labor market uncertainty: Graduates face shifting professional requirements, frequent technological changes, and economic crises. Resilience allows them to not give up after initial setbacks in their job search or career growth but to seek new opportunities. Adapting to change: The modern world requires constant learning and retraining. Resilience helps graduates accept the need for these changes and actively adapt to them. Military realities: For Ukrainian graduates, resilience is a vital skill. It is the ability to continue learning or working under constant threats, losses, destruction, and psychological pressure.

How to Develop Resilience in HEIs. Project-based learning: Involve students in projects that require solving complex, unpredictable tasks where failures are possible and alternative solutions must be found. Decision-making under uncertainty: Model situations where students have to make decisions with limited information or under pressure. Self-regulation development: Offer training on managing emotions, setting goals, planning, and self-control. Psychological support: Provide access to psychologists and hold seminars on mental health and stress management techniques.

2. Stress Tolerance

Stress tolerance is the ability of a person's body and mind to function effectively under stress without allowing it to have a destructive impact on their activity and health. It enables them to maintain calmness, concentration, and productivity under pressure.

Why Stress Tolerance is Important for Graduates. Work intensity: Modern professions often involve multitasking, tight deadlines, and a high level of responsibility. Conflict situations: The ability to remain professional and effective in conflict-ridden or uncomfortable situations. Wartime context: For Ukrainians, stress tolerance has become a fundamental skill. It is the ability to function during air raids, power outages, news of shelling, and the loss of loved ones.

How to Develop Stress Tolerance in HEIs. Workshops and simulation games: Create controlled situations that mimic stressful working environments. Time and workload management: Teach effective time and resource planning to prevent burnout. Relaxation and self-regulation techniques: Include elements of psychological relief, breathing techniques, and meditation or mindfulness practices in the educational process. Healthy routines: Promote a healthy lifestyle, physical activity, and sufficient sleep as a foundation for stress tolerance.

3. Adaptability

Adaptability is the ability to quickly and effectively adjust to new conditions and change one's behavior, approaches, and strategies according to the environment's demands. It is a proactive response to change.

Why Adaptability is Important for Graduates. Speed of technological change: New tools, programs, and methods are constantly appearing. Adaptability allows graduates to quickly master them and integrate them into their work. Changing professions: Some professions are disappearing, others are transforming, and new ones are emerging. Adaptability helps prepare graduates for retraining and a change in career path. International environment: Working in multicultural teams and interacting with people from different cultures requires adapting to new norms and values. Reconstruction of Ukraine: The future reconstruction will require specialists to quickly adapt to new projects, conditions, and technologies and to cooperate with international partners.

How to Develop Adaptability in HEIs. Cross-disciplinary learning: Integrate interdisciplinary courses and projects that require knowledge from various fields. Problem-based learning: Teach through solving real-world problems that have no single correct solution and require flexible thinking. Foreign language study: This broadens horizons and prepares graduates for interaction in a global environment. Critical thinking development: The ability to analyze information, question established approaches, and seek innovative solutions. Blended and distance learning: These formats already force students and instructors to demonstrate adaptability to new learning conditions.

To effectively develop resilience, stress tolerance, and adaptability, HEIs must. Shift focus: Move from purely academic knowledge to the comprehensive development of a student's personality. Integrate into curricula: Include these competencies as learning goals in the descriptions of educational programs and individual disciplines. Teaching methods: Actively use interactive methods such as case studies, role-playing, debates, projects, and simulations. Instructor example: Educators who themselves demonstrate these qualities are the best example for students. Create a supportive environment: Foster a campus atmosphere of trust and mutual assistance, where students are not afraid to make mistakes and learn from them.

Developing these "flexible" competencies is key to the success of Ukrainian graduates in the post-war world. It will allow them not only to survive but also to actively participate in the recovery and development of the country, using their knowledge and ability to overcome any obstacles.

3.3 A Methodology for Designing Adaptive Educational Resources for Agrarian HEIs in Crisis Situations

Designing educational resources during a crisis requires a specific approach that accounts for unique challenges and limitations. When traditional learning formats are unavailable or unsafe, as is the case in Ukraine, educational resources must be not just informative but also highly effective, sustainable, and secure. This requires adhering to several key principles.

1. Systemic Approach

Educational resources shouldn't exist in isolation. They must form a cohesive, interconnected system that covers all components of the educational process—from learning materials to assessment—and supports various forms of learning.

Importance in a Crisis. Continuity: A systemic approach ensures a logical and sequential transition between topics and modules, even if learning is interrupted or changes format. Comprehensiveness: Students receive a complete set of knowledge and skills rather than fragmented information, which is critical for preparing for professional work in uncertain conditions. Management: This approach simplifies administration and progress monitoring in a distance-learning environment.

Implementation: Use unified distance learning platforms (LMS, such as Moodle), integrate different resource types (videos, texts, tests, simulations) within a single course, and ensure a clear curriculum structure.

2. Interactivity

Educational resources should stimulate active engagement with the material, not just serve as a passive source of information. This fosters deeper learning, critical thinking, and practical skills.

Importance in a Crisis. Engagement: In distance learning or stressful conditions, interactivity helps maintain student attention, increase motivation, and reduce feelings of isolation. Risk-free practice: Virtual laboratories and simulators allow students to practice complex skills (e.g., operating machinery, diagnostics) in a safe environment. This is invaluable when access to real-world objects is limited or dangerous. Instant feedback: Allows students to immediately see and correct their mistakes, which accelerates learning.

Implementation: Embed tests and quizzes, use interactive exercises, virtual simulations, and incorporate opportunities for online discussions, collaborative projects, and gamification elements.

3. Multimedia

Using various types of media (text, images, audio, video, animation) to present information.

Importance in a Crisis. Clarity: Visualizing complex concepts and processes makes the material easier to understand and remember, especially for visual learners. Accessibility under various conditions: If watching a video isn't possible (due to slow internet or power outages), a student can listen to audio or read the text. This provides flexibility in content consumption. Emotional engagement: Quality multimedia content can make learning more interesting and emotionally resonant, which is important during stressful times.

Implementation: Use video lectures, podcasts, animated diagrams, 3D models, photo galleries, and interactive presentations.

4. Accessibility

Educational resources must be accessible to all students, regardless of their physical condition, technical capabilities, location, or financial situation.

Importance in a Crisis. Inclusivity: Ensures access for students with special educational needs (e.g., subtitles for people with hearing impairments, text-to-speech for people with visual impairments). Technical Accessibility: Optimizes resources for low-speed internet, allows for offline downloading, and ensures compatibility with various devices (smartphones, tablets). Geographical Accessibility: Provides the ability to access materials from anywhere in the world. Free or reduced-cost access: In crisis conditions, it's crucial to ensure free or highly affordable access to key resources.

Implementation: Design resources with accessibility standards in mind (WCAG), optimize file sizes, use platforms that support offline mode, and create open educational resources (OER).

5. Security

This involves ensuring data protection, information confidentiality, and the physical safety of educational process participants while resources are being used.

Importance in a Crisis. Cybersecurity: Protecting platforms and data from hacking, information leaks, and DDoS attacks is especially important in the context of cyber warfare. Personal data protection: Adhering to GDPR standards and other regulations regarding the confidentiality of student and instructor information. Physical safety: In wartime, this means educational resources (e.g., apps or instructions) may contain recommendations on what to do during alarms, where to find shelters, and mine safety rules for those in risk areas. Platform Reliability: Choosing stable and secure educational platforms that can handle heavy loads and ensure uninterrupted access.

Implementation: Use secure protocols (HTTPS), two-factor authentication, regular software updates, data backups, and user training on cybersecurity best practices.

6. Relevance

The content of educational resources must be up-to-date with the latest scientific achievements, technological developments, and labor market demands.

Importance in a Crisis. Labor Market Relevance: Rapid changes in the economy and society require quick program adaptation so that graduates get the knowledge employers truly need. Information Reliability: In an information war and with the spread of fake news, educational resources must be a source of verified, scientifically-based information. Response to New Challenges: For example, in agrarian education, this involves including materials on agricultural recovery after demining, new logistics chains, and the use of drones in wartime and their potential in peacetime.

Implementation: Constantly monitor scientific publications and industry trends, collaborate closely with employers and leading experts, regularly update content, and use a modular principle that allows for easy addition or replacement of individual information blocks.

Designing educational resources in crisis situations is a complex but extremely important process that requires a systemic, interactive, multimedia, accessible, safe, and relevant approach. Adhering to these principles not only ensures the continuity and quality of education during trials but also creates a foundation for the sustainable development of HEIs and the training of highly qualified specialists capable of overcoming future challenges. For Ukraine, this is a key element of the reconstruction and development strategy.

Designing educational resources in a crisis is an iterative process that demands flexibility, speed, and constant adaptation. Unlike normal conditions where the stages can be more linear, in a crisis (especially during a war), each step may require immediate adjustments. However, following the key stages ensures a systemic and effective approach.

1. Needs Analysis

This is the initial and critically important stage that determines exactly what needs to be created and for whom. In a crisis, it must be fast and accurate.

What we analyze. Target Audience: Who will use the resources? (students, instructors, schoolchildren, adults, IDPs). What are their technical capabilities (access to the internet, devices), psychological state, and prior experience? Current Challenges: What specific aspects of the educational process are disrupted by the crisis? (e.g., inability to hold in-person classes, lack of access to laboratories, psychological pressure). Educational Gaps: What knowledge and skills need to be urgently developed (e.g., safety, first aid, cyber hygiene, adaptation to new working conditions)? Available Resources: What materials, equipment, and specialists are already available and can be used or adapted.

Special considerations in a crisis: There is a need for rapid information gathering (online surveys, focus groups, analysis of the current situation in different regions). Needs can change very quickly.

2. Design

At this stage, the concept of the educational resource, its structure, and functionality are developed, taking into account the identified needs and principles (systemic approach, interactivity, multimedia, accessibility, security, relevance).

What we design. Learning Goals: What should users achieve after interacting with the resource? Content: What material will be included, and how will it be structured (modules, topics)? Formats: What multimedia elements will be used (video, animation, text, simulations)? Learning Methods: How will the material be presented (lectures, case studies, practical assignments, tests)?

Platform: What platform will host the resource (LMS, website, mobile app)? Navigation and Interface: How the user will interact with the resource to make it intuitive. Security Requirements: Cybersecurity and data protection measures.

Special considerations in a crisis: Flexibility in design—the plan can be changed at any moment. The priority is simplicity, functionality, and ease of use, not excessive complexity.

3. Development

This is the stage of directly creating the educational resources according to the developed design.

What we do. Content Creation: Writing texts, recording video lectures, developing animations, simulators, and tests. Technical Implementation: Programming interactive elements, uploading materials to the platform, and setting up access. Testing: Checking functionality, correct display on various devices, and the absence of errors.

Special considerations in a crisis. Speed: The need for rapid development, often using a minimally sufficient set of functions. Using ready-made tools: Priority is given to ready-made platforms and services that do not require complex development from scratch. Distributed team: The ability for developers to work from different locations.

4. Implementation

At this stage, the educational resources become available to the target audience, and their use begins.

What we do. Deployment: Placing resources on the platform and configuring access for users. Communication: Informing the target audience about the availability of the resources and providing instructions for their use. Support: Providing technical and methodological support for users.

Special considerations in a crisis. Phased implementation: Launching resources in parts to provide access to critical information as quickly as possible. Active communication: Constant contact with users, taking into account their needs and access problems. Prioritizing access: Ensuring priority access for the most vulnerable groups.

5. Evaluation.

The stage of evaluating the effectiveness of educational resources, their compliance with the set goals, and user needs.

What we evaluate. User satisfaction: How satisfied students and instructors are with the resources (surveys, feedback). Achievement of educational goals: Whether students are achieving the desired learning outcomes (analysis of performance, completion of tasks). Technical functionality: Stability of operation, absence of failures, and download speed. Accessibility: Whether the resource is truly accessible to all categories of users. Relevance: Whether the content corresponds to modern realities.

Special considerations in a crisis: Fast feedback—the evaluation must be operational to quickly identify problems. Using platform analytics tools to collect data.

6. Correction/Refinement

Based on the evaluation results, changes and improvements are made to the educational resources.

What we correct. Content: Updating data and adding new information. Functionality: Fixing errors, improving the interface, and adding new features. Formats: Changing the ways the material is presented if they were found to be ineffective. Implementation strategy: Adapting methods for distributing resources.

Special considerations in a crisis: It is an iterative process—correction happens continuously; it is not a one-time stage but a cyclical process that allows resources to evolve along with the changing crisis situation and needs.

The stages of designing educational resources in crisis situations are interconnected and cyclical. They require developers and managers to have a high degree of adaptability, the ability to respond quickly, and continuous analysis. Adhering to these stages, even in a simplified form, makes it possible to create effective, relevant, and sustainable educational resources, which is key to ensuring the continuity and quality of education in the face of unpredictable challenges.

A Learning Management System (LMS) is a software platform that provides a comprehensive set of tools for creating, hosting, organizing, managing, and delivering electronic learning courses, as well as for administering the educational process. Most Popular LMS in Ukraine and the World. Moodle: The most common in Ukrainian HEIs due to its open-source nature, flexibility, and extensive functionality.Google Classroom: Simple to use and integrated with other Google services, making it convenient for basic needs. Zoom, Microsoft Teams, Cisco Webex: While not full-fledged LMS platforms, they are widely used for conducting synchronous online classes (video conferences) as a supplement to main platforms. Coursera for Campus, edX for Business: Commercial platforms offering access to courses from leading global universities, adapted for corporate and institutional learning. Key LMS Features. Content Management: Uploading and organizing learning materials (texts, presentations, videos, audio). Course Management: Creating, editing, and archiving courses, as well as assigning instructors and students. Communication Tools: Forums, chats, private messages, announcements, and the ability to hold webinars and video conferences. Assessment Tools: Tests, assignments, essays, gradebooks, and the ability to provide feedback. Monitoring and Analytics: Tracking student progress, activity, and statistics on visits and task completion. User Management: Registration, authorization, and role management (administrator, instructor, student). Integration: The ability to integrate with other HEI systems (student databases, library systems). Stages of Developing and Implementing Innovative Resources (with a focus on Electronic Courses and LMS):

1. Strategic Planning and Needs Analysis. Defining the goal of implementation (e.g., transitioning to distance learning, improving quality, expanding access). Analyzing the needs of the target audience and the technical capabilities of the HEI and students. Selecting an LMS that meets the needs and budget.
2. Course Design and Development. Designing the course structure, learning goals, and assessment methods. Creating multimedia content (recording videos, developing interactive elements). Adapting existing materials for the online format. Special consideration in a crisis: Prioritize speed, functionality, and a minimally sufficient set of materials to ensure continuity.
3. LMS Implementation and Support. Installing and configuring the chosen LMS (for open-source solutions) or connecting to a cloud service. Training instructors and students on how to use the platform and its tools. This is a critically important stage that requires constant methodological support. Providing technical support for users. Special consideration in a crisis: Rapid deployment, informational work, and providing access to platform tutorials.
4. Monitoring, Evaluation, and Correction. Collecting feedback from students and instructors. Analyzing data on course and platform usage. Assessing the

achievement of educational goals. Regularly updating content and LMS functionality in accordance with identified needs and changes in the external environment. Special consideration in a crisis: Constant monitoring of the situation, quick response to failures, and adaptation to new security challenges (lack of electricity/internet).

Challenges in Implementation in Ukraine. Material and Technical Base: Insufficient level of modern computers and high-speed internet access for both HEIs and students. Digital Competence: The need for further professional development for instructors in the area of online course development and teaching. Energy Security: Power and internet outages due to Russian attacks are a major obstacle to distance learning, requiring alternative solutions (downloading materials, synchronous and asynchronous modes). Cybersecurity: Ensuring the protection of data and platforms from cyberattacks.

Despite the challenges, electronic courses and LMS are key tools for modernizing Ukrainian education, ensuring its stability in wartime, and integrating it into the global educational space. Their potential for providing quality, accessible, and flexible education is limitless.

The development of technologies, especially in conditions of limited access to real equipment and production facilities (as is often the case during crises or due to the high cost of modern agricultural equipment), brings virtual laboratories and simulators to the forefront of the agrarian education system. These innovative educational resources allow students to gain practical experience, practice skills, and study complex processes in a safe, controlled, and accessible digital environment. Virtual Laboratories: Software complexes that imitate real laboratory research and experiments, allowing students to perform practical work, manipulate virtual equipment, collect data, and analyze results. Simulators: Programs that reproduce the behavior of a real system or process, giving the user the ability to interact with it and observe the consequences of their actions (e.g., controlling machinery, imitating biological processes). Key Benefits for Agrarian Specialties

Virtual laboratories and simulators offer significant advantages for agricultural education, particularly in a crisis. Accessibility and Scalability: They provide 24/7 access, overcoming geographical barriers for students who are remote or abroad. They also allow HEIs to train students on expensive, modern equipment—like high-precision tractors and combines—that they couldn't otherwise afford. Safety and Control: Students can practice dangerous operations (e.g., using pesticides) without risk to their health or equipment. The simulations offer a controlled environment where experiments can be repeated under perfect conditions. This also allows for detailed data analysis of a student's actions, helping instructors identify common mistakes and provide targeted feedback. Learning Efficiency and Personalization: These tools make complex processes visible, such as nutrient movement in plants or microorganism development. Their interactivity and unlimited repeatability improve student engagement and mastery of the material. Adaptive simulators can also personalize the learning experience by offering tasks of varying difficulty based on the student's skill level.

Agronomy: Students can use simulators to practice crop cultivation, analyze soil composition in virtual labs, model the effects of plant diseases and pests, and learn precision farming techniques using GPS navigation and drones. Animal Science and Veterinary Medicine: Simulators can teach animal care procedures, while virtual anatomy tables allow students to study animal anatomy in 3D and perform virtual dissections. Agricultural Engineering: Simulators can be used for operating agricultural machinery, modeling irrigation systems, and designing and testing new farm equipment in a virtual environment.

Challenges of Implementation

While the benefits are great, there are challenges to consider. High Development Cost: Creating high-quality virtual labs and simulators is a resource-intensive process that requires significant financial and personnel investment. Realism and Authenticity: To be effective, the models must be highly realistic and scientifically accurate. Technical Requirements: Some simulations require powerful hardware and a stable internet connection. Integration: HEIs must adapt their curricula and train instructors to effectively use these tools. Lack of Tactile Feedback: Simulators cannot fully replace the physical experience of working with real equipment, which is essential for developing "muscle memory" and fine motor skills.

Despite these challenges, virtual laboratories and simulators have huge potential to modernize agrarian education. They allow HEIs to provide high-quality practical training, increase accessibility, reduce risks and costs, and adapt the educational process to the rapidly changing needs of the agro-industrial complex. Their implementation is a strategic priority for Ukrainian education, which aims to train competitive specialists for the country's recovery and development.

Online Resources for Self-Directed Learning

In a modern world where knowledge becomes obsolete at a rapid pace and the labor market is constantly changing, self-directed learning and continuous development are not just desirable but necessary for a successful career and personal growth. Online resources play a key role in this, providing unprecedented opportunities to access information, acquire new skills, and improve qualifications. For Ukrainian students and specialists, especially in a state of war, these resources are a vital tool for support and development. Reasons for the Growing Popularity of Online Resources for Self-Directed Learning. Accessibility: Most resources are available from anywhere with internet access, often for free or at a moderate cost. Flexibility: The ability to learn at one's own pace, choosing a convenient time and place, allows for combining learning with work, personal life, or volunteer activities. Relevance: Leading online platforms regularly update their content, reflecting the latest trends in science, technology, and business. Wide Selection: They cover virtually all fields of knowledge, from the humanities to high-tech and agriculture. Personalization: Many platforms offer personalized recommendations and adaptive learning paths.

Main Types of Online Resources and Their Characteristics:

1. Massive Open Online Courses (MOOCs): Courses developed by leading universities and companies worldwide, available to a large number of students. They usually have structured material, video lectures, assignments, and discussion forums. Platforms: Coursera, edX, FutureLearn, and the Ukrainian platform Prometheus, which

offers courses in partnership with leading Ukrainian HEIs. Advantages: High-quality content, the possibility of obtaining a certificate (often for an extra fee), and access to knowledge from global experts.

2. Specialized Online Platforms for Skills Development: Focused on specific fields or practical skills training. Platforms: Udemy, Skillshare, and LinkedIn Learning, which offer a wide selection of practical courses, including IT skills for the agricultural sector, marketing, and management. Khan Academy for basic disciplines and Duolingo for learning foreign languages.

3. Video Hosting and Educational Channels: YouTube is a huge source of educational content. Many universities, research institutes, and experts create channels with lectures and demonstrations. In the agricultural field, this includes channels from research institutions, agricultural machinery companies, and farmer-bloggers. Advantages: Free access, visualization of complex processes, and the ability to see the practical application of knowledge.

4. Electronic Libraries and Repositories: Provide access to scientific articles, books, dissertations, and methodological materials in a digital format. Examples include Google Scholar, ResearchGate, and the electronic libraries of Ukrainian HEIs. Advantages: Access to academic and research works, which are the basis for in-depth study and scientific activity.

5. Professional Communities and Forums: Platforms for sharing experiences, discussing problems, and finding solutions. Examples include specialized groups on Facebook, LinkedIn, and professional forums for agronomists, veterinarians, and engineers. Advantages: The ability to get advice from practitioners, find partners, and stay current with the latest industry trends. Importance for Ukraine in a Crisis. Learning Continuity: Even with limited access to traditional HEIs, online resources allow for continuous education. Knowledge Relevance: Quick access to up-to-date information and technologies necessary for the country's recovery and development, especially the agricultural sector. Mental Health Support: The ability to continue learning can be a source of stability during difficult times. Access to International

Experience: Ukrainian specialists can study advanced global practices, which is critical for European integration and competitiveness.

Online resources for self-directed learning are a powerful tool that democratizes education, making it accessible, flexible, and relevant. They allow everyone to become the architect of their own educational path, constantly updating knowledge and skills, which is the key to success in a dynamic world. For Ukraine, the active use and development of such resources are a key element of the reconstruction strategy and the formation of a competitive human capital.

In modern education, especially during times of constant change and crisis, traditional teaching methods based primarily on knowledge transfer are no longer sufficient. Interactive approaches that develop critical thinking, problem-solving skills, teamwork, and adaptability are coming to the forefront. Case-based learning and project-based learning are among the most effective tools for achieving these goals. Their application, considering the experience of the crisis, allows for training specialists who can act effectively in complex and unpredictable conditions.

Case-based learning is a teaching method where students analyze and solve specific situations (cases) that reflect real or hypothetical problems in a certain field. Students, working in groups or individually, analyze the situation, identify problems, propose solutions, and justify their choices. Key Features with Crisis Experience in Mind. Use of Real Crisis Cases: Analyzing cases related to the functioning of agricultural enterprises during wartime, such as transporting crops through blocked ports, restoring production in liberated territories, and operating in conditions of fuel or electricity shortages. Developing Critical Thinking and Decision-Making under Uncertainty: Crisis-based cases rarely have a single "right" solution. This encourages students to analyze deeply, evaluate risks, and find non-standard approaches. Building Stress Resistance and Adaptability: Discussing complex situations helps students mentally prepare for future challenges and develop the ability to stay calm and make rational decisions under pressure. Teamwork and Communication: Solving crisis cases often requires an interdisciplinary approach and effective teamwork, including exchanging ideas and defending one's position.

Project-based learning is a method where students work on a real or simulated project over a period of time, solving a specific problem or creating a product. It's an active, practice-oriented approach that develops a wide range of skills. Key Features with Crisis Experience in Mind. Projects Focused on Solving Current Problems: Developing projects for the restoration of agricultural lands after demining, rebuilding farms, or optimizing logistics for agricultural exports. Interdisciplinarity: Crisis situations often require integrated solutions that go beyond a single specialty. Project-based learning can bring together students from different fields (agronomists, engineers, economists) to work together on a complex project. Developing Self-Organization and Responsibility: Students manage their projects independently, plan work, and assign tasks, which fosters autonomy and accountability. Close Collaboration with Business and Stakeholders: Involving real agricultural businesses, local authorities, and non-governmental organizations in project-based learning allows students to work on real-world problems and gain practical communication experience. Building Resilience and Adaptability: Working on projects with limitations (time, financial, security) teaches students to find solutions in difficult situations, adapt their plans, and seek out unconventional solutions. Challenges and Prospects of Application. Access to Current Data: Getting access to real data for cases and projects can be difficult during wartime. Instructor Training: Educators need to be facilitators and mentors, not just sources of knowledge. Resources: Some projects may require specialized software, equipment, or consultants. Security: The security situation must be considered when implementing on-site projects.

Implementing case-based and project-based learning that accounts for crisis experience is a powerful tool for modernizing agricultural education in Ukraine. It will help train not just specialists, but leaders of change who can not only adapt to challenges but also actively participate in the reconstruction and development of the country's agricultural sector.

In the modern agricultural sector, which is rapidly developing under the influence of technological innovations and global challenges, access to up-to-date, verified information and best practices is critically important. The creation of databases of advanced agricultural experience is a strategic tool that allows for the accumulation, systematization, and dissemination of knowledge to optimize production processes, increase efficiency, and promote the sustainable development of the industry. For Ukraine, which is undergoing a period of reconstruction and modernization of the agricultural sector, this task is particularly relevant. Why are databases of advanced agricultural experience important?

Creating databases of advanced agricultural experience is a strategic tool that allows for the accumulation, systematization, and dissemination of knowledge to optimize production processes, increase efficiency, and promote the sustainable development of the industry. For Ukraine, this task is particularly relevant. Key Benefits

1. Accelerating Innovation: Provides farmers, agronomists, scientists, and students with quick access to information on new technologies, plant varieties, animal breeds, and cultivation and management methods.
2. Increasing Productivity and Efficiency: Allows users to study successful case studies, avoid common mistakes, and implement proven solutions to optimize production.
3. Adapting to Change: Access to adapted solutions is vital in the face of climate change, new pests, diseases, or shifting market conditions.
4. Supporting Decision-Making: Provides data to justify management decisions at various levels, from individual farms to regional and national strategies.
5. Education and Development: Serves as a valuable educational resource for higher education institutions, students, and professionals in need of continuous learning.
6. Reducing Losses: The experience of successfully overcoming crises or applying certain technologies helps minimize losses of resources, time, and crops.

These databases can vary in scope, subject matter, and level of detail, but they should include the following types of information. Agrotechnology and Innovation Data. Precision agriculture: Data from field monitoring (satellite images, drone data), yield maps, soil maps, and protocols for differentiated application of fertilizers and plant protection products. Biotechnology: Information on new plant varieties, hybrids, breeding methods, bio-fertilizers, and bio-pesticides. Robotics and Automation: Data on the effectiveness of using autonomous machinery, robotic systems, and IoT sensors. Energy Efficiency: Examples of implementing alternative energy sources (solar panels, biogas plants) and their economic feasibility. Management and Business Data: Business plans and financial models: Examples of successful business models in various agricultural sectors. Marketing strategies: Experience entering new markets, promoting products, and branding. Risk management: Case studies on overcoming economic, climatic, and logistical risks. Natural and Climatic Data. Weather data: Historical and forecast weather data that impacts agricultural planning. Soil data: Soil maps, their composition, and recommendations for cultivation. Agro-landscape planning: Examples of effective land use and biodiversity preservation. Experience in Overcoming Crisis Situations (especially for Ukraine). Production recovery: Case studies on successfully restarting agricultural enterprises in de-occupied territories, demining land, and restoring infrastructure. Wartime logistics: Information on alternative export/import routes and experience with "grain corridors." Ensuring security: Examples of adapting agricultural production to combat conditions (protecting machinery, workers, and crops). Social projects: Experience supporting farmers and communities affected by the war. Veterinary Medicine and Animal Science. Data on new methods for diagnosing and treating animal diseases. Information on effective feeding and housing systems, and animal genetics. Stages of Database Creation and Challenges

The process of creating these databases involves several key stages.

1. Defining the Goal and Target Audience: Clearly understand who the database is for and what tasks it needs to solve.

2. Information Collection and Systematization: Systematically gather data from various sources: scientific research, agricultural enterprise reports, farmer experience, international publications, and monitoring data.

3. Validation and Verification: Check the accuracy and relevance of the information and involve experts to evaluate the best practices.

4. Technical Implementation: Select a platform (specialized databases, cloud solutions, web portals) and develop a user-friendly interface.

5. Content Population and Constant Updates: Regularly add new data and update existing information.

6. Promotion and Training: Inform potential users about the database's existence and conduct training sessions on how to use it.

There are also significant challenges. Data Reliability: Ensuring verified information and avoiding fake or outdated data. Confidentiality: Protecting commercial and personal information. Funding: Creating and maintaining databases requires significant investment. Integration: The ability to combine data from various sources. Motivation for Knowledge Sharing: Incentivizing agricultural professionals to share their successes and failures.

The creation of databases of advanced agricultural experience is a strategic step for the development of the Ukrainian agricultural sector. It is a powerful tool for rapid adaptation to change, implementing innovations, and increasing competitiveness. The active participation of HEIs, research institutions, agricultural enterprises, and the government in this process will allow for the creation of a unique knowledge ecosystem that will become the driving force for the recovery and sustainable development of Ukraine's agricultural sector.

The effectiveness of educational resources is not just about their existence but their ability to ensure quality learning and achieve set educational goals. In a crisis, when traditional approaches can be disrupted, evaluating resource effectiveness becomes especially important. This helps HEIs quickly adapt and optimize the learning process using key criteria for a comprehensive assessment.

Accessibility is the ability of an educational resource to be reachable and usable by all students, regardless of their physical abilities, technical equipment, location, or other circumstances. If a resource is not accessible, it cannot be effective, as no one will be able to use it. During a crisis—with power outages, limited internet, and displaced persons—accessibility is critical.

Evaluation Metrics. Technical accessibility: Compatibility with various devices (PCs, laptops, tablets, smartphones), operating systems, and browsers. Optimization for low internet speeds and the ability to download materials for offline viewing. Physical accessibility: Usability for people with special educational needs (subtitles for videos, text-to-speech, the ability to change font size and contrast). Geographical accessibility: No restrictions based on the user's location. Financial accessibility: Free access or a moderate cost. Ease of access: A minimum number of steps to register and start using the resource.

The quality of an educational resource includes its pedagogical value, scientific validity, methodological soundness, and technical execution. High-quality resources contribute to deep and lasting knowledge acquisition, the formation of correct skills, and a positive attitude toward learning.

Evaluation Metrics. Scientific validity: The content's relevance and accuracy based on current scientific research and data. Methodological soundness: Clear learning objectives, a logical structure, a variety of information delivery methods, and appropriateness for age and psychological characteristics. Clarity and visualization: The quality of images, videos, and animations that help users better understand the material. Completeness and sufficiency: Whether the resource contains all the necessary information to achieve its stated goals. Technical quality: The absence of errors (typos, logical, software), clear audio and video, and the stable operation of all elements.

Relevance means that the content and functionality of an educational resource align with the needs of students, the demands of the labor market, and the strategic development goals of the industry or country. Relevant resources train specialists who are in demand, can solve real-world problems, and contribute to development. During a crisis, relevance also includes how well the materials address security and social challenges.

Evaluation Metrics. Labor market alignment: Does the resource develop the skills and knowledge that employers need today and will need tomorrow? (e.g., for agriculture: precision farming, digitalization, restoration). Information timeliness:

How quickly is the information updated to reflect the latest technologies and changes? Practical value: Can the knowledge and skills gained be applied in practice? Alignment with crisis challenges: Does the resource contain information or methods that help users adapt to war conditions, reconstruction, etc.? Learning objectives: Does the resource align with the stated goals of the educational program?

Usability is the degree to which a user can easily and effectively interact with an educational resource to achieve their learning goals without unnecessary effort. Even the highest-quality and most accessible resource will be ineffective if it is difficult to use. Usability reduces frustration and increases motivation to learn.

Evaluation Metrics. Intuitive interface: Simple navigation, logical layout of elements, and clear instructions. Efficiency: Fast page loading speeds and quick response times for interactive elements. Attractive design: Aesthetic appearance, a pleasant color scheme, and readable fonts. System feedback: Clear error messages and action confirmations. Learning support: The presence of help materials, FAQs, and the ability to ask for assistance.

Evaluating educational resources based on these criteria—accessibility, quality, relevance, and usability—allows HEIs to measure the success of their initiatives and continuously improve the learning process. In a crisis, regular and comprehensive evaluation using these criteria is the foundation for making informed decisions about developing, implementing, and correcting educational resources, ensuring their maximum benefit for students and society.

In a crisis, particularly during wartime, collecting quick and accurate data on the effectiveness of educational resources is crucial. This allows for a rapid response to challenges, adapting teaching materials and methods, and ensuring the continuity of the educational process. However, traditional data collection methods can be difficult, requiring a flexible approach and the use of accessible tools. Here are the key methods for collecting data on educational resources during a crisis.

A survey is a way to collect information from a large number of respondents using standardized questions. Surveys can be anonymous, which encourages more candid responses.

Features and Advantages in a Crisis. Mass reach: You can reach a large number of students, instructors, administrators, and parents. Flexible formats: Online surveys (Google Forms, SurveyMonkey, Miro, Mentimeter) allow you to quickly create and distribute a questionnaire, as well as automatically collect and analyze data. If needed, you can use phone surveys or simplified paper forms if online access is limited. Needs assessment: They quickly gather information about technical capabilities (internet access, devices), access problems, and preferences for content and format. Satisfaction evaluation: They help assess overall attitudes toward resources, usability, and quality.

Challenges. Digital divide: Not everyone has stable internet access to complete online surveys. Low motivation: In stressful conditions, respondents may be less motivated to complete long surveys. Superficial answers: Closed-ended questions may not provide a deep understanding of the problem.

A focus group is a qualitative research method that involves a group discussion on a specific topic (usually 6-10 participants) led by a moderator.

Features and Advantages in a Crisis. In-depth understanding: Allows for detailed answers and a deeper understanding of the reasons behind problems, as well as the identification of hidden needs and emotions that surveys can't capture. Interaction: Discussion among participants can stimulate new ideas and highlight different viewpoints. Flexibility: Can be conducted online (via Zoom, Google Meet) or offline (if possible and safe). Especially useful for: Understanding the psychological impact of a crisis on the perception of educational resources and identifying issues with interactivity or motivation.

Challenges. Difficulty of organization: Requires an experienced moderator, and it's harder to gather a group due to displacement and restrictions. Small data volume: The data is not statistically significant for the entire audience but provides a qualitative understanding. Moderator influence: The moderator can unconsciously influence participants' answers.

Usage statistics analysis is the collection and analysis of quantitative data on user interaction with educational resources and platforms. This data is automatically collected by learning management systems (LMS) and web analytics tools.

Features and Advantages in a Crisis. Objectivity: The data reflects users' actual behavior, not their subjective opinions. Speed: Data collection is automatic and in real time, allowing for the quick identification of trends. Identification of "bottlenecks": You can track which resources are least popular, at which stages students drop out, and which tasks cause the most difficulty. Accessibility evaluation: Analyzing the geography of logins, device types, and access times helps assess the actual accessibility of resources.

Metrics Analyzed. Number of unique users and visits: How many people and how often they access the resource. Time spent on the resource: How long users interact with the materials. Course/module completion rate: How many students successfully complete a course. Test and assignment results: Performance and common errors. Activity in forums/chats: The level of interaction and communication. Device and browser types: Information for resource optimization. User geographic data: To understand where students are located (useful for identifying IDPs).

Challenges. Data interpretation: Statistics show the "what," but not always the "why." Other methods are needed to understand the reasons. Platform technical capabilities: Not all platforms provide deep enough analytics. Confidentiality: The need to comply with personal data protection rules when collecting and using statistics. Interviews: In-depth conversations with key stakeholders (e.g., individual students, innovative instructors, administrators) to get very detailed information. Journals/Reflective Reports: Asking students to keep a diary of their impressions and problems while learning. Observation: Monitoring student behavior during online classes (with their consent).

Each of these methods has its advantages and disadvantages, especially in a crisis. The most effective approach is a combination of methods (data triangulation). For example, start with a broad online survey to identify general trends, then conduct focus groups to get an in-depth understanding of the problems found, and simultaneously analyze usage statistics for objective confirmation of hypotheses. This allows HEIs to quickly and accurately adapt their educational resources, ensuring maximum learning effectiveness even in the most difficult conditions.

In a modern world of rapid change, especially during prolonged crises like the war in Ukraine, a higher education institution's (HEI) ability to quickly correct and update educational resources is not just desirable—it's critical. This allows them to maintain the relevance of learning content, respond to new challenges, and ensure the continuity and quality of the educational process.

To effectively and quickly update resources, well-established mechanisms are essential.

The foundation of rapid correction is the constant collection and analysis of information on resource usage. Learning Management Systems (LMS): Use the built-in analytics tools of your LMS (Moodle, Coursera for Campus, Google Classroom) to track student activity, such as page views, time spent on a page, test results, and comments. This helps identify "bottlenecks," confusing sections, or outdated information. Surveys and Focus Groups: Conduct regular, short surveys with students and instructors (via Google Forms, SurveyMonkey) and hold focus groups to gather qualitative feedback on usability, content quality, and relevance. Direct Feedback: Encourage students and instructors to directly report errors, inaccuracies, or suggestions for improvement through special forms on platforms or via email. Monitoring the Labor Market and Industry Changes: Continuously analyze the current requirements for specialists from employers and track new technologies and research in the agricultural sector. This can be done through professional associations, conferences, and collaboration with businesses. Monitoring the Security Situation: For Ukraine, this includes tracking changes on the front lines, the risks of shelling, and power supply issues, which directly impact the format and content of resources.

The structure of educational resources should be designed to allow for easy changes. Modular Principle: Break down educational courses into small, self-contained modules or topics. This lets you update or replace individual modules without having to rework the entire course. Use of Templates: Develop standardized templates for creating learning materials. This speeds up development and updates while ensuring a consistent style and quality. Cloud Technologies: Host resources in cloud storage and on platforms that allow for remote updates and access from anywhere. Open Formats:

Use open file formats that are easy to edit and convert, as well as Open Educational Resources (OER) that can be freely adapted.

Use technological solutions to speed up and simplify the process of making changes. Version Control Systems: Use systems like Git to track changes in code or content. This makes it easy to revert to previous versions, allows a team to work on a single resource, and records all changes. Automated Content Creation Tools: Use specialized software that simplifies the creation and editing of multimedia materials and interactive elements. Data Integration: Connect the LMS with databases of up-to-date information (e.g., weather data for agricultural simulators, yield data) to automatically update certain elements.

Effective updating is impossible without a coordinated team and relevant competencies. Responsible Individuals: Appoint individuals responsible for the relevance and updating of specific sections or courses. Content Development Teams: Form multidisciplinary teams that include subject matter experts, methodologists, multimedia specialists, designers, and IT specialists. Systematic Professional Development: Train instructors and staff to use the tools for creating and updating digital resources, as well as methods for rapid adaptation of learning material. Involvement of Practical Experts: Maintain constant cooperation with business representatives and practicing scientists to get the most current information and experience. Flexible HEI Policy: Develop internal regulations that allow for quick changes to educational programs and course descriptions. Funding: Allocate a budget for the continuous updating of software, purchasing tools, and paying specialists for resource development and support. State Support: Adapt higher education standards to rapid changes, simplifying licensing and accreditation procedures for innovative programs.

Mechanisms for rapid correction and updating of educational resources are an integral part of a modern education system. For Ukraine, which is striving for reconstruction and European integration, their effective implementation is key to training highly qualified specialists who can quickly adapt to any challenges and contribute to the country's innovative development. This allows Ukraine to not just react to crises, but to emerge from them stronger, with a more flexible and relevant education system.

Conclusions

The prospects for developing the educational resource design system for Ukrainian agrarian higher education institutions (HEIs) are incredibly broad and ambitious. Integrating artificial intelligence, virtual reality, and blockchain, along with developing micro-credentials, strengthening cooperation, and deeply adapting to crisis experiences, will allow these HEIs to become leaders in training the specialists of the future. This will not only ensure high-quality education but also contribute significantly to the reconstruction, innovative development, and food security of Ukraine.

This study delves deeply into the issues and outlines key approaches to the theory and methodology of designing educational resources for agrarian HEIs in crisis situations. It underscores the urgent need to adapt the educational process to extreme challenges and defines pathways for its sustainable development and innovative growth. Crisis situations, particularly the experience of full-scale war, demand a fundamental rethinking of educational content. Educational resources must not just reflect but also integrate this experience, offering students case studies and project-based learning that model real-world challenges for the agricultural sector. This includes skills in restoring destroyed production facilities, optimizing logistics under restrictions, working in demined areas, and ensuring food security. This approach builds not only professional but also vital life skills like resilience, adaptability, and quick decision-making.

Effective educational resource design in a crisis is only possible with a systemic approach. The developed model outlines a cyclical process that includes needs analysis, design, development, implementation, evaluation, and rapid correction. This approach ensures resources are accessible, high-quality, relevant, and user-friendly, which is critical for ensuring continuous learning and training qualified personnel. The success of designing and developing educational resources depends directly on effective data collection methods. Combining surveys, focus groups, and usage statistics analysis provides both quantitative effectiveness indicators and deep qualitative insights. This allows for an objective analysis of the pilot results and the identification of the model's strengths and areas for improvement, considering the specific operational conditions of HEIs in various crisis situations. In conditions of constant change and uncertainty, mechanisms for the rapid correction and updating of educational resources play a crucial role. A flexible modular structure, the use of modern technologies, a clear distribution of responsibilities, and well-established procedures for a quick response allow for the swift adaptation of educational content to new challenges, current technologies, and changing needs. For the educational resource design system to function and develop fully in a crisis, it is critically important to improve the regulatory framework. This involves legally defining the status of digital educational resources, allowing for flexible learning formats, creating funding mechanisms for digitalization, incentivizing instructors, and regulating the use of best-practice databases. The future of the educational resource design system for agrarian HEIs is tied to the integration of new technologies like artificial intelligence, virtual and augmented reality, and the Internet of Things. This opens up new opportunities for personalized learning, immersive simulations, developing micro-credentials, and creating a holistic learning ecosystem. Strengthening cooperation with agribusiness and international partners, along with developing open educational resources, will be catalysts for innovation and sustainable development.

Ultimately, the developed theory and methodology for designing educational resources are a viable and adaptive response to modern challenges. Their implementation and continuous improvement, with appropriate support at all levels, will allow Ukraine's agrarian HEIs to not only effectively train highly qualified specialists for the country's reconstruction but also to take leading positions in the global system of agrarian education and science.

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4. Mathematical modeling of biological systems in Mathcad

Abstract. Modern challenges associated with climate change, population growth and the need to ensure sustainable development require new, highly accurate and predictive tools from agronomy and ecology. Traditional methods of agricultural production management often turn out to be insufficiently flexible and accurate for making informed decisions in a dynamic and complex environment. In this context, mathematical modeling appears as one of the most powerful and promising approaches. It allows not only to quantitatively describe complex biological and ecological processes, but also to predict their dynamics, optimize management decisions and minimize environmental risks. The subject of the study is methods, algorithms and mathematical models used to describe, analyze and predict the state and development of biological systems. ***The methodological basis*** of the study is based on a systems approach and the paradigm of mathematical modeling, which allows moving from a qualitative description of biological and ecological phenomena to their quantitative analysis and forecasting.

The purpose of the work is to systematize, analyze and provide an in-depth presentation of the theoretical foundations and practical application of mathematical modeling methods for effective analysis, optimization and forecasting of key processes in agronomy and ecology. In particular, attention is paid to the study of the Leslie matrix model, which allows predicting the population size and its age composition over time; the Lotka-Volterra model, which analyzes the dynamics of the interaction of two or more species; plant growth models, which are central to the optimization of agricultural technologies.

Conclusions. The results of the study have direct practical significance for the development and implementation of information systems for decision-making support in agriculture, and can be used as a methodological base for students of the faculties of agronomy, horticulture and plant protection and ecology, forestry and horticulture.

Introduction

Mathematical modeling of natural processes consists of sequentially passing through certain stages and using different types of models to describe and predict phenomena. The process of constructing and using a mathematical model usually includes the following main techniques:

1) analysis of the subject area and problem statement: defining the object and its boundaries, for example, population, ecosystem; highlighting key factors that influence the process and ignoring secondary ones; clear formulation of the modeling goal, id est forecasting, understanding mechanisms, optimization,

2) construction of a mathematical model: choosing a mathematical apparatus (differential equations, probabilistic methods, algebraic relations); recording the basic laws and relationships to which the object is subject; establishing initial and boundary conditions,

3) analysis and solution of the model: using analytical methods, if possible, to obtain an exact solution; applying numerical methods for complex systems,

4) verification and adequacy: checking the compliance of the modeling results with real observations; calibration (selection of model parameters for the best fit to experimental data); model adjustment in case of inconsistency,

5) interpretation and prediction: analysis of the obtained results in the context of the real process; prediction of the behavior of the system under new conditions [1].

The main types of mathematical models used in agronomy and ecology can be classified according to their purpose, structure and nature of the processes they describe. These models help to predict the dynamics of systems, optimize resource management and assess the impact of various factors.

Table 1 shows the classification of models according to the mathematical approach.

Table 1

Classification of mathematical models

View	Description	Application
Deterministic	The process is described by precise, single-valued equations (e.g., differential equations). The result is determined by the initial conditions.	Population dynamics, energy flows, crop growth patterns.
Stochastic	They take into account the element of chance. They use probability theory and statistics.	Disease spread modeling, weather forecasting, risk assessment.
Empirical	They are based on establishing relationships between variables through regression analysis of data, without an in-depth description of the mechanisms.	Rapid yield forecast, correlation between pollution and health.
Imitation	Reproduce the behavior of a complex system step by step, allowing you to experiment with different scenarios.	Complex ecosystems, management of large agro-industrial systems.

Created by the author

Mathematical models in agronomy are focused on predicting yields, optimizing resource use (fertilizers, water) and risk management.

Crop growth and development models are known as yield models or crop system models. They can be very detailed. Phenological models predict the onset of key phases of plant development (emergence, flowering, ripening) based on temperature. Physiological models describe the processes of photosynthesis, transpiration, nutrient uptake and biomass formation.

Agroclimatic and soil models describe the interaction of a plant with its environment. Soil water balance models predict soil moisture, the required amount of irrigation and the risk of drought, taking into account precipitation, evaporation and transpiration. Nutrient dynamics models calculate the transformation of nitrogen, phosphorus and potassium in the soil, which allows optimizing fertilizer application rates (precision farming).

Risk management and optimization models are used for decision-making. In particular, pest and disease distribution models predict the time and rate of development of pest populations or infections, helping to determine the optimal moment for the application of protective measures. Optimization models use linear or nonlinear programming to determine the best solutions. For example, the optimal distribution of crop areas, minimizing costs at a given yield.

Mathematical models in ecology are aimed at describing the dynamics of populations, energy and matter flows in ecosystems, as well as the impact of pollution. Population dynamics is the most classic type of model that describes changes in the number of organisms. The exponential growth model describes population growth in the absence of resource constraints. The logistic growth model takes into account resource constraints and the concept of environmental carrying capacity. The Lotka-Volterra model describes fluctuations in the number of two interconnected populations. The Leslie matrix model is also a powerful tool in ecology, using matrix algebra to model discrete population dynamics, especially those with age or stage structures. Unlike simple differential equations, these models allow us to track in detail how life events of survival, fertility, and transitions between stages affect overall population growth. System and simulation models of ecosystems include many interconnected components: plants, animals, soil, water, and atmosphere. Matter and energy flow models describe the transfer of carbon, nitrogen, phosphorus, water, and energy through different trophic levels and between biotic and abiotic components of an ecosystem. Spatial models use geographic information systems to model the distribution of species, pollutants, or soil degradation in a given area. Pollution and self-cleaning models describe the transport and transformation of pollutants in different environments. Transport models use differential equations to describe the diffusion, advection, and dispersion of pollutants in water or air. Balance models calculate the overall balance of a pollutant in a system, taking into account input, output, decay, and accumulation.

4.1 Leslie Matrix Model

One of the early versions of the matrix model was developed by Leslie [2]. It is a discrete model of population dynamics that takes into account its age structure. It allows to determine the future age structure of the female population from the known structure at a given time and hypothetical survival and fecundity coefficients.

The population is divided into $n+1$ age groups (i.e. $0, 1, 2, \dots, n$, with each group consisting of individuals of the same age) so that the oldest group, or the group in which all individuals survive to this age, has the number n. Denoting by x_n the number of individuals in each age group, we obtain a vector $\vec{a}_t = (x_{0t}, x_{1t}, \dots, x_{nt})$ that represents the age structure at time t. The variable t takes into account discrete changes in time (generations).

The model is described by the matrix equation $\vec{a}_{t+1} = A \cdot \vec{a}_t$ (1), which we write in expanded form by transposing the matrix-vector $\vec{a}_t$:

$$\begin{bmatrix} x_{0,t+1} \\ x_{1,t+1} \\ \vdots \\ \vdots \\ \vdots \\ x_{n,t+1} \end{bmatrix} = \begin{bmatrix} f_0 & f_1 & f_2 & \cdots & f_n \\ p_0 & 0 & 0 & \cdots & 0 \\ 0 & p_1 & 0 & \cdots & 0 \\ 0 & 0 & p_2 & \cdots & 0 \\ 0 & 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & p_{n-1} & 0 \end{bmatrix} \cdot \begin{bmatrix} x_{0,t} \\ x_{1,t} \\ \vdots \\ \vdots \\ \vdots \\ x_{n,t} \end{bmatrix} \tag{1}$$

where A – the Leslie matrix,

the quantities $f_i, (i = 0,1, \dots, n)$ represent the number of females born to a female of age i,

$p_i, (i = 0,1, \dots, n-1)$ – the probability that a female of age i will survive to age $i+1$.

For example, consider a population consisting of individuals of 5 age groups.

$$A = \begin{pmatrix} 2 & 4 & 1 & 5 & 8 \\ \frac{1}{2} & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{3} & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{4} & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{3} & 0 \end{pmatrix}, \tag{2}$$

where the numbers 2, 4, 1, 5, 8 – the number of females born to females of the corresponding age group,

$\frac{1}{2}$ – the probability that the female of the youngest age will survive to the next.

Let us show that the behavior of the model can be predicted by analyzing some formal properties of the matrix A.

First, by successively multiplying equation (1) by the matrix A (2), it is easy to obtain more general equations for the number of age groups by time t_{0+k}: $\vec{a}_{t_0+k} = A^k \cdot \vec{a}_{t_0}$.

Second, since the matrix A is square with $(n+1)$ rows and columns, it has (n+1) eigenvalues $(n+1)$ (taking into account multiplicity) and $(n+1)$ eigenvectors. The elements of A are positive numbers, or zeros, so the largest (in absolute value) eigenvalue and the coordinates of its corresponding eigenvector are positive and have some ecological meaning.

Let us illustrate this with one of the simplest models proposed by Williamson. The initial population has a vector representing the age structure $\vec{a}_0 = (0,0,1)$, that is, the population consists of one older female. The matrix A, which is called the Leslie matrix, has the form:

$$A = \begin{pmatrix} 0 & 9 & 12 \\ \frac{1}{3} & 0 & 0 \\ 0 & \frac{1}{2} & 0 \end{pmatrix} \tag{3}$$

After one time interval, multiplying the matrix A (3) by the transposed vector $\vec{a}_0$ (using the matrix multiplication rule), we have

$$A \cdot a_0 = \begin{pmatrix} 0 & 9 & 12 \\ \frac{1}{3} & 0 & 0 \\ 0 & \frac{1}{2} & 0 \end{pmatrix} \cdot \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} = \begin{pmatrix} 12 \\ 0 \\ 0 \end{pmatrix}. \tag{4}$$

i.e. $a_1 = (12, 0, 0)$ and there will already be 12 younger females in the population. Re-applying the model gives the following results:

$$A \cdot a_1 = \begin{pmatrix} 0 & 9 & 12 \\ \frac{1}{3} & 0 & 0 \\ 0 & \frac{1}{2} & 0 \end{pmatrix} \cdot \begin{pmatrix} 12 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ 4 \\ 0 \end{pmatrix} = a_2, \tag{5}$$

$$A \cdot a_2 = \begin{pmatrix} 0 & 9 & 12 \\ \frac{1}{3} & 0 & 0 \\ 0 & \frac{1}{2} & 0 \end{pmatrix} \cdot \begin{pmatrix} 0 \\ 4 \\ 0 \end{pmatrix} = \begin{pmatrix} 36 \\ 0 \\ 2 \end{pmatrix} = a_3, \tag{6}$$

$$A \cdot a_3 = \begin{pmatrix} 0 & 9 & 12 \\ \frac{1}{3} & 0 & 0 \\ 0 & \frac{1}{2} & 0 \end{pmatrix} \cdot \begin{pmatrix} 36 \\ 0 \\ 2 \end{pmatrix} = \begin{pmatrix} 24 \\ 12 \\ 0 \end{pmatrix} = a_4. \tag{7}$$

So, after three time intervals, each older individual, before dying, manages to produce an average of 12 offspring, each middle-aged individual, before dying (or with the same probability moving to the next class), manages to produce an average of 9 offspring. Young individuals do not produce offspring and with probability $\frac{1}{3}$ fall into the middle age group.

Let us find the main eigenvalue λ (λ - indicates the population growth rate, $\lambda > 0$ - the population is growing, $\lambda < 0$ - it is decreasing, $\lambda = 0$ - the number is constant) and the eigenvector $\vec{v}$ of the matrix A. They can be found by the methods described in the section Eigenvalues and Vectors, having

$$A \cdot \vec{v} = \lambda \cdot \vec{v} \tag{8}$$

Let us denote the coordinates of the eigenvector $\vec{v} = (x, y, z)$. To find them, we will compose a system of three linear algebraic equations:

$$\left.\begin{matrix} 9y + 12z = \lambda x \\ \frac{1}{3}x = \lambda y \\ \frac{1}{2}y = \lambda z \end{matrix}\right\}, \tag{9}$$

determinant of which

$$\begin{vmatrix} -\lambda & 9 & 12 \\ \frac{1}{3} & -\lambda & 0 \\ 0 & \frac{1}{2} & -\lambda \end{vmatrix} = -\lambda^3 + 3\lambda + 2 = (2 - \lambda) \cdot (\lambda + 1)^2. \tag{10}$$

By equating (10) to zero, we find the principal eigenvalue $\lambda_1 = 2$. This means that the population size doubles for each time interval.

To find the eigenvector that determines the stable age structure of the population, we substitute $\lambda_1 = 2$ into each equation of system (9). We have:

$$\begin{cases} -2x + 9y + 12z = 0 \\ \frac{1}{3}x - 2y = 0 \\ \frac{1}{2}y - 2z = 0 \end{cases} \tag{11}$$

Since the system is homogeneous, it has many solutions. Express y and z in terms of x in the second and third equations and substitute into the first. We have: $y = \frac{1}{6}x$, $z = \frac{1}{24}x$, then $z = 1$, то $y = 4$, $x = 24$.

The eigenvector of equality $\vec{v}_1 = (24, 4, 1)$. The other eigenvalues of equality have the form $\lambda_2 = -1$, $\lambda_3 = -1$. Similarly, the eigenvector of $\vec{v}_2$ has the form $\vec{v}_2 = (6, -2, 1)$. Since the eigenvalue is -1 of multiplicity 2, to find the vector $\vec{v}_3$, we solve the system of equations $(A - \lambda_2)\, \vec{v}_3 = \vec{v}_2$:

$$\begin{pmatrix} 1 & 9 & 12 \\ \frac{1}{3} & 1 & 0 \\ 0 & \frac{1}{2} & 1 \end{pmatrix} \cdot \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} 6 \\ -2 \\ 1 \end{pmatrix}. \tag{12}$$

It is easy to verify that the corresponding system admits the solution $\vec{v}_3 = (0, -2, 2)$.

Based on the concept of a basis of vectors and its geometric interpretation, we assume that the age structure of the population is represented by a vector in three-dimensional space, for which the vectors $\vec{v}_1 = (24, 4, 1)$, $\vec{v}_2 = (6, -2, 1)$ and $\vec{v}_3 = (0, -2, 2)$ – the basis, i.e.

$$\vec{a}_0 = a_0 \cdot \vec{v}_1 + \beta_0 \cdot \vec{v}_2 + \gamma_0 \cdot \vec{v}_3, \tag{13}$$

where a_0, β_0, γ_0 – some positive numbers.

For example, if $\vec{a}_0 = (258, 30, 17)$, then we find the coordinates of this vector in the new basis $\vec{v}_1, \vec{v}_2, \vec{v}_3$ by composing and solving the system of linear algebraic equations:

$$\begin{cases} 24\alpha_0 + 6\beta_0 + 0\gamma_0 = 258 \\ 4\alpha_0 - 2\beta_0 - 2\gamma_0 = 30 \\ 1\alpha_0 + 1\beta_0 + 2\gamma_0 = 17 \end{cases}. \tag{14}$$

We have $\vec{a}_0 = 10$, $\vec{\beta}_0 = 3$, $\vec{\gamma}_0 = 2$.

Since $\frac{k}{2^k} \to 0, k \to \infty$, then at $t = +k \to \infty$ the population grows exponentially

$$\vec{a}_{+k} \approx 2^k \cdot a_0 \cdot \vec{v}_1. \tag{15}$$

Therefore, the principal eigenvalue λ_1 gives the rate at which the population size grows (in our example, the population doubles in each time interval), and the eigenvector $\vec{v}_1$ determines the stable age structure of the population, i.e. the ratio of the numbers of individuals of different age groups remains constant and equal to 24:4:1.

Knowing the principal eigenvalue λ_1 and using the following formula, we can also estimate the number of individuals that need to be removed from the population so that its size is equal to the initial one:

$$H = 100\frac{\lambda-1}{\lambda}. \tag{16}$$

The remaining eigenvalues and vectors can characterize the stability and oscillatory tendencies in the models.

It is easy to see that if at the end of each time interval we remove half of the population and use it for food, then its size will become equal to the initial $\vec{a}_0$.

Therefore, matrix models are indispensable in conservation biology in determining the most critical life cycle stages for endangered species. This helps to direct efforts to protect those groups whose survival has the greatest impact on $\bar{\lambda}$; in resource management to predict population growth of commercial species (e.g., fish) to set catch quotas; in ecological toxicology to assess the impact of pollutants on specific life stages of organisms; in modeling stage development using a stage transition matrix instead of a pure age structure, which is better suited for plants, invertebrates, and other organisms whose development depends on size or stage, rather than just age.

The algorithm for individual calculation stages in the Mathcad environment is shown in (Listing 1).

Listing 1

Which displays the population characteristics over time intervals: t=3,30,100,300, where t is the generation time

$$A := \begin{pmatrix} 0 & 9 & 12 \\ \frac{1}{3} & 0 & 0 \\ 0 & \frac{1}{2} & 0 \end{pmatrix} \quad A\cdot\begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \to \begin{pmatrix} 12 \\ 0 \\ 0 \end{pmatrix} \quad A\cdot\begin{pmatrix} 12 \\ 0 \\ 0 \end{pmatrix} \to \begin{pmatrix} 0 \\ 4 \\ 0 \end{pmatrix} \quad A\cdot\begin{pmatrix} 0 \\ 4 \\ 0 \end{pmatrix} \to \begin{pmatrix} 36 \\ 0 \\ 2 \end{pmatrix}$$

$$A^3\cdot\begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \to \begin{pmatrix} 36 \\ 0 \\ 2 \end{pmatrix} \quad A^{30}\cdot\begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \to \begin{pmatrix} 2863311408 \\ 477218628 \\ 119304628 \end{pmatrix} = \begin{pmatrix} 2.863\times 10^9 \\ 4.772\times 10^8 \\ 1.193\times 10^8 \end{pmatrix}$$

$$A^{100}\cdot\begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \to \begin{pmatrix} 3380401600608611737324541880600 \\ 563400266768101956220756980300 \\ 140850066692025489055189244976 \end{pmatrix} = \begin{pmatrix} 3.38\times 10^{30} \\ 5.634\times 10^{29} \\ 1.409\times 10^{29} \end{pmatrix}$$

$$A^{300}\cdot\begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} = \begin{pmatrix} 5.432\times 10^{90} \\ 9.053\times 10^{89} \\ 2.263\times 10^{89} \end{pmatrix} \quad A^{1000}\cdot\begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} = \begin{pmatrix} 2.857\times 10^{301} \\ 4.762\times 10^{300} \\ 1.191\times 10^{300} \end{pmatrix}$$

Determining the eigenvalues of a matrix

$$A := \begin{pmatrix} 0 & 9 & 12 \\ \frac{1}{3} & 0 & 0 \\ 0 & \frac{1}{2} & 0 \end{pmatrix} \quad \left| A - \lambda\cdot\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \right| \to 3\cdot\lambda - \lambda^3 + 2$$

$$3\cdot\lambda - \lambda^3 + 2 \text{ solve} \to \begin{pmatrix} -1 \\ -1 \\ 2 \end{pmatrix}$$

$$\begin{pmatrix} 24\alpha + 6\beta + 0\gamma = 258 \\ 4\alpha - 2\beta - 2\gamma = 30 \\ 1\alpha + \beta + 2\gamma = 17 \end{pmatrix} \text{ solve}, \alpha, \beta, \gamma \to (10 \;\; 3 \;\; 2)$$

4.2 Lotka-Volterra Mathematical Model

The classical Lotka-Volterra mathematical model describes the dynamics of the number of two interacting populations in a predator-prey ecosystem. The model is a system of two first-order nonlinear differential equations that show how the number of each population changes over time, depending on their interaction.

Let there be two biological species that live together in some isolated territory. The environment is considered stationary and provides the «prey» species with everything necessary for existence. The other species, the «predators», is also in stationary conditions, but feeds only on representatives of the first «prey» species. Such simple models can approximately describe the interaction of populations of hares and wolves, crucian carp and pike, competition between producers of products, competition between sellers.

The predator-prey system is a complex ecosystem for which long-term relationships between predator and prey species are implemented in a common territory. One of the important problems in studying this ecosystem is the problem of its stability and its manageability.

Let us consider a simplified Lotka-Volterra mathematical model of the coexistence of two biological species. It consists of two components: Y_0 – the number or biomass of the prey or plant population and Y_1 – the number of the consumer (predator) population.

The predator-prey model describes the dynamics of average values. This is a system of two first-order ordinary differential equations that describes the dynamics of the population size with one type of predator and one type of prey.

Let us consider the case when, in the absence of a predator, the prey population will grow along an exponential curve.

Let us construct the simplest model of the development of predator and prey populations. To simplify the model, we will consider their numbers as continuous functions of time, the number of prey is unlimited. The limitations of the proposed model also include the fact that it does not take into account the spatial parameters of the interaction of predators and prey, the dependences between the values are considered linear. Also, this model does not take into account the existing evolution of prey and predator species.

The variables in the model will be:

$Y_0 = Y_0(t)$ – number of victims,

$Y_1 = V_1(t)$ – number of predators.

Let's write an equation that describes the change in the number of victims over time. The change in the number dY_0 of victims over time dt will occur due to three reasons. Since there are no restrictions on the number of food resources for victims, they will multiply indefinitely in proportion to their number:

$$dY1_0 = \alpha Y_0 dt, \quad (17)$$

where α – the generalized proportionality coefficient, which depends on the living conditions and birth rate of the victims.

The decrease in the number of victims will occur due to the extinction of the population: the number of such deceased victims will be proportional to the total number of existing victims:

$$dY2_0 = -\beta Y_0 dt, \quad (18)$$

where β – the proportionality coefficient that takes into account natural mortality.

The change in the number of victims due to natural causes (if predators are absent) can be written as:

$$dY_0 = dY1_0 + dY2_0 = \propto Y_0 dt - \beta Y_0 dt = (\alpha - \beta) Y_0 dt = \mu Y_0 dt, \quad (19)$$

where $\mu = \alpha - \beta$ – the total coefficient, $\mu > 0$, which reflects environmental conditions, birth rate and mortality of victims in the absence of predators.

Let us determine the value of the coefficient μ. To do this, we solve the differential equation (19) for some time interval $[0, t]$:

$$dY_0 = \mu Y_0 dt. \quad (20)$$

Let's separate the variables:

$$\frac{dY_0}{Y_0} = \mu dt.$$

Let's integrate:

$$\int_{V_0^0}^{V_0^t} \frac{dY_0}{Y_0} = \int_0^t \mu dt$$

$$lnV_0^t - lnV_0^0 = \mu(t-0),$$

$$ln\left(\frac{V_0^t}{V_0^0}\right) = \mu t, \tag{21}$$

$$ln\left(\frac{V_0^t}{V_0^0}\right) = \mu t lne = lne^{\mu t}$$

$$\frac{V_0^t}{V_0^0} = e^{\mu t}.$$

We obtained the equation of simple exponential growth:

$$V_0^t = V_0^0 e^{\mu t}, \tag{22}$$

In real ecological systems, the food resource for victims is limited, so the number of victims for real systems is described by a system of equations of simple exponential growth:

$$\begin{cases} V_0^t = V_0^0 e^{\mu t} \text{ при } 0 \le t \le t^* \\ V_0^t = V_0^{t^*} \text{при } t > t^* \end{cases}. \tag{23}$$

Let the number of victims increase by a factor of $V_0^\tau = eV_0^0$ over a period of time τ, then according to (21) we can write:

$$ln\left(\frac{V_0^\tau}{V_0^0}\right) = ln\left(\frac{eV_0^0}{V_0^0}\right) = lne = 1 = \mu\tau,\ \mu\tau = 1,$$

$$\mu = \frac{1}{\tau}, \tag{24}$$

i.e. the coefficient μ is the reciprocal of the time it takes for the number of prey to increase by e times. But since there are also predators in the ecosystem that feed on prey, the number of prey will decrease as a result of their destruction by predators. The number of prey that will be destroyed is proportional to the number of predators and the number of prey: $dY_0^з = kY_0Y_1dt$. The proportionality coefficient k – a total coefficient that takes into account the probability of a predator meeting a prey, as well as the number of prey that can be eaten by one predator.

Therefore, the first equation of the model is written as follows:

$$dY_0 = \mu Y_0 dt - kY_0 Y_1 dt,$$

$$Y_0' = \frac{dY_0}{dt} = \mu Y_0 - kY_0 Y_1. \tag{25}$$

Let's write the second equation of the model, which will describe the change in the number of predators. Since predators feed only on prey, without the presence of prey the population of predators will decrease. The number $dY_1^{\Pi}$of those who died without food dt during the time of predators will be proportional to the number of predators: $dY_1^{\Pi} = mY_0 dt$, where the coefficient m – the proportionality index, obtained similarly to the same index for the first equation of the model (see equation (17-25)).

But in the presence of prey, predators will be able to increase their population proportional to their number and the number of prey: $dY_1^{з} = bY_0 Y_1 dt$, where b – the proportionality index, which takes into account the ability of predators to reproduce and the probability of a predator meeting a prey. Therefore, the second equation of the model can be written:

$$dY_1 = -mY_0 dt + bY_0 Y_1 dt,$$

or

$$Y_1' = \frac{dY_1}{dt} = -mY_1 + bY_0 Y_1. \tag{26}$$

System of differential equations:

$$\begin{cases} \frac{dY_0}{dt} = \mu Y_0 - kY_0 Y_1 \\ \frac{dY_1}{dt} = -mY_1 + bY_0 Y_1 \end{cases}, \tag{27}$$

is called the Lotka-Volterra model. The coefficients μ, k, m, b are the parameters of the model.

The steady state of the system is described by the system of equations:

$$\begin{cases} Y_0 = const \\ Y_1 = const \end{cases},$$

$$\begin{cases} \frac{d_0}{dt} = 0 \\ \frac{dY_1}{dt} = 0 \end{cases},$$

$$\begin{cases} \mu Y_0 - kY_0 Y_1 = 0 \\ -mY_1 + bY_0 Y_1 = 0 \end{cases},$$

$$\begin{cases} \mu - kY_1 = 0 \\ -m + bY_0 = 0 \end{cases}.$$

Therefore, stationary solutions of the system of differential equations (27) can exist under the condition:

$$Y_0 = \frac{m}{b}, \quad (28)$$

$$Y_1 = \frac{\mu}{k}. \quad (29)$$

System of differential equations $\begin{cases} \frac{dY_0}{dt} = \mu Y_0 - kY_0Y_1 \\ \frac{dY_1}{dt} = -mY_1 + bY_0Y_1 \end{cases}$ with initial conditions:

$$\begin{cases} Y_0(0) = YZ \\ Y_1(0) = YV \end{cases}, \quad (30)$$

(where $YZ -$ the number of victims at time $t = 0$, $YV -$ the number of predators at time $t = 0$) is solved in Mathcad by numerical methods.

For solving differential equations and their systems by numerical methods, Mathcad has more than 30 different functions built in.

For the system of differential equations (27), the built-in function $rkfixed$ gives quite good results. It gives a solution to the system of differential equations of the problem on a given interval by the Runge-Kutta method with a constant step.

The function has the format:

$$Z = rkfixed(\mathrm{y}, t1, t2, N, D), \quad (31)$$

where Y – the vector of initial conditions, $t1, t2$ – the initial and final points of the integration segment of the system; N – the number of nodes on the segment $[t1, t2]$; when solving a problem on a segment, the result contains $N + 1$ lines; D – the name of the vector function $D(t, y)$ of the right-hand side of the system of differential equations (it contains expressions for the derivatives of the system of differential equations), Z – the result of the function-matrix, the format of which depends on the type of problem, for example, for first-order differential equation systems of type (27), their first column contains the coordinates of the grid nodes t_i (time), the second column - the calculated approximate values of the solution Y_{0_i} (number of victims), the third – Y_{1_i} (number of predators).

To analyze predator-prey systems, phase diagrams are used. A phase diagram – a graph that quantitatively characterizes the dependence of one population on another. If the phase diagram on the plane is a smooth closed curve, and the phase diagram in space is a spiral line, then the system exists in a stable state the pitch of the spiral line characterizes the cyclicity of the system in time.

If the phase diagram on the plane is a non-smooth closed curve and the phase diagram in space is a distorted spiral-shaped line, then the system may exist but it is weakly stable, the connections between its elements are inharmonious, and any minor disturbances in the system can lead to its collapse.

If the phase diagram on the plane is an open curve, and the phase diagram in space is not a spiral line then the system cannot exist.

Let us consider the Mathcad program-document for studying the simplified Lotka-Volterra predator-prey model, for a system with parameters: $\mu = 0{,}5$, $k = 0{,}002$, $m = 0{,}2$, $b = 0{,}0015$. The initial number of hares $YZ = 200$, wolves – $YV = 150$, the time interval is 300 conventional units, the number of nodal integration points $N = 1000$. The solution to the problem is given in (Listing 2).

The developed mathematical model (Listing 2) makes it possible to change the values of the system parameters, that is, to investigate the behavior of the system at different parameter values, therefore it can be attributed to the class of simulation models.

Listing 2

Simplified Lotka-Volterra predator-prey model

Model parameters:

$\mu := 0.5 \qquad k := 0.002 \qquad m := 0.2 \qquad b := 0.0015$

$YZ := 200$ <== Number of hares at the initial time t1=0

$YV := 150$ <== Number of wolves at the initial time t1=0

$t1 := 0$ <== Initial time (in conventional units)

$t2 := 300$ <== Final point in time (in conventional units)

$N := 1000$ <== The number of points for which a solution to a system of equations found

Relationship between model parameters:

$\frac{m}{b} = 133.333 \qquad \frac{\mu}{k} = 250$

Initial condition vector:

$Y := \begin{pmatrix} YZ \\ YV \end{pmatrix}$ <== Number of hares at the initial time t1=0
<== Number of wolves at the initial time t1=0

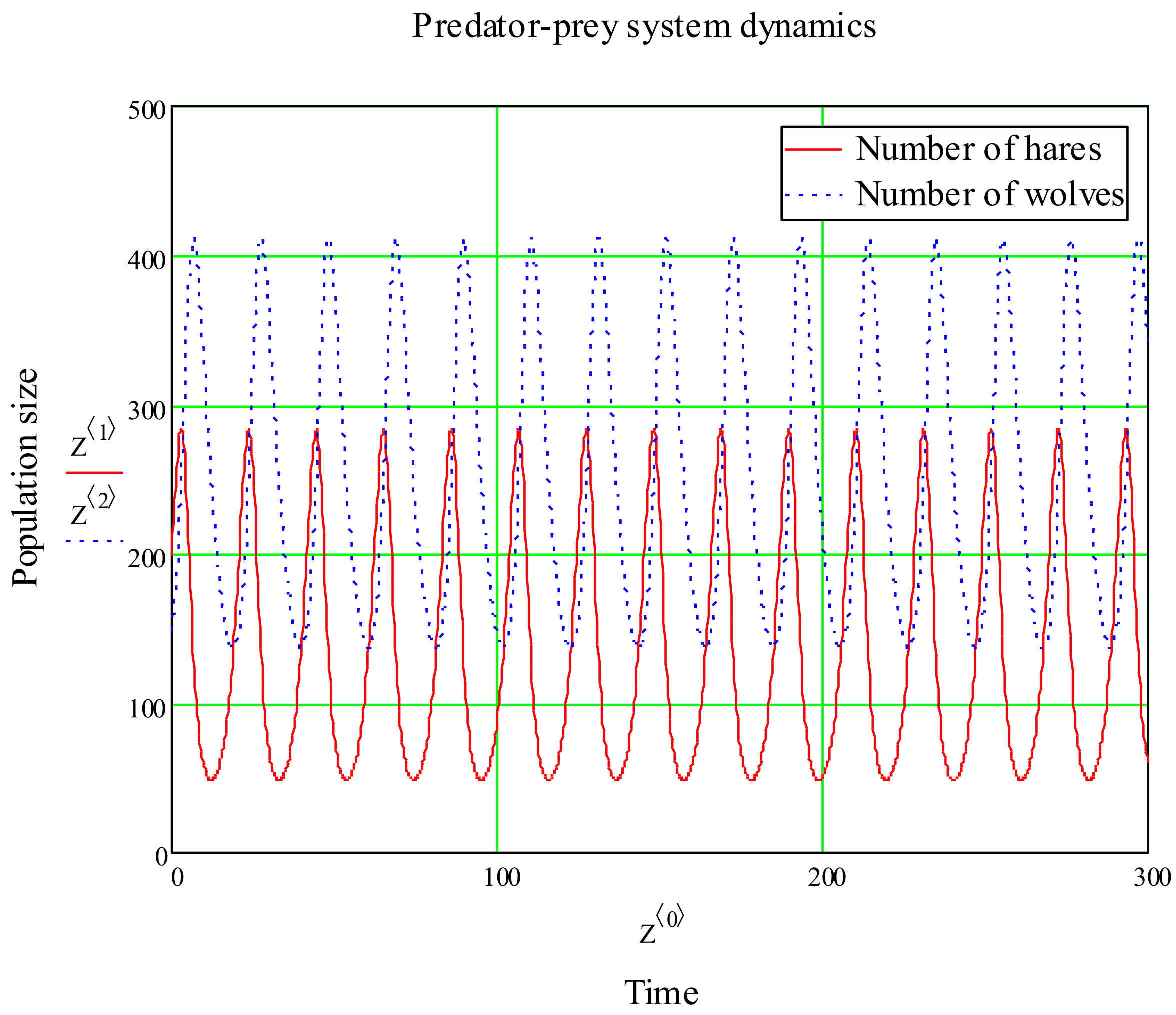
The vector D (t,Y), which contains the left-hand sides (values of derivatives) of the system of differential equations (27)

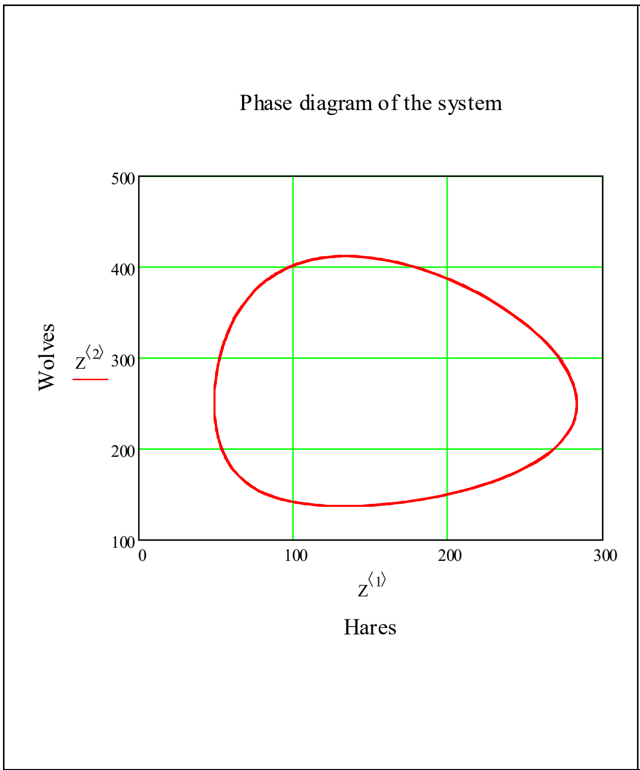
$$D(t,Y) := \begin{pmatrix} \mu \cdot Y_0 - k \cdot Y_0 \cdot Y_1 \\ -m \cdot Y_1 + b \cdot Y_0 \cdot Y_1 \end{pmatrix}$$

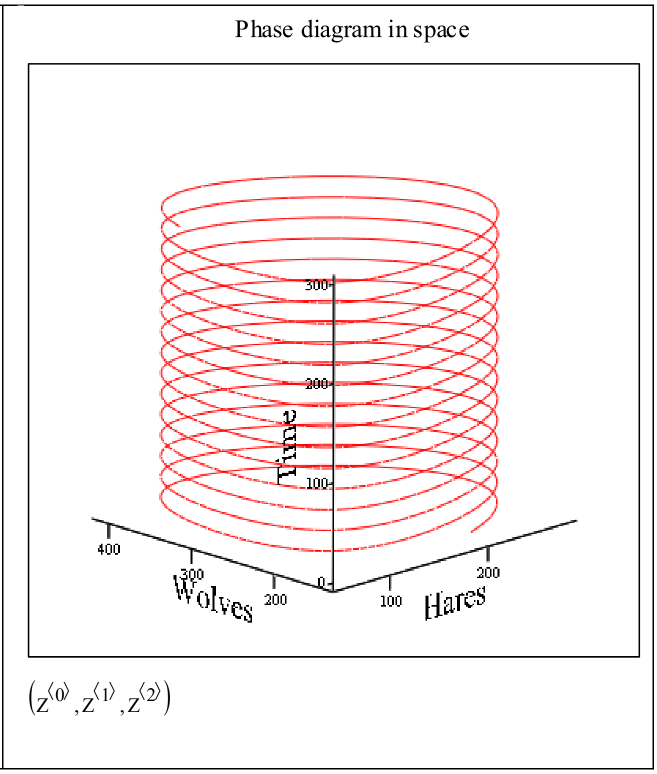
Solving a system of differential equations by the Runge-Kutta method (rkfixed function). Solution Z - a matrix of dimension Nx3. Its first column $Z^{\langle 0 \rangle}$ contains the time t, the second $Z^{\langle 1 \rangle}$ and the third $Z^{\langle 2 \rangle}$ contain the values of the functions Y_0 and Y_1 corresponding to the given moments of time t

$$Z := \mathrm{rkfixed}(Y, t1, t2, N - 1, D)$$

Continuation of Listing 2







4.3 Dynamic plant growth models

In agriculture, S-shaped models are often used to describe the dynamics of biomass accumulation over time. These curves reflect typical limited growth: a slow start, rapid exponential growth, and a slowdown until reaching a maximum or constant value. The most common such models used to model plant growth are the logistic growth equation, Gompertz, and Chanter [3].

The logistic model is the simplest and most common model of limited growth. It was first proposed by Pierre-François Verhulst. The growth curve is symmetric about the inflection point (the highest growth rate), which is exactly half the maximum mass. It is suitable for modeling growth where factors limiting growth (such as lack of space or nutrients) begin to act proportionally as the object increases in size.

The Gompertz model is often used in biology and medicine to describe the growth of tumors or organs, as well as plant growth. Unlike the logistic curve, the Gompertz curve is asymmetric. The inflection point (maximum growth rate) is located at $\approx 37\%$ of maximum mass. It better models those biological processes where the highest growth rate is achieved in the early stages (low mass), and the growth slowdown is more gradual in the later stages. In agronomy, it is often used to model fruit growth or dry mass accumulation.

The Richards equation, also sometimes called the Chanter equation in the context of plant growth, is a generalization of both the logistic and Gompertz models. It introduces an additional parameter that controls the shape of the curve. Chanter used specific forms of this equation to model the growth of agricultural crops, in particular root crops. The Richards equation can be reduced to either the logistic model or the Gompertz model. Due to its flexibility, the Chanter equation allows for the most accurate modeling of various growth patterns of agricultural crops (root crops, tubers, leaves), where the point of maximum growth rate can differ greatly from half of the final mass.

We analyze the growth dynamics of Brussels sprouts using a mathematical model constructed upon a system of differential equations. For every plant subsystem, a distinct differential equation is formulated to describe its development and interconnection with other components. This system of equations is solved utilizing a numerical approach. The final step involves selecting solutions from the generated set where the cumulative sum of squared deviations from observed experimental values is minimal.

Plant subsystems undergo continuous dynamic transformations during the growth process, which poses several challenges for mathematical modeling. Conventionally, plant parameters are measured at specific time intervals. For these discrete time points, researchers often formulate regression equations, aiming to generalize the findings for intermediate and subsequent time moments by introducing time as a variable into the regression model. However, it is widely recognized that the results derived from simple regression equations frequently diverge from empirical observations. Such a semi-empirical approach may fail to capture the true dynamics of plant development, thereby leading to the construction of inefficient models.

An adequate mathematical description of the unique characteristics of a real agrobiological system requires a dynamic model. Such a model must inherently describe the interaction among plant subsystems, uncover the underlying mechanisms of their temporal change, and reveal the patterns governing the internal processes. Typically, dynamic models are constructed using differential equations and their systems [4, 5, 6]. Consequently, the task of developing methodologies for generating mathematical models to describe complex, multidimensional dynamic systems remains highly relevant.

Plant growth and developmental trajectories can be mathematically captured using growth functions that establish the relationship between accumulated dry matter and time. We will now examine some of the most widely recognized growth equations, including the logistic, Gompertz, and Chanter's models [4, 5, 14].

Focusing on the latter, we proceed to analyze the specifics of Chanter's equation:

$$M = \frac{M_0 \cdot B}{M_0 + (B - M_0) \cdot exp\{-[\mu(1 - e^{-D \cdot t})/D]\}} \qquad (32)$$

where, M,M_0, B, μ, D – parameters that have a biological meaning.

Let $M = 100\ g$ – the mass of dry matter for the period of harvest;

$M_0 = 1\ g-$ the mass of dry matter of the plant at the time $t = 0$;

B – availability of nutrient medium;

$$B = \frac{M \cdot M_0 \cdot (e^{\mu/D} - 1)}{M_0 \cdot e^{\mu/D} - M}, \quad (33)$$

$\mu = 0{,}5$ – specific growth rate;

D – an indicator of complication, which characterizes μ the change with plant development.

The derivation of the logistic equation is predicated on the assumption that the plant's growth rate is limited by the available nutrient resources in the medium. Conversely, the Gompertz equation posits that the nutrient medium resource is unlimited. Specifically, it assumes that the growth energy remains unaffected and is directly proportional to the dry mass, while the specific growth rate remains constant [4].

By selecting the value D for from the interval $0 \leq D \leq \mu/[ln(M/M_0)]$, you can build a family of curves, which is bounded on the left by the logistic curve, and on the right – the Gompertz curve. When $D \to 0$ (for example, $D = 0{,}00086$), and B determined by formula (33), equation (32) becomes logistical. When $D \to \mu/[ln(M/M_0)] = 0{,}1086$ – in the Gompertz curve, when $D = 0{,}05$ the curve is between the logistic curve and the Gompertz curve. All plotted growth curves share identical values for the initial and final dry weight of the plant, as well as the starting specific growth rate. As a parameter increases, the inflection point shifts towards later time values. The Gompertz curve is characterized by more rapid growth during the initial stages, a slower convergence towards the asymptote, and an extended linear segment around the inflection point. (Fig. 1).

Consequently, the Chanter, Gompertz, and logistic growth curves are suitable for integration as fundamental components within dynamic models designed for plant growth.

By integrating these specific growth curves (Chanter, Gompertz, and logistic), it is possible to construct a more robust mathematical model for plant growth dynamics, typically represented by a system of differential equations.

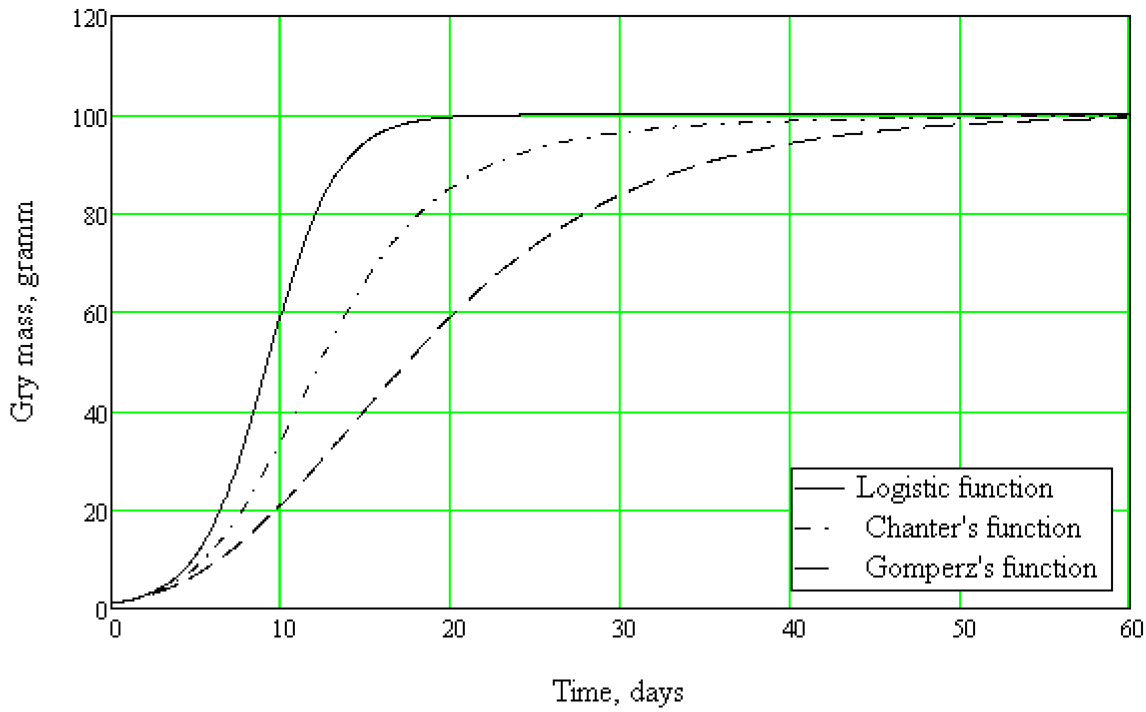


Fig.1 Chanter's growth function

The majority of differential equations and equation systems used to model the dynamics of agrobiological systems lack closed-form (analytical) solutions, or such solutions are excessively complex [4, 5, 6]. Consequently, the ability to solve these differential equations and their systems using numerical techniques is essential. The Mathcad system provides the necessary capabilities for this purpose [1].

The Mathcad environment provides capabilities for solving differential equations and their systems using both symbolic and numerical approaches. While symbolic methods for equation solving are unfortunately constrained, the system compensates with robust numerical techniques designed for solving problems such as the Cauchy problem (initial value problem). Numerical solution of the generalized differential equations (GDE) within the framework of the Cauchy problem constitutes a sophisticated and detailed process. Crucially, the ease of interpreting the results and analyzing how solutions respond to changes in system parameters are key advantages in this proces.

The majority of computational tasks are straightforwardly managed (often solved using the standard Runge-Kutta algorithm). Conversely, particularly "stiff" problems necessitate the application of specialized numerical techniques. Since all these algorithms are integrated into the Mathcad system, the user can select the appropriate method based on the specific characteristics of the equation being analyzed.

When modeling biological processes, systems, or ecosystems, one must assume the validity of fundamental laws from physics, chemistry, and biology. The core principles and laws governing processes in non-living nature maintain their relevance for living systems. Consequently, every robust mathematical model must be grounded in the laws of conservation (mass, electric charge, energy, linear and angular momentum) and the laws governing mass interaction, radioactive, and chemical transformations.

We now explore a methodology for constructing a dynamic plant growth model that relies on empirical data. Developing such a mathematical model necessitates a substantial volume of experimental measurements. Crops like potatoes [6], tomatoes, sugar beets [15], and cabbage are particularly suitable subjects for developing these growth models.

A significant contribution to the study of cabbage growth was made by Cherednichenko V.M. [7, 8, 10, 11], Lykhatsky V.I. [9], Chernensky V.M. [12, 13]. Cherednichenko V.M. during 2009-2013 conducted fundamental field experiments on the cultivation of cauliflower and broccoli at the experimental sites of Vinnytsia National Agrarian University. The effect of water-retaining granules, mulching with film and black agrofiber on plant growth was studied. Phenological observations, biometric measurements and records were carried out, the relationship between plant subsystems was studied, and a statistical analysis of plant growth indicators was performed.

As an illustrative case, we will construct a model detailing the growth dynamics of Brussels sprouts, basing our approach on the framework established by Zagorodny Y. V. [6]. In plants, we distinguish separate subsystems: W_1 – root, W_2 – stem, W_3 – leaves, W_4 – heads. The total dry weight of the plant is:

$$W = \sum_{i=1}^{4} W_i, \tag{34}$$

The growth of subsystems (stem roots, leaves) for Brussels sprouts is described by the growth equation:

$$W_i = \frac{A_i \cdot B_i}{A_i + (B_i - A_i) \cdot e^{-\kappa_i t}}, \tag{35}$$

where A_i is the dry weight of the corresponding subsystem for seedlings;

B_i – dry mass of the relevant subsystem for the period of completion of harvesting.

The model is built according to the following algorithm:

1. In plants, we distinguish separate subsystems: W_1 – root, W_2 – stem, W_3 – leaves, W_4 – head.

2. We determine the dry weight of plant subsystems with a period of 5-7 days throughout the growing season.

3. Based on experimental data, we determine the unknown parameters of growth functions for each subsystem of the plant.

4. We write the differential equations for the dynamics of each subsystem.

We combine differential equations into a system:

$$\begin{cases} \frac{dW_1(t)}{dt} = a_{1,1}W_1(t) \cdot \rho(t) \cdot f(t) \cdot \frac{k_1 e^{-k_1 t}(B_1 - A_1)}{A_1 - e^{-k_1 t}(A_1 - B_1)} + a_{1,2}wW_2(t) - a_{1,3}W_3(t) - a_{1,4}W_4(t) \\ \frac{dW_2(t)}{dt} = a_{2,1}W_1(t) + a_{2,2}W_2(t) \frac{k_2 e^{-k_2 t}(B_2 - A_2)}{A_2 - e^{-k_2 t}(A_2 - B_2)} + a_{2,3}W_3(t) - a_{2,4}W_4(t) \\ \frac{dW_3(t)}{dt} = a_{3,1}W_1(t) \cdot a_{3,2}W_2(t) + a_{3,3}W_3(t) \cdot f(t) \cdot \frac{k_3 e^{-k_3 t}(B_3 - A_3)}{A_3 - e^{-k_3 t}(A_3 - B_3)} - a_{3,4}W_4(t) \\ \frac{dW_4(t)}{dt} = [a_{4,1}W_1(t) + a_{4,2}W_2(t) + a_{4,3}W_3(t) \cdot f(t)]s(t) - a_{4,4}W_4(t) \end{cases} \tag{36}$$

where $\begin{bmatrix} a_{1,1} & a_{1,2} & a_{1,3} & a_{1,4} \\ a_{2,1} & a_{2,2} & a_{2,3} & a_{2,4} \\ a_{3,1} & a_{3,2} & a_{3,3} & a_{3,4} \\ a_{4,1} & a_{4,2} & a_{4,3} & a_{4,4} \end{bmatrix}$ – matrix of coefficients of the system of equations, which characterizes the interaction of elements of plant subsystems;

$a_{1,1}$ – coefficient characterizing the strength of root growth;

$a_{1,2}$ – coefficient that characterizes the rate of exchange between the subsystem «root – stem»;

$a_{1,3}$ – coefficient that characterizes the rate of exchange between the subsystem «root – leaf» through the stem;

$a_{1,4}$ – coefficient that takes into account the decrease in the rate of root growth due to the growth of the head;

$a_{2,1}$ – rate of exchange between subsystems «stem – root»;

$a_{2,2}$ – characterizes the growth rate of the stem;

$a_{2,3}$ – rate of exchange between subsystems «stem – leaf»;

$a_{2,4}$ – takes into account the decrease in the growth rate of the stem due to the growth of the heads;

$a_{3,1}$ – rate of exchange «leaf – root» through the stem;

$a_{3,2}$ – rate of exchange «leaf – stem»;

$a_{3,3}$ – characterizes the growth rate of leaves;

$a_{3,4}$ – takes into account the decrease in leaf growth due to the growth of heads;

$a_{4,1}$ – characterizes the influence of roots on the growth rate of dry weight of heads;

$a_{4,2}$ – characterizes the influence of the stem on the growth rate of dry weight of the heads;

$a_{4,3}$ – characterizes the influence of leaves on the growth rate of dry weight of heads;

$a_{4,4}$ – takes into account the decrease in the intensity of the growth rate of the heads due to the aging of the plant organism;

$\rho(t)$ – soil moisture function;

$f(t)$ – soil temperature function;

$F(t)$ – air temperature function;

A_1 – dry mass of seedling roots;

B_1 – dry mass of roots for the period of completion of harvesting;

K_1 – coefficient of the logistic equation of root growth;

A_2– dry mass of seedling stem;

B_2– dry weight of the stem for the period of completion of harvesting;

K_2 – coefficient of the logistic equation of stem growth;

A_3 – dry mass of seedling leaves;

B_3 – dry weight of leaves for the period of completion of harvesting;

K_3 – coefficient of logistic level of leaf growth;

$S(t)$ –a function that characterizes the growth rate of heads.

4. We set the initial conditions – values $W_{i,0}$ for the moment of time $t = 0$.

5. We give the initial approximations of the unknown coefficients $a_{i,j}$ of the system of differential equations.

6. We solve the system of differential equations in Mathcad by the Runge-Kutta method with a constant step. We use the built-in function:

$rkfixed(y, x1, x2, n, D)$.

7. We find the weighted sum of the squares of the deviations of the experimental values from the calculated ones $\sum_{i=1}^{n}\sum_{j=0}^{m}\left(\frac{W_{i,j}-WP_{i,j}}{WP_{i,j}}\right)^2$.

8. By the method of coordinate descent we change the values of the coefficients $a_{i,j}$.

9. We solve the system of equations and calculate the sum of squares of deviations.

10. The computational procedure is completed at

$$\sum_{i=1}^{n}\sum_{j=0}^{m}\left(\frac{W_{i,j}-WP_{i,j}}{WP_{i,j}}\right)^2 = min. \quad (37)$$

11. We fix the optimal values of the coefficients $a_{i,j}$.

12. We substitute the obtained optimal values of the coefficients into the system of differential equations (36) and solve it.

13. We analyze the solution of the system of equations and investigate the interaction between the individual elements of plant subsystems. We build graphs.

To determine the dry weight of plant subsystems, field experiments were performed (table 2). The plants were cleaned from the soil, their components were isolated: root, stem, leaves, heads, placed in a thermostat with a temperature of 50-60°C and dried for 4-5 hours. After that, at a temperature of 103-110 °C the plants were dried (brought to constant weight) for 3-5 hours. The average value was determined by averaging the masses of 5-7 plants.

Table 2

Dry mass of plant subsystems

t	0	10	30	37	46	55	60	67	75	91	98	112
W_1, *g*	0.53	2.2	3.7	6	12.8	12.4	14.1	16.1	16.2	18.5	17.3	18.9
W_2, *g*	0.34	1.1	6.7	7	15.2	20.1	23.8	26.0	26.1	28.7	28.8	28.5
W_3, *g*	2.61	5.8	18.5	28	57.3	65.2	66.0	69.6	75.9	77	75.3	78.1
W_4, *g*	0	0	0	0	0.9	6.8	22.1	30	36	38	39.6	41.7

The function that characterizes the growth rate of Brussels sprouts has the form:

$$S(t) = \begin{cases} 0, & if \;\; t < 50 \\ e^{-\eta_1 t}, & if \;\; 75 < t \;\geq 50, \\ e^{-\eta_2 t}, & if \;\; t \;\geq 75 \end{cases} \qquad (38)$$

where: $\tau -$ the period of time from planting seedlings to the beginning of tying the head,

$\eta_i -$ exponent coefficients ($\eta_1 = 0.09704, \quad \eta_1 = 0.09623$).

Unknown coefficients k_i of growth functions of plant subsystems were determined by a statistical method based on the results of field experiments, the value was obtained: $k_1 = 0{,}0880; \;\; 0{,}0825; \;\; 0{,}0995.$

Nonlinear equations were employed to approximate the mean daily values of soil temperature, air temperature, and soil moisture.

We will now construct a mathematical model for the growth of Brussels sprouts based on the experimental data provided in Table 1, following the previously described algorithm. The next step involves estimating the model parameters using the experimental dataset (Table 2) and specifying the initial conditions (the dry weight values of plant subsystems at the time of seedling transplantation):

$$W_1(0) = 0{,}53$$
$$W_2(0) = 0{,}34$$
$$W_3(0) = 2{,}6$$
$$W_4(0) = 0$$

The optimal solution of the system of differential equations (36) will be at the values of the coefficients $a_{i,j}$ (Table 3):

Table 3

Values of model coefficients

j / i		1	2	2	4
		Root	Stem	Leaf	Heads
1	Root	0,047	0,0041	0,0038	0,0083
2	Stem	0,015	0,675	0,0031	0,0134
3	Leaf	0,069	0,0078	0,064	0,036
4	Heads	0,35	0,27	0,43	0,00068

The simulation results are shown in Fig. 2.

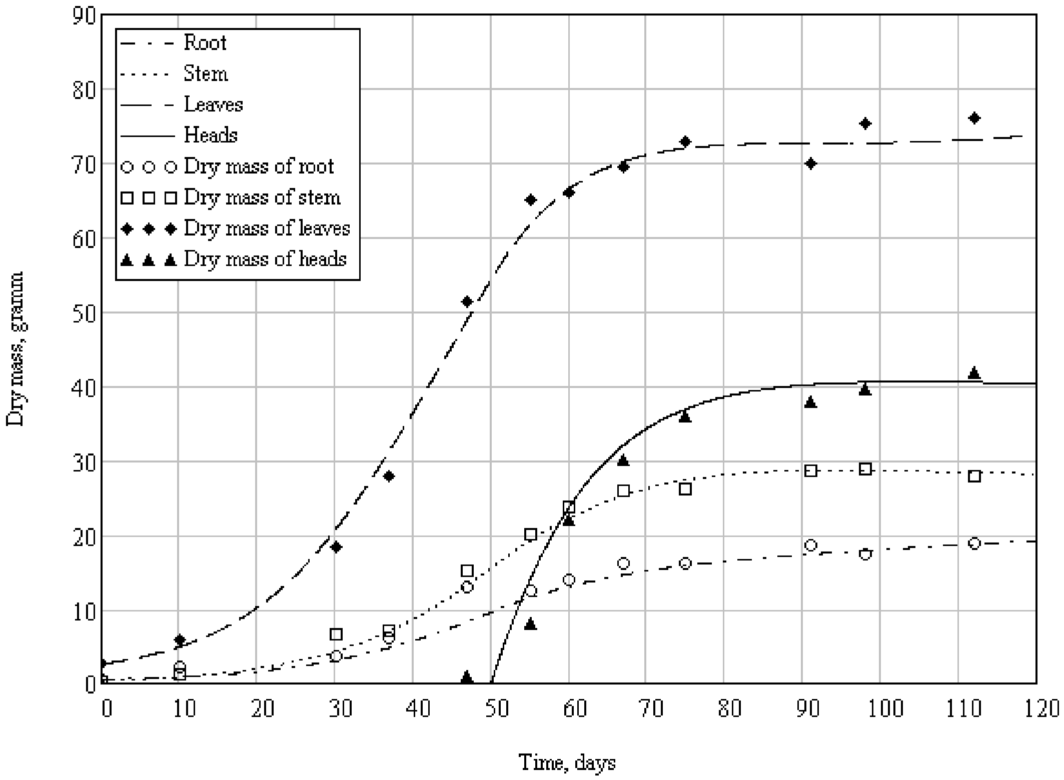


Fig.2. Dynamics of dry mass of Brussels sprouts

The developed model demonstrates significant sensitivity to parameter variation, enabling the simulation of plant growth. For instance, adjusting the coefficient a_{31}, which represents the rate of nutrient exchange between the leaf and root via the stem, from 0,069 to 0,076 results in a heavier head and a notable increase in leaf mass (Fig. 3). Further experimental testing is necessary to accurately quantify the actual impact of these coefficients on overall plant development.

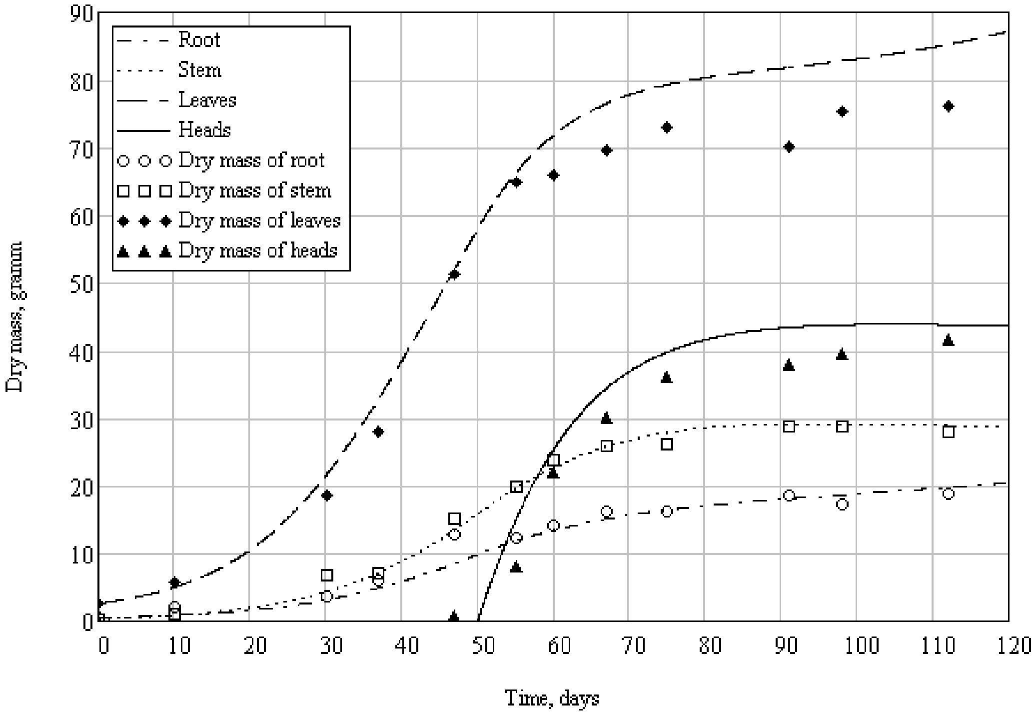


Fig. 3. The effect of changing parameters (the value of the coefficient of the model a_{31} changed from 0,069 to 0,076)

The creation of mathematical models for dynamic processes within the agro-industrial sector is pivotal. This modeling approach facilitates a detailed characterization of dynamic systems and enables computer-based process simulation. Such capabilities, in turn, accelerate the adoption of novel technologies, decrease the time needed for the design and refinement of new agricultural equipment and mechanisms, optimize crop growth, and ultimately lower the overall production cost of agricultural products. A primary benefit of this tool is its capacity to effectively convert empirical results from field experiments into a quantifiable digital format.

The presented mathematical model offers an accurate depiction of the plant development cycle. It allows for the investigation of how various external and internal parameters influence the growth process. These factors include, but are not limited to, irrigation levels, mulching practices, soil humidity, ambient temperature, light exposure, climatic variations, and the application of nutrients (fertilizers) and plant growth regulators.

Disadvantages of the mathematical model: the model is closed on itself; it requires a significant array of field experimental data; it is accompanied by cumbersome mathematical calculations.

Conclusions

The conducted study confirms the key role of mathematical modeling in agronomy and ecology. The considered models constitute a powerful analytical tool for quantitative assessment, prediction and optimization of complex biological and ecological processes. They allow to move from qualitative observations to quantitatively based decisions in the field of natural resource management and agricultural production.

The Leslie matrix model has demonstrated its effectiveness for analyzing the structure of populations (by age or stages of development) and predicting their long-term dynamics. It is an indispensable tool for assessing the impact of agrotechnical measures or environmental changes on the viability of populations, providing clear indicators such as growth rate and reproductive value.

The analysis of the Lotka-Volterra model emphasizes its fundamental importance for understanding species interactions (predator-prey, competition) in both natural ecosystems and agrocenoses. It provides a theoretical basis for studying the stability of ecological systems and developing integrated plant protection strategies that take into account the dynamics of natural enemies.

The logistic model of plant growth is the main tool for describing the S-shaped growth curve, which includes phases of acceleration, linear growth and saturation. Its use allows to estimate the yield potential and determine critical periods for fertilizer application or irrigation in agronomy.

The Gompertz model has been found to be particularly useful for describing growth, where maximum growth rate is reached early in the growth cycle and the deceleration is gradual. It often describes better than the logistic model the growth of fruits, plant organs or biomass accumulation, where the asymmetry of the curve is more pronounced.

The Chanter model, as an empirical model with practical application, is effective for predicting yield based on a limited number of parameters. Its advantage is its ease of use and sufficient accuracy for operational crop management.

The results of the monograph indicate the need for further development of hybrid and simulation models that integrate physiological knowledge such as the effects of temperature, moisture, nutrients with the considered classical dynamic approaches.

The main recommendation is to implement these mathematical models in decision support systems in agronomy and environmental monitoring. This will ensure the transition to precision agriculture and ecosystem management, minimizing environmental risks and maximizing production efficiency based on scientifically sound forecasts.

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